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M.Sc. Urban Planning and Policy Design

DESIGNING AND MANAGING PUBLIC LIGHTING

The Assessment of Urban Public Lighting Consumption
and the Management of a Responsive Public Lighting System

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PART I
GENERAL INTRODUCTION

1. ABSTRACT

ITALIANO

I consumi energetici per la pubblica illuminazione costituiscono il 17% dei consumi totali in Italia per l'illuminazione urbana per gli spazi pubblici e privati, costando ai comuni italiani più di un miliardo di Euro escludendo i costi di manutenzione. Al giorno d'oggi, nonostante esistano numerose ricerche che trattano la Pubblica Illuminazione da un punto di vista tecnologico e gestionale, sono ancora poche le ricerche condotte da un punto di vista urbanistico. Questa tesi si propone in un primo momento di indagare quali sono i percorsi di stima dei consumi legati alla pubblica illuminazione attraverso l'uso dei dati e delle informazioni territoriali ad oggi reperibili, applicando le indicazioni contenute nelle normative nazionali e comunitarie.

La metodologia è strutturata quindi attraverso il un modello di stima che parte dalla ricognizione del fabbisogno (in questo caso di flusso luminoso), per poi determinare quali sono i consumi necessari a soddisfare questo fabbisogno quantificando l'energia elettrica necessaria.

La tesi in una sezione successiva si propone invece di indagare la relazione tra la dimensione percettiva dell'essere umano che vive e osserva la città attraverso l'utilizzo di analisi visuali, e la ricognizione del fabbisogno luminoso attraverso il modello di analisi indizio-ipotesi di sviluppo futuro, con lo scopo di porre le basi per successive ricerche e approfondimenti su particolari indizi che sono stati colti in seguito alle analisi dei risultati.

L'ultima parte, invece, è dedicata allo studio della gestione di un sistema di illuminazione pubblico sviluppando una "Responsive Smart Lighting System" attraverso un architettura composta da nuove tecnologie atte a raccogliere informazioni che, dopo adeguate elaborazioni, supporteranno il processo decisionale, in particolare focalizzandosi da una parte sulla manutenzione e dall'altra sul controllo dei flussi luminosi con l'obiettivo di raggiungere risparmi in termini energetici ed economici.

ENGLISH

The energy consumption for public lighting are 17% of total consumption in Italy for urban public and private lighting, costing Italian municipalities more than one billion euros excluding maintenance costs. Nowadays, despite the existence of many researches that deal with Public Lighting from a technological and management point of view, there are still few research which are performed by a planning point of view.

This thesis aims at a first time to investigate what are the methods for estimating consumption related to public lighting through the use of spatial information and data available today, applying the guidance contained in national and Community legislation.

The methodology is structured so through an estimation model that starts from the recognition of the requirements (in this case of luminous flux), and then determine what consumption necessary to satisfy this requirements, quantifying the electricity needed.

In the thesis in a subsequent section, I will propose, instead, to investigate the relationship between the perceptual dimension of the human being who lives and see the city through the use of visual analytics, and reconnaissance needs light through the analysis model clue-hypotheses for future development, with the aim of laying the groundwork for subsequent research and insights on specific clues that were taken following the analysis of the results.

The last part is dedicated to the management of the public lighting system developing a Responsive Smart Lighting System, through an architecture composed by new technologies able to grasp information that after elaboration will support the Decision Making process focusing on one hand in maintenance system, and on the other in the control of the luminous flux in order to achieve energy and economical savings.

2. FOREWORD

The purpose of this dissertation is not commonly investigated in the current research context on public lighting design and management; indeed, there is few research that proposes solutions, or discuss about the estimation of the light requirements and the derived consumption at urban level. Because of the lack of research, the work carried on is based on the study of theoretical lecture notes, legal requirements, and official documents of the public administration.

The idea to investigate on the Urban Public lighting consumption has taken place during my collaboration with the "Laboratorio di Simulazione Urbana Fausto Curti" at the Politecnico di Milano. This thesis is part of a bigger and ambitious research about the investigation on urban consumption for the estimation of an urban energy balance. A first investigation was already carried out by another student that assessed the energy consumption of the built environment (Bignardi, 2012), and now in order to integrate that model, other forms of urban energy consumption such as that of the public lighting, have to be assessed.

The purpose of this thesis is to investigate urban the public lighting system, both in terms of design (estimation of consumption) and management (towards a responsive system), with a particular focus on the role that the urban planner can play. Only recently, the topic of public lighting has raised the attention of the public administration, thus becoming a priority after the large number of researches that underline the potential saving in terms of energy consumption, which a forward-looking design and management of this infrastructure can lead.

Before going in-depth into the structure of the thesis, a consideration to the approach should be highlighted. Until now, the common approach has been what is called 'point to point', or rather the approach used in the design of the public illumination. The approach is based on a detailed study of the light-pole position and after a risk analysis, the designer decides the lighting class upon which s/he can perform the lighting calculation and the subsequent verification. This approach, clearly, is the most effective in order to perform a light design, because according to the legal framework in charge, some requirements should be guaranteed. Anyway, it is unthinkable to perform this calculation throughout a city, even more so because in most of the city there is a lack information about the public lighting especially the position of the light poles. For this reason, the approach of this thesis is more generalized and focuses on aspects more related to the urban environment such as the morphology and the function of a given public space in order to assess its light requirements and its derived consumption. These data should be useful to get an idea, during the design stage likewise the maintenance process, how much light a given typology of street requires and consequently how much consumes in terms of electric energy.

The basic assumption is that, studying the European and national legal framework in the public lighting field, where a minimum standard of light luminance is required, and through the study of physical and functional characteristics of the urban spaces, it is possible to quantify the total light demand needed to satisfy these standards. Through the use of the illuminating engineering and his measures is possible to shift from values as the illuminance, to values that measure the power needed to satisfy the minimum standard for each street.

Nevertheless, the lack of data is a problem that spread out in every city, especially in the Italian one. The effort of this thesis is to use data that every municipality should have in their "data equipment" in order to perform an assessment of the energy consumption due to the public lighting. This means avoiding the calculation that considers the distribution of the light poles over the territory, preferring a more general calculation making sure that the requirements are calculated, not according to the position or the number of the poles, but starting from the need of the citizens to have a more or less bright urban space.

Another exploration of the thesis is the experimentation using the Visual Graph Analysis in order to define the requirements of a given street starting from the perceptual dimension of the public space. In this part experimental explorations of trying to link the perceptive dimension of urban space and public lighting will be presented. The goal is to look for clues that may suggest methods to enlighten the public space using tools that nowadays are available and which allow analyzing the public space from the point of view of perception. Several studies conducted over the years have demonstrated a close correlation between the indicators and the resulting increase or decrease of pedestrian flows.

The last part is dedicated to the management of the public lighting system focusing on one hand on the scheduled and targeted maintenance, because a good maintenance management can lead to substantial savings on the operational costs. On the other hand, a development of an architecture that can lead to a responsive and smart lighting system will be proposed.

The lighting project of a given territorial reality as explained in the part one, is connected to the functional and technical classes of roads. Once established the lighting classes, the luminous flow of the street-light is almost the same throughout the night. The model developed in this parts starts from the idea that the management of a lighting system could become more dynamic, and in some way responsive in order to satisfy the demand in the different hours of the night.

The main target of the construction of a Smart and Responsive Lighting System is the achievement of savings in terms of energy consumption by the supplying of the light. The luminous flow during the night is almost the same, with some exception of reduction of the lighting flow turning off in an alternate way the streetlights. The matter of this pattern of supply is due to the fact that the decision about how much to light-up and when is decided "a priori", according also to the technology that a lighting system has implemented, while the approach proposed by this architecture is more "on demand" oriented. While the decrease of the supply of light due to the responsive system can lead to remarkable savings in the cost of the energy supply, there is another domain of the public lighting that presents high costs, i.e. the maintenance system. A good management in the maintenance system of the public lighting can lead to a double saving: firstly, the decrease of the cost due to the ordinary maintenance, and, secondly, a scheduled maintenance contributes to the optimization of the efficiency of the streetlights. But this kind of maintenance can be already implemented in a standard lighting system, therefore, the purpose of the "smart lighting architecture" is to construct a model of Responsive Maintenance System leading on one hand to a more immediate detection of the faults thus guaranteeing a quick fixing, and on the other hand to the good scheduling of the maintenance system optimizing the costs.

PART I
GENERAL INTRODUCTION

PART II
METHODOLOGY OF ASSESSMENT OF THE PUBLIC LIGHTING CONSUMPTION

1. ABSTRACT OF THE FIRST PART

ITALIANO

I consumi energetici per la pubblica illuminazione costituiscono il 17% dei consumi totali in Italia per l'illuminazione civile, incidendo fortemente sulle casse comunali italiane, superando di gran lunga le medie europee. Al giorno d'oggi, nonostante esistano numerose ricerche che trattano la Pubblica Illuminazione da un punto di vista tecnologico e gestionale, sono ancora poche le ricerche condotte da un punto di vista urbanistico. Oltre a costituire un problema di consapevolezza del Pianificatore, questo ha comportato nel tempo la mancanza della costruzione, o in alcuni casi la mancata messa a disposizione di banche dati che contenessero le informazioni utili a sviluppare analisi e stime dei consumi urbani per questa componente. La ricerca condotta in questa sezione di tesi propone una metodologia di stima dei consumi basato sulla ricognizione della domanda. A causa della mancanza di informazioni necessarie è stato sviluppato un metodo che aggirasse il problema ricercando indizi e informazioni nelle normative vigenti e nelle caratteristiche morfologiche e funzionali dello spazio pubblico grazie anche alla disponibilità oggi ti un Database Topografico. Questa metodologia quindi basa i suoi principi sullo studio della normativa apportando le adeguate semplificazioni, sullo studio della città attraverso analisi morfologica e funzionale dell'ambiente urbano, ed infine, molto importante sull'acquisizione di nozioni e conoscenze fondamentali di illuminotecnica generale ed applicata all'illuminazione stradale. La metodologia utilizzata, ha permesso di ottenere diversi risultati degni di nota. In primo luogo è stato possibile quantificare il fabbisogno di illuminazione pubblica in termini di flusso luminoso delle sorgenti necessario ad illuminare in modo adeguato lo spazio pubblico. Questo valore costituisce il punto di partenza su cui si possono impostare ragionamenti di risparmio energetico, perché è vero che il flusso luminoso garantito deve rimanere costante, ma giocando sulle efficienze delle sorgenti utilizzate è possibile sviluppare lo stesso flusso con minori potenze. In secondo luogo quindi, seguendo questo principio di rapporto flusso luminoso/potenza, è stato possibile stimare i consumi energetici ipotizzando un valore minimo di efficienza luminosa delle sorgenti. I valori ottenuti dall'applicazione della metodologia di stima del fabbisogno e dei consumi, sono stati successivamente validati attraverso l'utilizzo ed il confronto di un rilievo delle lampade effettivamente presenti su un tratto stradale del caso studio Milanese, e di seguito i valori validati sono stati riportati ad una classificazione tassonomica delle strade per ottenere dei valori medi che ci suggeriscano in tempi brevi il fabbisogno luminoso a seconda di determinate caratteristiche dei tratti stradali presi in considerazione.

ENGLISH

The energy consumption for public lighting represents 17% of total lighting consumption in Italy, costing Italian municipalities more than one billion euros excluding the maintenance costs. Italy pays a lot lighting at night far outstripping the EU averages. Nowadays, despite the existence of many researches, which deal with the Public Lighting from a technological point of view and management, there are still few researches conducted by an urban planning point of view. Besides representing a problem of awareness of the planner, this lack of research corresponds to the absence of databases for developing analyses and estimating of urban consumption for this component, or in some cases even their non-availability. The research conducted in this section of the thesis proposes a methodology for estimating consumption based on the recognition of the lighting demand. Because of the lack of information required, a method that avoids these issues has been developed, by searching for clues and information into the regulations in force and in morphological and functional characteristics of public space. This methodology, therefore, bases its principles on the study of law by making the appropriate simplifications, the study of the city through morphological and functional urban environment, and finally, it was very important to the acquisition of notions and basic knowledge of general lighting engineering and applied to street lighting.

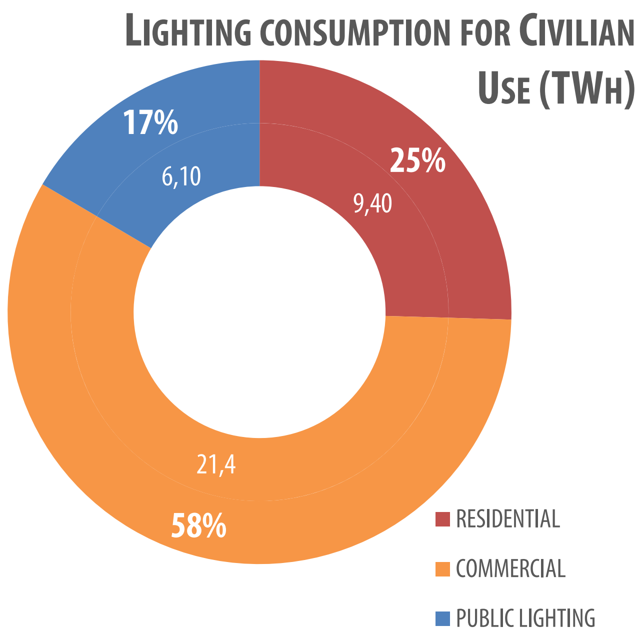
The methodology used, has resulted in several remarkable results. In the first place, it was possible to quantify requirements of public lighting in terms of lighting flux of the sources needed to properly light up the public space. This value is the starting point on which reasoning on energy saving can be developed because it is reasonable that the luminous flux guaranteed should remain constant, but by using energy saving lighting sources can be guaranteed flow with fewer power.

Hence, secondly, following this principle of relationship luminous flux / power, it was possible to estimate the energy consumption assuming a minimum value of luminous efficiency of the sources.

The values obtained from the application of the methodology for estimating the demand and consumption, were subsequently validated through the use of a survey and comparison of the lamps actually installed on a road section of the Milan case study , and the following values validated have been reported to a taxonomic classification of the roads to obtain the average values suggest that there in a short time the light needs depending on certain characteristics of road sections taken into consideration.

2. INTRODUCTION

The Stern report on climate change and environmental sustainability reports that about 80% of the emissions-originates from urban areas (the Graphics 2.1 shows the percentages by type in Italy). It is easy to understand how an agreement is necessary in order to address the issue and revise the urban models and energy, in the absence of a national energy plan. The lighting, as can be seen, is responsible for 17% of consumption equivalent to 6,10 Terawatt per hours[1], that percentage can be reduced by developing targeted actions. This revision type requires knowledge of the actual consumption for the city, in order to establish and quantify the achievable interventions.



Graphics 2.1 – Lighting consumption for Civilian Use (TWh) (Terna S.P.A, 2012)

Nowadays, in Italy there is a lack of a recent census regarding public lighting. The only data and studies quoted here come from some regions and municipalities that have collected and used this information for the preparation of regional energy plans. Legambiente shows the latest available data, which refer to 2006, but these data are considered old, given the progress that the technological innovation in the field of enlightenment had in the past five years. The most significant information refers to approximately 10 million points of light, of which about 50% more sources with mercury (probably at present this percentage has decreased).

The control of power consumption for street lighting is essential for an assessment of what is the actual required intervention for a perfect plant optimization. However, monitoring is not enough to prove the sustainability of existing lighting systems from the point of view of energy and security.

Inhabitants of the cities and urban areas in particular, are still rising; consumption derived from it reach up to 70% of global energy. The challenge in this area is to get the city more sustainable and livable at the same time. All over the world people understood that the city is the cause of increased consumption and that they themselves show the potential of being able to reverse this situation to their advantage, thanks to the use of new technologies.

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[1] *1TWh= 1.000.000.000 KWh*

This part of the thesis is proposed as an urban analysis of consumption of public lighting, first, starting from considering the physical dimension of public space on which illumination during the night is required and then assessing the functional characteristics of it, which determines the variation of the requirements. This analysis differs from standard methods in part because of lighting design interface with an urban dimension, and therefore during the analysis this will require appropriate simplifications. The survey was conducted through the use of GIS software (ESRI, 2013) that can handle and enable the processing of large amounts of data which support the analysis.

2.1. RESEARCH QUESTION

The researches about the urban public lighting consumption are very few, mostly due to the lack of information and data available about the public lighting system. The purpose of this part of the thesis is to explore and model a way to estimate the energy consumption due to the lighting system starting from the different morphologies and functions of the urban public spaces. Is it possible to estimate an overall lighting requirement at the city scale and then to derive the corresponding energy consumption needed to satisfy that requirement?

2.2. CHAPTER'S SYNTHESIS

CHAPTER 3 – STATE OF THE ART

In this chapter, the theoretical, technical and legal contents concerning the public lighting will be examined. In the first part, there will be a close examination of the basic concepts of lighting starting from the general photometric and illuminating engineering concepts, to the technology of lighting sources. Then, an examination of the research context that concerns the public lighting studies will be proposed, and then finally closing the chapter with the legal framework. The outcome of this chapter is the construction of a knowledge about the lighting measures and the illuminating engineering applied to the public illumination.

CHAPTER 4 – METHODOLOGY

The purpose of this chapter is to build-up a methodology able to support the entire analysis. The construction is based on some targets and assumptions useful to create a functional framework, one of those is the fact that the entire methodology is built-up according to the data available, thus the TDB become of grate relevance in this framework. Then, the steps that together compose the entire methodology will be identified. Given the nature and the large amount of data, is of fundamental importance was the use of a Geographic Information System software (here and after GIS) that allowed the management and processing of all information and the creation of the variables identified by the technical regulations in the field of public lighting. Through the use of spreadsheets these variables were subsequently managed.

CHAPTER 5 – PREDISPOSITION TO THE METHODOLOGY, DATA ELABORATION

In this chapter the set of data useful to the construction of the algorithm will be analysed and elaborated, and therefore it will be necessary to carry out a set of procedures for making sure that all the variables are manageable and referred to a common ID in order to construct the database on which the algorithm works. The Analysis Database will have, besides the ID referred to the street element, the entire set of ID key of the other shape files to keep the connection with them.

CHAPTER 6 – THE FIRST VERSION OF THE ALGORITHM FOR THE LIGHTING CATEGORY'S DEFINITION

In this chapter, the functioning of the first version of the algorithm that is based on a simple estimation of the light requirements of the road will be explained. The calculation will focus only on the side of the road belonging to the vehicular traffic because of the missing data about the pedestrian area. In this way, this first version of the algorithm is proposed as an easy way to have a quick idea of the requirements and consequently the consumption of the streets.

CHAPTER 7 – THE SECOND VERSION OF THE ALGORITHM FOR THE LIGHTING CATEGORY 'S DEFINITION

In this chapter, the second version of the algorithm for the identification of the lighting categories will be presented, based on the improvement and the enhancement of the physical dimension of the roads with the implementation of new information that consequently leads to different results due to the consideration of further variables. The first step will be the identification of such variables that after the construction of the algorithm will lead to the identification of the lighting categories. At the end of the chapter a set of statistics will be proposed and the results will be analysed and compared to the first version of the algorithm. Then, once identified the illuminance values, such values will be used in order to calculate with the total flow method the luminous flow necessary to lit up the roads according to the requirements. Once the luminous flow is obtained, it will be possible to calculate the yearly consumption starting from the assumption that all the light sources guarantee a given performance.

CHAPTER 8 – RESULTS OBTAINED AND INTERPRETATION OF THE OUTPUT

In this chapter, the results will be analyzed and interpreted according to the taxonomy identified in the last chapter. Then also, a validation of the results comparing them with real data coming from a survey will be proposed.

2.3. *THE MILAN CASE STUDY*

The case study chosen for applying the analysis, the experimentations, and the methodology elaborated in this work, is the Municipality of Milan, Italy. The first reason why we chose this case study are various: firstly, it is because of the availability of the data that have played a central role in the decision. The second reason is because this Municipality hosts the Politecnico di Milano, and thus, there is more possibility to make a comparison with other studies besides the possibility to improve the findings with new analysis and data. The third one is the possibility to put besides the studies about the consumption of the roads, those belonging the consumption of the built environment already carried out. Once identified the case study, it is useful to introduce it with some figures, but first some premises should be underlined.

2.3.1. Premises and Assumption

The Starting point of the analysis was the identification of the spaces of the city that must be lighted-up during the evening and the night. In order to better identify the space we are interested in, here and after I will use the concept of the "Nolli Map"[2], which in this case is useful to identify all the public areas freely accessible to the pedestrian and vehicular flows. The Nolli Map, in our analysis, is conceived like a black and white map where the white is the space where there is a requirement of public illumination, and where the black almost corresponds to the built space. Nevertheless, not all the public spaces are lighted up in the same way. Each space has his own requirements of light and since the aim of this thesis is to assess the consumption of public illumination, a classification should be done. Afterwards, the Nolli map was classified in three different categories taking in to account the indications of the norms EN 13201 and the UNI 11248, because as it will be presented later, each category has different degree of specific requirements.

ROADS

For roads in this thesis, we will consider those spaces composed by a street and/or pedestrian way like sidewalks (Figure 2.1). The difference between street and road is crucial to understand the operation of the model, because the road can be composed by a street and sidewalks, while a street is considered only the side of the road where the vehicle is crossing by. Under the road, thus, there is the distinction of what is sidewalk, and what is street that is an important concept because, as we will see after, these two sides of the road, have different behaviours in terms of lighting requirements.

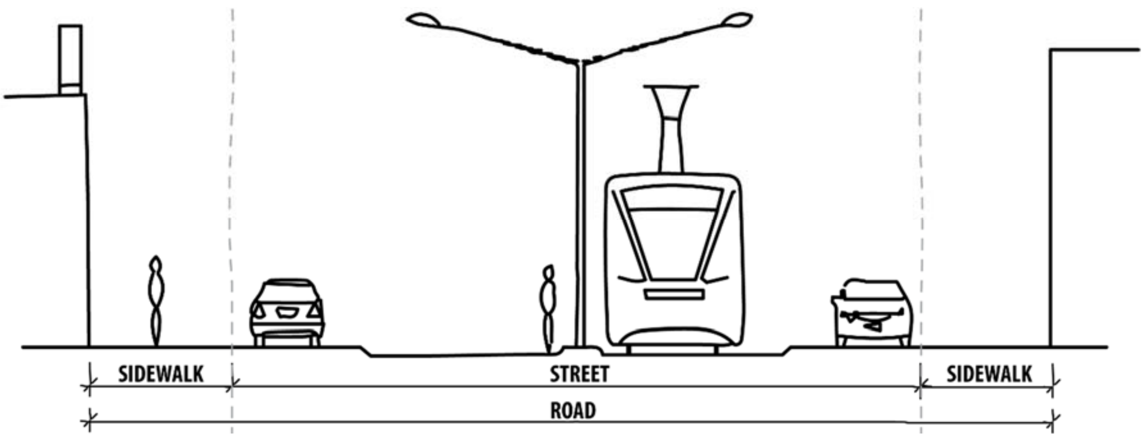


Figure 2.1 - Scheme of clarification of the difference between Road and Street (Smitka, 2011)

[2] Giambattista Nolli (or Giovanni Battista, April 9, 1701 – July 1, 1756) was an Italian architect and surveyor. He is best known for his ichnographic plan of Rome, the Pianta Grande di Roma which he began surveying in 1736 and engraved in 1748, and now universally known as the Nolli Map. The Nolli map reflects Bufalini's map of 1551, however Nolli made a number of important innovations. Firstly the reorientation of the city from east to magnetic north. Secondly, Nolli represents enclosed public spaces. Finally, the map was a significant improvement in accuracy. The map was used in government planning for the city of Rome until the 1970s; it was used as a base map for all Roman mapping and planning up to that date.

PARK

The parks, in lighting, are treated often in two ways. The first one is by lighting up all the areas with few poles with powerful lighting sources; the second one is to light-up only the paths inside them. In our case, we have assumed to be in the second case, because of the need for generalization and ease of producing results for the model.

CYCLE AND PEDESTRIAN PATH

Pedestrian road and cycle path: that are outside of the road.

Each one of the above presented categories contains inside different kinds of degrees of requirements, according to specific characteristics. It is clear that for having a very good estimation, the categorization should be very detailed, but given the purpose of the thesis, it was enough to find a good compromise between a good classification and a simplification of the categories that have a similar behaviour in terms of light requirement.

2.3.2. A PICTURE OF THE ROADS OF MILAN

The classification demonstrate in the previous paragraph makes a clear distinction inside the public space identifying what is road and what is not, but now there is the need to match this classification with the data available. The Topographic Database (here and after DBT) is composed, as regards the public spaces area, in two different layers (A010101 for the vehicular area and A010102 for the pedestrian area). The sum of these two are contained in another one more general named A010104. Since the path inside the park, and the cycle and pedestrian paths are inside the A010102 shape file the new hierarchy of public space that compose the Nolli Map of Milan, is summarized as reported in the Table 2.1.

SHAPE	DESCRIPTION	AREA (sqm)	OCCUPATION OF ROAD	OCCUPATION OF MILAN
	Milan Area	**181.763.693**		**100%**
A010104	Road's area	31.403.507	100%	18%
A010101	*Vehicular traffic area*	*21.776.839*	*67%*	*12%*
A010102	*Pedestrian area*	*10.776.919*	*33%*	*6%*
	Sidewalk	*9.778.872*	*30%*	*5%*
	Other pedestrian area	*998.048*	*3%*	*1%*
	No street area	150.360.187		82%

Table 2.1 – Total distribution of the different road zones, comparing with the total road area and the Milan's area

As it can be seen in the Table 2.1 the roads, in the total of the Milan's Municipality area, occupy 18% of the total surfaces, corresponding to 3.140 hectares. Inside them, we can count 67% of the vehicular areas, and 33% of the pedestrian areas that respectively are quantified in 2.177 Hectares and 1.078 Hectares.

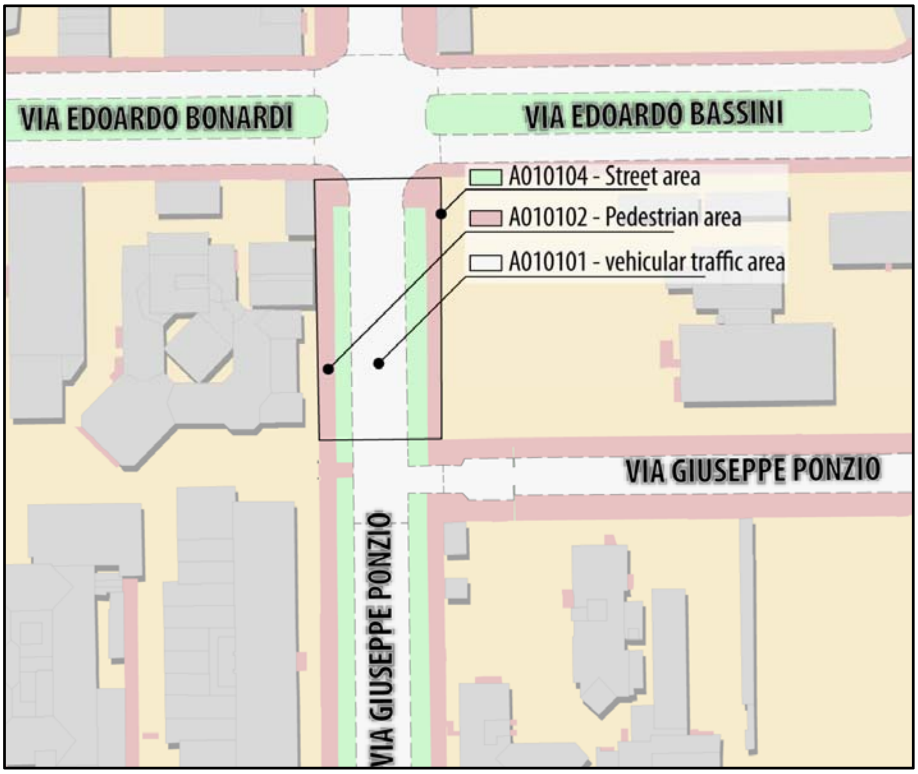


Figure 2.2 – Stratification of the road layer used in the analysis (Own GIS Production based on DBT Shape File)

The Figure 2.2 better shows the distinction inside the name Road, underlying what is street and what is pedestrian area, in this case a sidewalk. While in the Figure 2.3 the difference between a pedestrian area computed in the methodology, and one that is not, is shown.

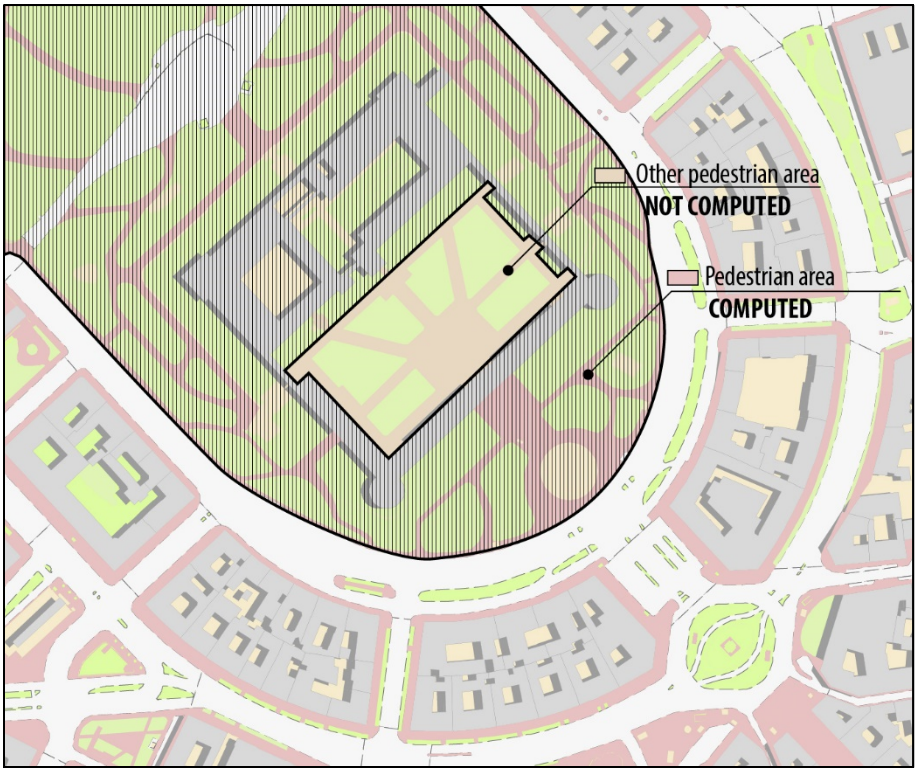
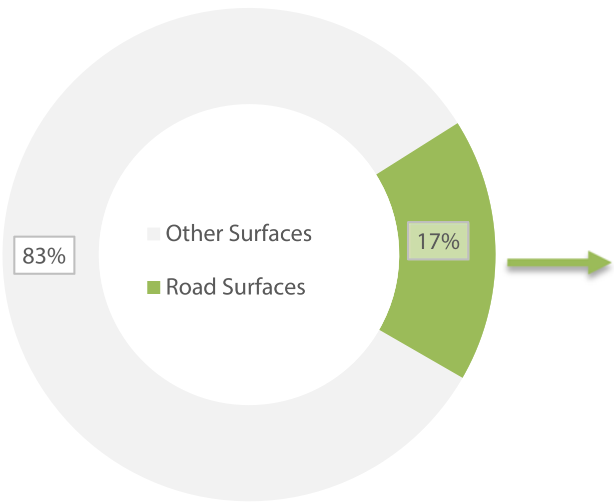
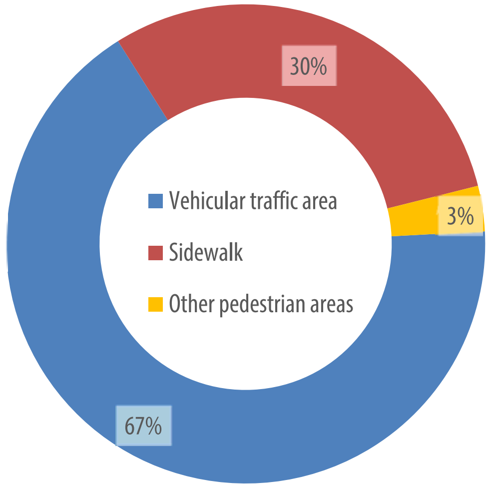


Figure 2.3 – Stratification of the pedestrian area layer used in the analysis inside a park (Own GIS Production based on DBT Shape File)

The two graphics below, better display how the distribution of the road inside the Municipality of Milan and then their sub-division according to the DBT shape file.





Graphics 2.2 – Distribution on the different streets area compared with the Milan's total surface (Own Elaboration)

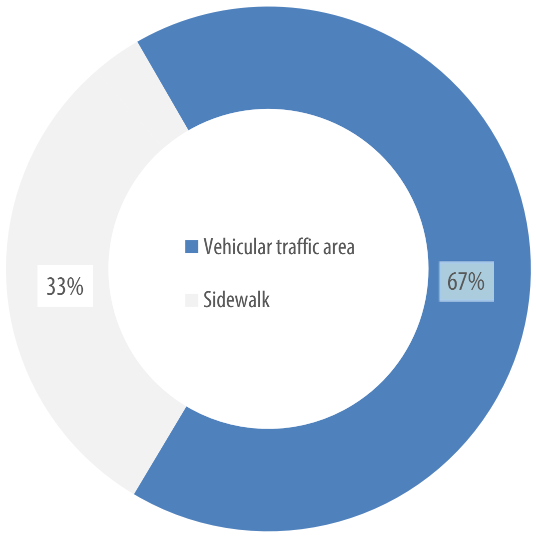
Graphics 2.3 – Distribution on the different streets area (Own Elaboration)

Hence, the 67% of the road area is occupied by the streets that anyway, according to the Road Code, in terms of functional characteristics are not the same. In order to define the lighting category of a given road, the determination of the functional characteristics of a given street is crucial. Therefore, a classification of the streets according to their functional characteristics is reported in the Table 2.2.

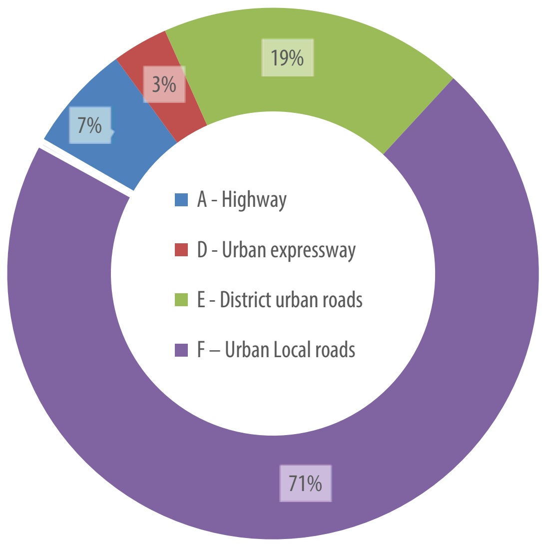
CODE	ATTRIBUTE NAME	LENGTH *(M)*	LENGTH *(KM)*		AREA *(SQM)*		MEA. WIDTH *(M)*
0301	A – Highway	94.222	94,22	**4%**	1.327.116	**7%**	12,50
0304	D – Urban expressway	76.203	76,20	**3%**	682.056	**3%**	9,13
0305	E – District urban roads	407.832	407,83	**18%**	3.720.380	**19%**	8,79
0306	F – Urban Local roads	1.647.857	1.647,86	**73%**	14.279.433	**71%**	7,81
0391	Not defined	16.690	16,69	**1%**	55.991	**0%**	2,91
0395	Other	6.452	6,45	**0%**	15.775	**0%**	3,97
		2.249.256	**2.249**		**20.080.752**		8,07

Table 2.2 – Figures referred on the road elements

In the previous table each street was classified according to their length and area; the value that we are going to take in to account anyway is the second one. The most frequent street functional class is the "F" one, i.e. "Urban Local Roads" corresponding to those streets that have a predominant residential function. The extension of this class reaches 71%. At the second place, by extension, we found the class "E" or "District Urban Roads" hence those roads that have, in a hypothetical graph of the streets, an integration coefficient medium high, and thus are streets with a role of connection inside the city. The other remarkable two categories are the "A" or "Highway" at the 7% and the "D" or Urban expressway at the 3%.



Graphics 2.4 – Distribution on the different streets area between streets and pedestrian areas (Own Elaboration)



Graphics 2.5 – Surface distribution based on the functional classification of the roads referred to Table 2.2 (Own elaboration)

3. STATE OF THE ART

In this chapter the theoretical, technical and legal contents concerning the public lighting will be introduced. In the first part, a close examination of the basic concepts of lighting starting from the general photometric and illuminating engineering concepts, to the technology of lighting sources is presented. Then, an examination of the research context that concerns the public lighting studies will be proposed, and finally, the chapter will end up with the description of the legal framework. The outcome of this chapter is the construction of a knowledge about the lighting measures and the illuminating engineering applied to the public illumination.

3.1. THEORETICAL AND TECHNICAL REFERENCES

3.1.1. GENERAL PHOTOMETRIC AND ILLUMINATING ENGINEERING CONCEPTS

In order to introduce the analysis carried out, and explain some basic concepts useful to understand the technical framework behind the methodology, it is important to explain photometric and illuminating engineering concepts used in this work. These theoretical concepts were supported by different lecture notes found in the internet (Grattieri, Menga, 2012; Nicolini, 2013).

LUMINOUS FLUX

In photometry, luminous flux (Symbol "**Φ")** or luminous power is the measure of the perceived power of light. It differs from radiant flux, the measure of the total power of electromagnetic radiation (including infrared, ultraviolet, and visible light), in that luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light.

The SI unit of luminous flux is the **lumen (lm).** One lumen is defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian.

$$\varphi(lm) = \mathrm{I}(cd) * sr \tag{3.1}$$

LUMINOUS INTENSITY

In photometry, luminous intensity (Symbol "**I**") is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle, based on the luminosity function, a standardized model of the sensitivity of the human eye. The SI unit of luminous intensity is the candela (cd), an SI base unit.

$$I(cd) = \frac{\varphi(lm)}{sr} \tag{3.2}$$

LUMINANCE

Luminance (Symbol "**L**") is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square metre (cd/m2).

$$L(cd/m2) = \frac{I(cd)}{m^2} \tag{3.3}$$

ILLUMINANCE

In photometry, illuminance (Symbol "**E"**) is the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception. In SI derived units these are measured in **lux (lx)** or lumens per square metre.

$$E(lux) = \frac{\varphi(lm)}{m^2} \tag{3.4}$$

LUMINANCE COEFFICIENT

The luminance coefficient (**q**) describes the reflection characteristic of a given surface and it is variable according to the emission and receiving angle. This coefficient is useful to convert the Illuminance in luminance. For instance, the asphalt coefficient is equal to 0.07:

$$\boldsymbol{q} = \frac{L\,(cd/m^2)}{\mathrm{E\ (lux)}} \quad or \quad L(cd/m^2) = 0.07 * E(lux) \tag{3.5}$$

LUMINOUS EFFICACY

Luminous efficacy (Symbol "**η**") is a measure of how well a light source produces visible light. It is the ratio of luminous flux to power. Depending on context, the power can be either the radiant flux of the source's output, or it can be the total power (electric power, chemical energy, or others) consumed by the source. In which sense of the term is intended, it must usually be inferred from the context, and it is sometimes unclear. The former sense is sometimes called luminous efficacy of radiation, and the latter luminous efficacy of a source.

$$\boldsymbol{\eta} = \frac{\varphi(lm)}{\mathrm{W}} \tag{3.6}$$

SUMMARY TABLE

Measure	*Symbol*	*Unit name*	*Unit*
Luminous flux	**Φ**	Lumen or lm	$\varphi(lm) = \mathrm{I}(cd) * sr$
Luminous intensity	**I**	cd	$I(cd) = \frac{\varphi(lm)}{sr}$
Luminance	**L**	Cd per square meter	$L(cd/m2) = \frac{I(cd)}{m^2}$
Illuminance	**E**	Lux or lx	$E(lux) = \frac{\varphi(lm)}{m^2}$
Luminous efficacy	**η**	Φ per W	$\boldsymbol{\eta} = \frac{\varphi(lm)}{\mathrm{W}}$

Table 3.1 – Table of photometric characteristic

3.1.2. Illuminating engineering applied to the public illumination

SOME DEFINITIONS:

For a correct understanding of the lighting features required for each category is good to remember the following definitions:

MEASURES

L_m – Mean Luminance: mean value of the luminance on road surface calculated on the carriageway;

U_o – General Uniformity: ratio between the minimum illuminance and the mean illuminance evaluated on the carriageway;

U_l – Longitudinal Uniformity: minimum value between the minimum illuminance and the maximum illuminance on the roadway measured along the centre line of a traffic lane

T_i – Threshold increment: measure of the loss of visibility caused by the debilitating glare of the lighting devices

SR – Contiguity ratio: mean illuminance of the zones out of the carriageway in ratio with the mean illuminance evaluated on the zones just inside the carriageway

E_m – Mean Illuminance: mean value of the horizontal illuminance calculated on a given area of the carriageway

E_{min} – minimum illuminance of a vertical plane: minimum value of the illuminance of a given vertical plan on a specific height above the street zone

E_{hs} – hemispherical illuminance: luminous flow on a small hemisphere with horizontal base, divided per the hemisphere surface

E_{sc} – hemi-cylindrical illuminance: total luminous flow that fall on a curved surface of a very small hemi-cylinder, divided per the area of a curved surface of the hemi-cylinder

ILLUMINANCE CALCULATION

The illuminance of a given point depends firstly on the position of the source and of the observerFigure 3.1. The geometrical dimensions considered for identifying each point on the carriageway on the illuminance calculation are:

- The tilt γ angle related with the vertical of the luminous intensity emitted by the centre S
- The β angle between the two projections on the carriageway of the incidence direction of the light. For simplifying the angle between the observer and the road surface is considered =1°

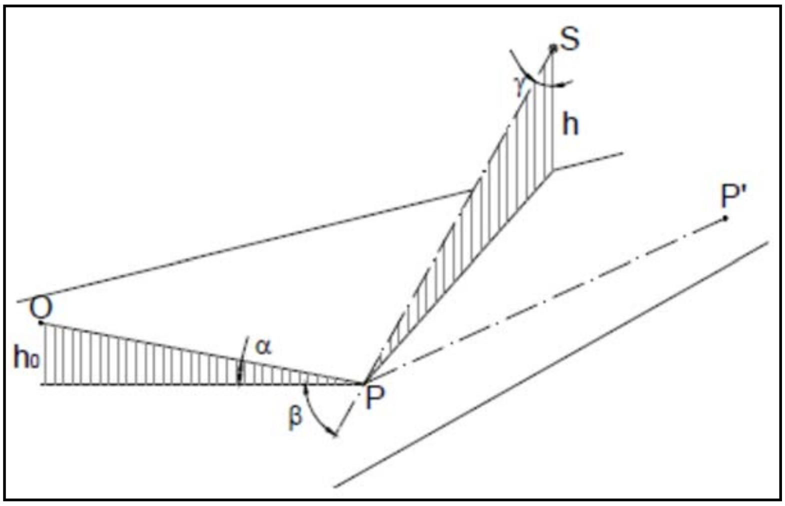


Figure 3.1 – Geometric dimension considered in the Illuminance calculation

(Grattieri, Menga, 2012)

The illuminance E on the point P, of better Luminous intensity I directed toward P results:

$$E = I\ cos^3\gamma/h^2 \qquad 3.7$$

Given that the reflection characteristic of the road surface is identified through the illuminance coefficient (q), that vary for each material in function of the angle γ and β, being:

$$q = \frac{L}{E} \qquad 3.8$$

The illuminance of the point P results:

$$L = q \frac{I}{h^2} \cos^3 \gamma \qquad 3.9$$

If more than one luminous, centre light up the point P, his illuminance results:

$$L = \sum_i q_i \frac{I}{h^2} \cos^3 \gamma_i \qquad 3.10$$

Light centres that determinates the illuminance of a point are localized along a street trunk that are long four time the height towards the observer and 12 time the height in the opposite direction.

MINIMISING THE POTENTIAL NUISANCE OF LIGHT – THE GLOW AND THE LIGHT POLLUTION

Pedestrian lighting can sometimes be criticised for causing nuisance through misdirection of illumination creating glare or 'spill' light. It is also possible to create 'inappropriate lighting' through over-lighting a location or certain features. Each of these can represent illumination distributed at unnecessary angles or intensities. Thus, besides other potentially adverse effects, they can indicate inefficient design and usage of lighting energy. 'More illumination' does not necessarily create better pedestrian lighting. Over-lighting of spaces and objects can diminish the contrast and effect of highlighting, thus diminishing the overall aesthetic appeal of a place. Additionally, the potential for pedestrian lighting to communicate the type of usage intended for a pedestrian area during the hours of darkness can be diminished if the entire area has a uniformly bright illuminance.

Moreover, over-lighting of particular areas or features with intense, directed illumination can create glare that may reduce pedestrians' perceptions of comfort and security.

THE GLOW

Glare occurs when light is seen as too bright, relative to the ambient brightness that the viewer has adapted to. For instance this occurs when the pedestrian moves rapidly between an area of low luminance and an area of high luminance, or if a light source within the pedestrian's field of view provides illumination much more intensely than the general level of ambient lighting. Building a lighting system that does not cause glow problems is the second quality criterion for a good lighting system:

- Pedestrians may squint, or avert or shade their eyes from sources of 'discomfort glare'. This type of glare may not affect vision, but it can be irritating or produce adverse psychological effects.
- 'Disability glare' affects, and can impair, viewing ability. The surfaces and fluids of the eye are not perfectly clear, and these can cause scattering of light entering the eye. This scattering can form a veil of light that reduces available contrasts and visibility, creating disability glare.

- Glare can be distracting as, at night, the human eye is drawn to the most luminous element in its field of vision.

How to reduce the glare(Nicolini, 2013):

- The lamp should be shielded in order to decrease the lighting flow to the observer and concentrate the light on the floor
- The low shielding, increase the mean luminance making perceiving the luminance of the street low and consequently because of the decrease of the contrast between the obstacle and the background the perception of the obstacle are decrease
- The drivers have meanly a viewing angle for 20 degrees, in this field the light should not be emitted in order to avoiding the dazzling (Figure 3.2)

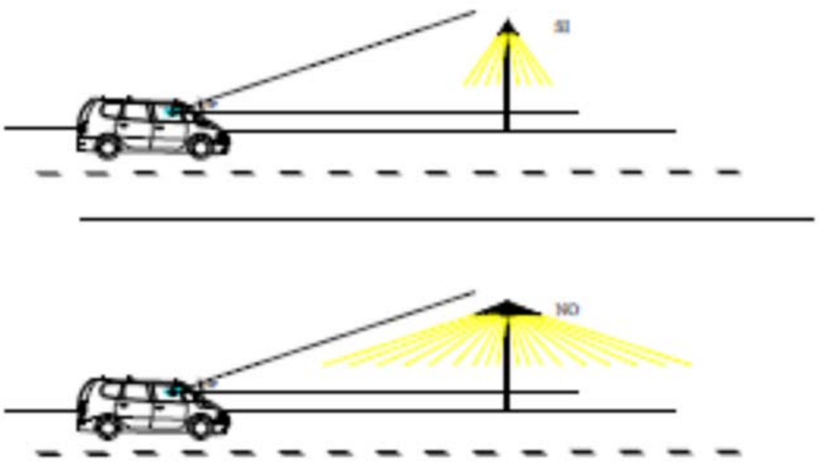


Figure 3.2 – Example of how to direct the lighting sources (Nicolini, 2013)

THE SPILL LIGHT AND THE LIGHT POLLUTION

Spill light occurs where illumination is provided outside of the target area. Illumination can also spill upwards, creating 'sky glow'. The potential for a pedestrian lighting scheme to produce spill light should be assessed both within the lit area, and more broadly outside the subject area. Physical measures and careful consideration through the design of a pedestrian lighting scheme can restrict glare and spill light. For example:

- Luminaires should be positioned and aimed to minimise the incidence of bright light shining straight into a person's field of view.
- Luminaire mounting heights need to be carefully considered for all likely users of a lit space. For instance, some areas lit for pedestrians are also used by buses or delivery trucks. While a low luminaire mounting height may provide well for pedestrians' lighting needs or preferences, it could create glare for drivers of higher vehicles, as illustrated in Figure 3.2.
- Bright sources of light can be replaced with a larger number of weak sources, to reduce glare levels but still provide the same overall level of illumination.

- Interactions with glossy surfaces creating reflected glare should be avoided.
- Luminaire fittings can be selected to control the distribution of light. As Figure 3.3 illustrates, different luminaires control the maximum angle between the central perpendicular axis of illumination (or straight down) and the extent at which no illumination from the luminaire is visible. Luminaires recommended for a pedestrian area should be assessed in terms of the angles of illumination they permit and the resultant extent of glare or unwanted spill light.

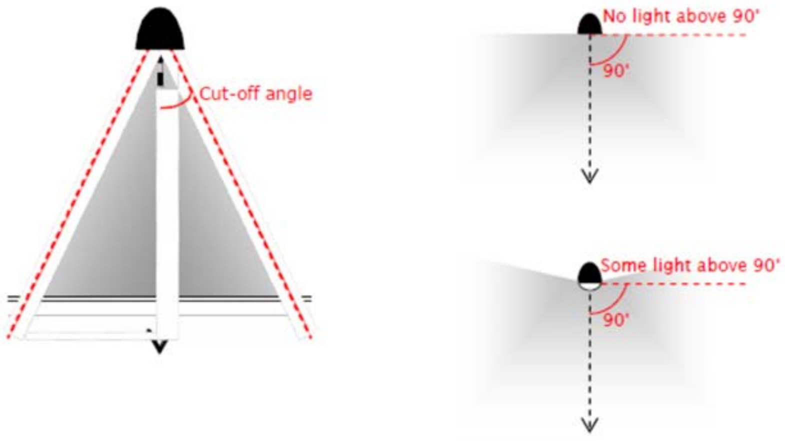
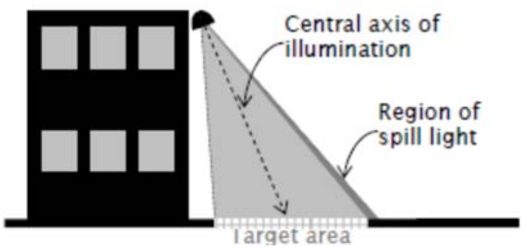


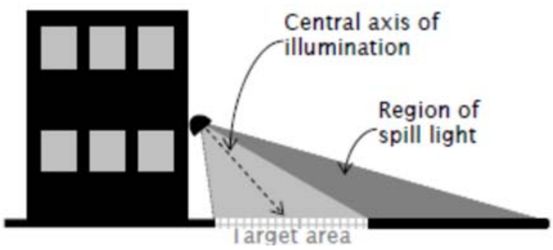
Figure 3.3 – Luminaire fittings can be chosen to control the range of angles of illumination they provide. (Lighting Research Center, 2003)

Figure 3.4 illustrates how illumination can be better managed by using narrower, controlled beams of light mounted at greater heights. This can ensure the same overall lighting coverage as wider beams of light mounted at lower heights, but the narrower beams of light can be more effectively aimed towards a confined area, thereby reducing the amount of spill light that is created.



With the central axis of illumination on the centre of the target area, the target area can be lit from a high mounting height with a narrow-angled luminaire

→ there is only a small region of spill light.



With the central axis of illumination on the centre of the target area, the target area can be lit from a low mounting height with a wide-angled luminaire

→ there is a large region of spill light.

Figure 3.4 – A controlled light source at a higher mounting height provides the same amount of useful light to a target area, with less spill light than would be achieved with a luminaire with a wide-angle beam at a lower mounting height (Lighting Research Center, 2003)

DISPOSAL CRITERIA OF THE LIGHT CENTRES

Like the Figure 3.5 on the straight roads is not preferable to adopt one side configuration (1) of the light centres. On the curves, the one-side disposal is preferable instead of the two-side (2) because constitute an optical guide that helps the perception of the curve. For road with wide track, both for straight and curves traits, the solution suggested is that one with the two-side disposal. If the carriageway has mid dimension often the designer choose for the axial configuration

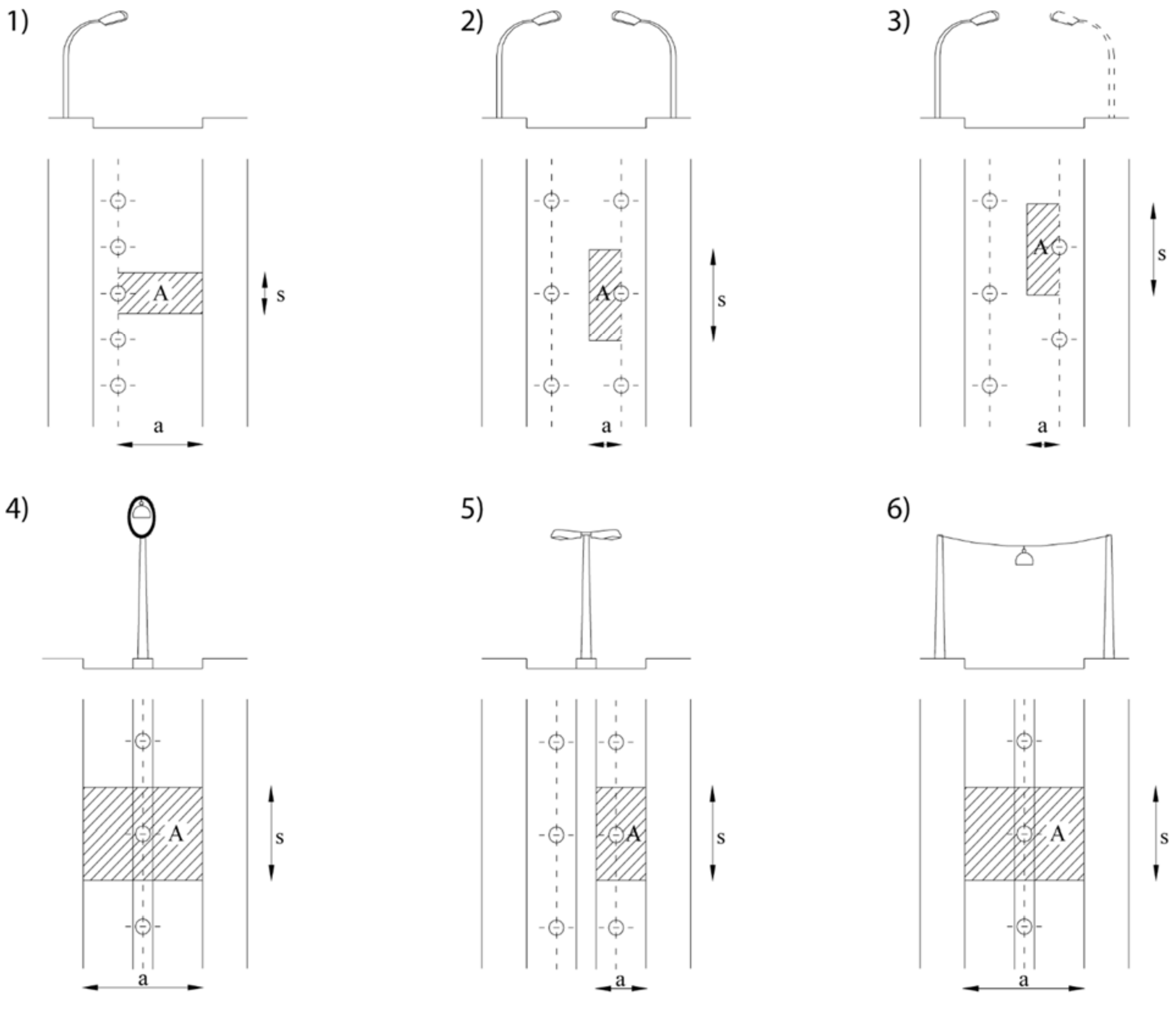
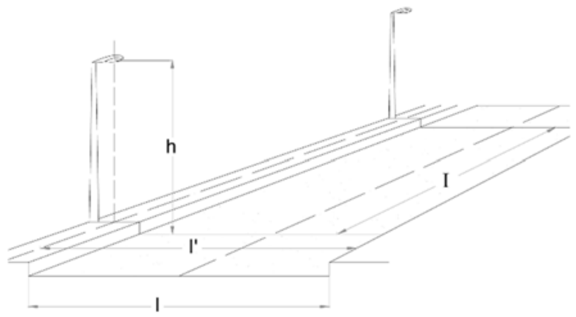


Figure 3.5 – Disposal geometry of light centre (Grattieri, Menga, 2012) *in order:*

1) One side; 2) Two side; 3) Quincunx; 4)Axial; 5)Axial with two arms; 6) Overhead catenary
A = Area of relevance of each lamp;
a = length of area of relevance;
s = spacing between poles and length of area of relevance of light centres

The height of the luminous centres must be compared with the distance from the projection of the centres on the road to the opposite board of the carriageway as displayed in the Figure 3.6, in order to reach the illuminance uniformity in a transversal way.



Values suggested

For all the light with exception of the low-pressure sodium:

$$h \geq l' \tag{3.11}$$

$$I \leq 4h \tag{3.12}$$

For all the light with low pressure sodium technologies:

$$h \geq 1.2l' \tag{3.13}$$

$$I \leq 3.5h \tag{3.14}$$

Figure 3.6 – Disposal Geometry and proportion between height and distance of the light centres. (Nicolini, 2013)

The height "h" must be choose between values imposed by the UNI EN 40 that are 8,10,12,15 meters

The distance between the centres have to be compared to their height, in order to reach the desired value also for the illuminance uniformity on the longitudinal way of the carriage

CRITERIA FOR THE CHOICE OF THE LAMPS

The light sources used on the streets with motorized traffic are choose according economic criteria that tends to minimalize: i) the annual cost of energy; ii) the annual maintenance cost; iii) the financial cost of the realization.

In terms of efficiency in Italy some regions have some restriction, for instance Regione Umbria have established a minimum value of ≥90 lm/Watt for the extra-urban areas, and ≥80 lm/Watt for the urban areas.

The most appropriate light sources are:

- for highway, extra-urban and urban roads standard low/high pressure sodium lamp
- for central roads halogen gases lamps, lamps high-pressure sodium
- connection between neighbours roads halogen gases lamps, lamps high-pressure sodium

CRITERIA FOR THE CHOICES OF THE LIGHT DEVICES

The performances request to each street light device are:

1) Life of the appliance;

2) Conservation time in the photometric characteristics;

3) ease of installation and maintenance;

4) Security towards of personnel involved and third parties;

5) Aesthetics of the device

6) Conformity with the regional Law on light pollution

In relation with the point 6 are conformed the cut-off devices that allow to "cut" the light emission in specific direction and are characterize of a very low or often null emission for angle between 80° and 90° and no emission for angle beyond 90°.

In order to obtain a high and homogeneous illuminance of the carriageway and at the same time grants a sufficient limitation of the glare, the "photometric solids" Figure 3.7 must have this condition: the photometric curve in the vertical plane parallel to the road axis must have a lengthened form, in order to have the maximum intensity on the closest part to the roads

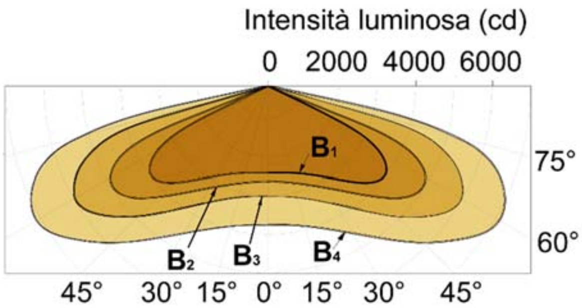


Figure 3.7 – Vertical photometric curve, to highlight the flattening of the curve on the bottom (Nicolini, 2013)

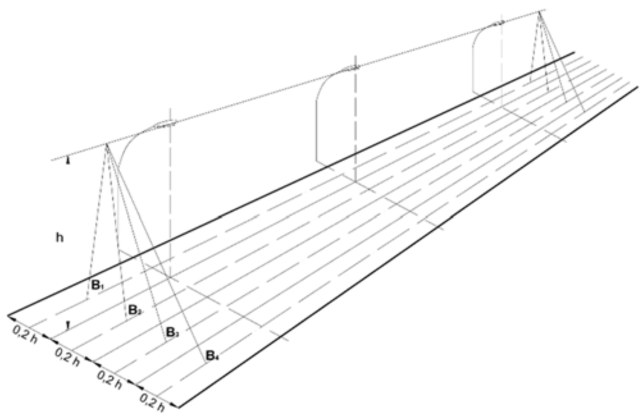


Figure 3.8 – Scheme of disposal and correspondence with the previous figure (Nicolini, 2013)

Transversally of the road, the photometric curve must appear sufficiently full, in order to cover the way across its width; beyond a given angle (see plan B4 in the Figure 3.9), the light emission, however, must be suddenly decreased In order to avoid wastage of light.

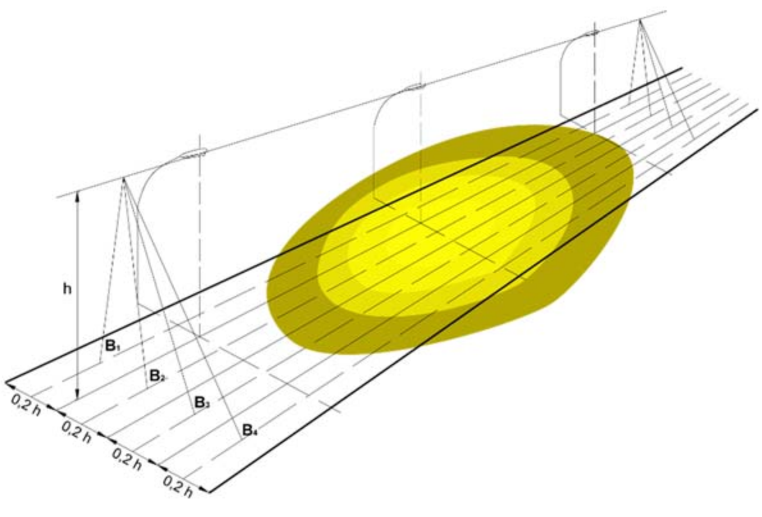


Figure 3.9 – Horizontal photometric curves, to highlight the with along the longitudinal way (Own elaboration)

METHODS OF CALCULATION OF LUMINOUS FLOW – THE TOTAL FLOW METHOD

The methods used for the lighting project of the roads are the total flow method and the point-point method. For the purpose of the thesis I have choose to use the total flow method because is the best method to calculate the total flow starting from the necessity of luminous flux (Φ).

The total flow method is used for the general calculation of the luminous flux to install for each light the expression for calculate him is the follow

$$\Phi_{TOT} = \frac{E * A}{Ku * Kd} \qquad 3.15$$

Where:

- E is the illuminance
- A is the area of relevance of each street light
- K_u is the utilization coefficient
- K_d is the depreciation coefficient

UTILIZATION COEFFICIENT K_U

The coefficient of utilization (K_U) is a measure of the efficiency of a luminaire in transferring luminous energy to the working plane in a particular area, in our case the street. The CU is the ratio of luminous flux from a luminaire incident upon a work plane to that emitted by the lamps within the luminaire. As a ratio, the coefficient of utilization is unit less. A CU measures the light actually reaching the desired plane as a percentage of the total light produced by the fixture (Figure 3.10.

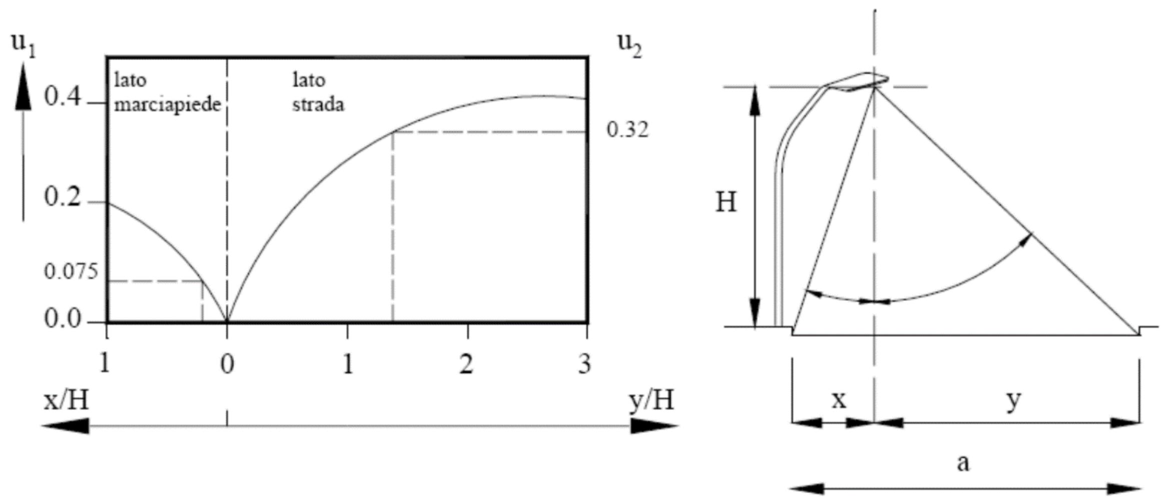
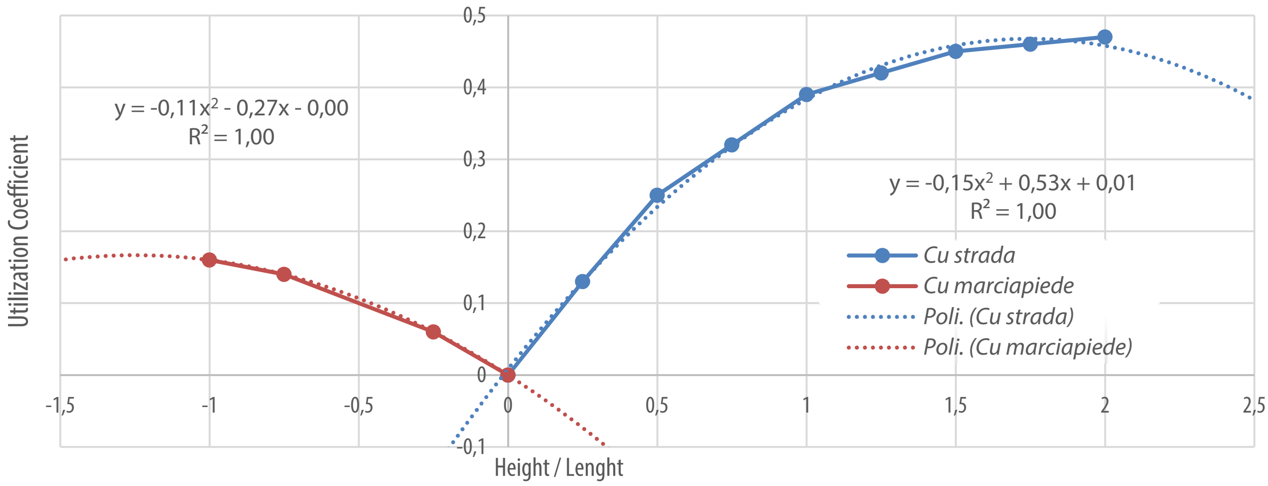


Figure 3.10 – Generic utilization factor (Nicolini, 2013)



Graphics 3.1 – Utilization factor for a high-pressure sodium lamp of 150W (Own elaboration)

Having developed the curve of utilization (Graphics 3.1), using excel is possible to extract the formula for calculate it according to the width of the street:

$$= \left(-\frac{1}{7}\left({}^{W}/_{H}\right)^2\right) + \left(\frac{1}{2} * {}^{W}/_{H}\right) + (0{,}0087) \qquad 3.16$$

As will be better explained in the next part, the choice of the utilization faction is crucial because can affect all the estimation of the need of luminous flux. Generally it is better to choose a low utilization factor because validation done on site show how the basic need of luminosity is over satisfied according to the regulation, less according to the opinion of the population.

DEPRECIATION COEFFICIENT K_D

The depreciation coefficient (K_u) is consists of two basic factors, lamp lumen depreciation and luminaire dirt depreciation. Light loss factors, along with the total lamp lumen output vary with manufacturer and type of lamp or luminaire and are determined by consulting the manufacturers published data. Often the depreciation factor is between 0.7 and 0.85 for the open lamp and between 0.85 and 0.95 for the close one. For simplification I've choose for the next analysis a value of 0.75 for simulating the bad condition.

THE TOTAL FLOW METHODOLOGY

The choice of the light and the lamp useful to satisfy the need of illumination follow a precise methodology. This outline have inspired this thesis, because most of these steps are considered crucial in the final methodology:

1. Individuation of the L_{med} desired taken from the regulation according to the kind of road
2. Individuation of the E_{med} desired taken in consideration the Luminance coefficient (q) of the asphalt (See 3.8)

3. Choice of the disposal of the light centres (see Figure 3.5)
4. Choice of the height of the light according to the UNI EN 40
5. Choice of the distance between the light
6. Determination of the utilization factor
7. Determination of the area of relevance of each light
8. Calculation of the luminous flux (See *3.15*)
9. Choice of the lighting device

Once given the luminous efficacy "**η**" of the lighting device, it is possible to calculate the power engaged for each light centre (see the 3.6)

The limit of the total flow methodology is that is not possible to verify the distribution of the luminance on along the road.

3.1.3. LIGHTING TECHNOLOGIES

In this paragraph will be introduced the lighting sources technologies used for the public illumination. In general two big families could differentiate the lighting sources: on one hand we have the gas-discharge lamp or rather the most diffused technology, and on the other we can find the solid state lighting of which the common one is the Light Emitting Diode. The solid state lighting is a technology that is progressively replacing the gas-discharge technology.

Is important acquire a general knowledge about the lighting sources because, according to the technology used, some improvements can be provided. For each situation is useful to understand which sources is able to guarantee given performants regarding the quality of light, the color rendering index, and the energy efficiency. Recently a massive substitution of the old gas-discharge light sources with the LED technology have taken place, besides this solution, according some researches (Cielobuio, 2008) is not always the best solution both economically and from the wealthy point of view. Anyway, in this thesis this concern will not be discussed in-depth.

GAS-DISCHARGE LAMP

Gas-discharge lamps are a family of artificial light sources that generate light by sending an electrical discharge through an ionized gas, a plasma. The character of the gas discharge depends on the pressure of the gas as well as the frequency of the current. Typically, such lamps use a noble gas (argon, neon, krypton and xenon) or a mixture of these gases. Most lamps are filled with additional materials, like mercury, sodium, and metal halides. Compared with incandescent lamp and even with LED lighting, gas-discharge lamps offer higher efficiency, (Energy Star, 2013) but are more complicated to manufacture, and require auxiliary electronic equipment such as ballasts to control current flow through the gas. Some gas-discharge lamps also have a perceivable start-up time to achieve their full light output. Still, due to their greater efficiency, gas-discharge lamps are replacing incandescent lights in many lighting applications.

SODIUM-VAPOR LAMP

A sodium-vapor lamp is a gas-discharge lamp that uses sodium in an excited state to produce light. There are two varieties of such lamps: low pressure and high pressure. Low-pressure sodium lamps are highly efficient electrical light sources, but their yellow light restricts applications to outdoor lighting such as street lamps. High-pressure sodium lamps have a broader spectrum of light than the low pressure, but still poorer color rendering than other types of lamps. Low-pressure sodium lamps only give monochromatic yellow light and so inhibit color vision at night.

Low Pressure

Low-pressure sodium (LPS) lamps have a glass gas discharge tube containing solid sodium, a small amount of neon, and argon gas. When the lamp is turned on, it emits a dim red/pink light to warm the sodium metal and within a few minutes, it turns into the common bright yellow as the sodium metal vaporizes. These lamps produce a virtually monochromatic light. As a result, the colors of illuminated objects are not easily distinguished because they are seen almost entirely by their reflection of this narrow bandwidth yellow light. LPS lamps are one of the most efficient electrically powered light source when measured for photopic lighting conditions—up to 200 lm/W, primarily because the output is light at a wavelength near the peak sensitivity of the human eye. As a result, they are widely used for outdoor lighting such as streetlights and security lighting where faithful color rendition was once considered unimportant.

LPS lamps are available with power ratings from 10 W up to 180 W; however, longer bulb lengths create design and engineering problems.

Another unique property of LPS lamps is that, unlike other lamp types, they do not decline in lumen output with age. LPS lamps, however, do increase energy usage slightly (about 10%) towards their end of life, which is generally around 18,000 hours for modern lamps.

High pressure

High-pressure sodium (HPS) lamps are smaller and contain additional elements such as mercury, and produce a dark pink glow when first struck, and an intense pinkish orange light when warmed. Thanks to the presence of mercury, more colors can be distinguished compared to a low-pressure sodium lamp. This leads them to be used in areas where improved color rendering is important or desired.

High-pressure sodium lamps are quite efficient (about 100 lm/W) when measured for photopic lighting conditions. The higher-powered versions of 600 W have an efficacy of even 150 lm/W. They have been widely used for outdoor area lighting such as streetlights and security. Understanding the change in human color vision sensitivity is essential for proper planning when designing lighting for roads.

MERCURY-VAPOR LAMP

A mercury-vapor lamp is a gas discharge lamp that uses vaporized mercury to produce light. Mercury vapor lamps are more energy efficient than incandescent and most fluorescent lights. Their other advantages are the lifetime in the range of 24,000 hours and a high intensity, clear white light output. For these reasons, they are used for large area overhead lighting, such as in factories, warehouses, and sports arenas as well as for streetlights. They offer better color rendition than the more efficient high or low-pressure sodium vapor lamps. They require a warm-up period of 4 – 7 minutes to reach full light output. Mercury vapor lamps are becoming obsolete due to the higher efficiency and better color balance of metal halide lamps.(Gendre, 2003) The use of mercury vapor lamps for lighting purposes will be banned in the EU in 2015.

METAL-HALIDE LAMP

A metal-halide lamp is an electric lamp that produces light by an electric arc through a gaseous mixture of vaporized mercury and metal halides (Hordeski, 2004) (Kwok et al., 2009). It is a type of high-intensity discharge (HID) gas lamp similar to mercury vapor lamps that contain additional metal halide compounds. This improve the efficacy and color rendition of the light.

Metal-halide lamps have high luminous efficacy and produce an intense white light. Lamp life is 6,000 to 15,000 hours. (Kwok et al., 2009) They are used for wide area overhead lighting (Kwok et al., 2009) of commercial, industrial, and public spaces, such as parking lots, sports arenas, factories, and retail stores, (Hordeski, 2004) as well as residential security lighting and automotive headlamps (xenon headlights).They require a warm-up period of several minutes to reach full light output. (Kwok et al., 2009)

LIGHT EMITTING DIODE

A light-emitting diode (LED) is a two-lead semiconductor light source. When an LED's anode lead has a voltage that is more positive than its cathode electrons inside are able to releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor and therefor by the voltage.

The majority of light sources used in public lighting are high-intensity discharge lamps; but light emitting diode (LED) lamps are being presented as a more energy-efficient alternative. This is due to the fact that LED lamps, unlike conventional light sources, make a direct transfer of electrical energy into light and are being strongly promoted (Gil-de-Castro et al., 2012). Nevertheless many research have been criticized the use of the LED for the street-lighting doubting the actual energy savings considering in the cost of the operation the consumption and the maintenance plus the cost of purchasing the new devices.(Cielobuio, 2008). Moreover, according to other research, there are some concerns relating to human health about the use of the LED technology for lit-up the urban night environment: this due to the dominating blue component in the visible spectrum that affect the biologic clock of the human being, in particular in the ancient population.

3.2. RESEARCH CONTEXT

The purpose of this dissertation is not commonly investigated in the current research context; indeed, there is no research that proposes solutions, or discuss about the estimation of the light requirements and the derived consumption at urban level. Because of the lack of research, the work carried on, is based on theoretical lecture notes, legal requirements, and official documents of the public administration.

The idea to investigate on the Urban Public lighting consumption has taken place during my collaboration with the "Laboratorio di Simulazione Urbana Fausto Curti" at the Politecnico di Milano. This thesis is part of a bigger and ambitious research about the investigation of the urban consumption. A first investigation was already carried out by another student that assessed the consumption of the built environment (Bignardi, 2012), and now in order to integrate that model, there is the need to evaluate other forms of consumption such as that of the public lighting.

The first exploration on the data available was made on the Sustainable Energy Action Plan[EM1] of the Municipality of Milan that in the municipality context we count about 126.000 points of light with an assessed consumption by the year 2005 of 108 GWh/year (S.E.A.P. Comune di Milano, 2009: p. 145). This value will become the point of reference for assessing the closeness of the methodology developed to the real values. Meanwhile, given that for reaching the target of the thesis it was necessary deepen the notion about the Illuminating engineering, it was useful to study some lecture notes that have allowed me to understand the different measures that are commonly used in this field (Nicolini, 2013). The lighting engineering basis was useful in order to better understand the different requirements and performance calculation that are needed in order to classify the roads following the legal framework (UNI11248, 2007).

3.3. LEGAL FRAMEWORK

3.3.1. CODICE STRADALE L. N. 285 DEL 30/4/92

Please, refer to the ANNEX on page A-1.

3.3.2. PUBLIC LIGHTING, A NEW LEGAL FRAMEWORK

In the October 2007 the new Italian code that goes deeper together with the UNI EN13201 into the legal framework about the public illumination it was published. The new legal context reviews in a radical way the approach to the design of the public illumination, first of all because it defines specific competences and responsibilities of the different actors involved, then it proposes a change also on the algorithm of the definition of the different lighting classes.

3.3.3. THE EUROPEAN MODUS OPERANDI WITH THE REGULATION EN 13201

The EN13201 in particular is composed by four parts: a first part of introduction, and three parts that regards in particular:

I. **EN13201-2 Performance Requirements**, or qualitative and quantitative parameters that the different environments taken in to account has to observe;

II. **EN13201-3 Performance Calculation**, that shows the algorithm and the standards for the calculation of the performance;

III. **EN13201-4 Measuring methods of photometric performance**, which shows and suggest methods and procedures for the performance's validation.

Those three parts indicates the standard of reference and are common to all the member state. The classification of the different environment include aspect connected to the security of the population, and each member state has the responsibility on the security aspect, consequently each one has produced their own regulatory documents for the classification. Inside those documents are taken in to account the indication of the European document, in Italy the document of reference is the UNI 11248.

3.3.4. THE UNI 11248, THE ITALIAN LEGAL FRAMEWORK ADDRESSED BY THE EN13201

The UNI 11248 is a document composed by four main sections, the first one referred to the road code and the determination of the reference lighting category and the other three parts adopts the European Indication (EN13201-2/3/4) for granting a homogeneity among the member states.

SECTION ONE – REFERENCE CLASSES AND RISK ANALYSIS

Selection of the lighting category, this first part introduces some consideration on the competences of different actors, imposing to the owner or the managing authority of the road and to the designer a precise responsibility about the parameters of design. The regulation gives a framework for determining the illumination condition of a given traffic zone.

ROAD TYPE	DESCRIPTION	SPEED LIMITS KM/H	REFERENCE LIGHTING CATEGORY
A_1	Extra-urban Highway	130-150	ME1
	Urban Highway	130	ME1
A_2	Highway road services	70-90	ME3a
	Urban Highway road services	50	ME3a
	Main extra-urban roads	110	ME3a

B	Main extra-urban road service roads	70-90	ME4a
C	Subsidiary extra-urban roads (C1 and C2 types)	70-90	ME3a
	Subsidiary extra-urban roads	50	ME4b
	Subsidiary extra-urban roads with particular limitations	70-90	ME3a
D	Urban expressway	70	ME3a
		50	ME3a
E	Inter-district urban roads	50	ME3a
	District urban roads	50	ME3c
F	Extra-urban local roads (F1 and F2 types)	70-90	ME3c
	Extra-urban local roads	50	ME3a
		30	ME4b
	Urban local roads (F1 and F2 types)	50	S3
	Urban local roads: town centre, environmental isles, zone 30	30	ME4b
	Urban local roads: other situations	30	CE4
	Urban local roads: pedestrian areas	5	CE5/S3
	Urban local roads: town centre (pedestrian, other users accepted)	5	CE5/S3
	Inter-zonal local roads	50	-
		30	-
-	Cycle lane[3]	-	-
	Particular destination roads[4]	30	-

Table 3.2 – Reference lighting category according to the road typology (Allegato 6, UNI 11248)

The regulation indicates how to classify the zones starting from a reference classification and arriving to a designing classification according to an evaluation process that take in consideration different variables, this process is known as Risk analysis. After this first classification, the designer applies the "Risk analysis" or better an evaluation of the specific characteristic of the environment that can address the choice of the category. After the Risk analysis, the category is now called "Project light category".

Road type	Traffic flow	View field complexity	Conflict zone	Slow speed bump	Attack risk index	Average slope	Field lighting level index	Pedestrian
A1		High	-					
A2		Normal						
B			None					
C		-						
D	Max							
E								
F		Normal		None	Normal			
Cycle lane		-	-	-	-	<=2%	Urban field	Not allowed

Table 3.3 – Influence parameter (Allegato 6, UNI 11248)

Most of the evaluation elements and their weight in terms of risk are written in the regulation document through tables and decision process, but the designer is free to improve and implement the evaluation according to other aspects that are consider relevant by the designer. At the end of this analysis that the

[3] *Decreto Ministeriale 30 novembre 1999 n° 557 del Ministero dei Lavori Pubblici.*

[4] *Secondo l'art. 3.5 del Decreto Ministeriale 5 novembre 2001 n° 6792 del Ministero delle Infrastrutture e dei Trasporti.*

designer have to support by proof, it will be possible to obtain the operating sub-categories according to the variation of the traffic flow.

The legislation UNI11248 and the correlated UNI EN13201/2/3/4 recognize lighting prescription for all the circulating public areas, intended for motorized traffic, cycle and pedestrian, defining for all the typologies specific reference parameters. The regulation moreover presents some informative annexes useful for the designer, namely:

ANNEX A, That suggests and provide example useful to the evaluation and the variation of the reference lighting categories according to the parameters considered inside the risk analysis

ANNEX B, that provides notes concerning the determination of the lighting categories for the”F” road.

ANNEX C, which gives notes concerning the road intersection as crossing or roundabout with information about their calculation and classification.

ANNEX D, which characterizes the road luminance.

SECTION TWO, UNI EN 13201-2 PERFORMANCE REQUIREMENTS

This second part defines, in a qualitative and quantitative way, the lighting categories through photometric requirements to be observed in order to satisfy the needs of both motorized and cycle-pedestrian users.

At the end of the analytical process the designer will recognize the lighting category that can belong to three main macro categories: i) ME or MEW; ii) CE; iii) S,A,ES,EV.

ME and MEW Series

These categories refer to the motorized roads were applicable the luminance calculation, the difference between them is the weather condition: for the road with a dry weather condition:

	ROAD COATING LUMINANCE			DISABILITY GLARE	PROXIMITY LIGHTING
CATEGORY	L min [cd/m2]	Uo min.	Ul min.	TI% max (+5% for low luminance sources)	SR 2 min. (in absence of traffic zone with proper requirements near the lane)
ME1	2,0	0,4	0,7	10	0,5
ME2	1,5	0,4	0,7	10	0,5
ME3a	1,0	0,4	0,7	15	0,5
ME3b	1,0	0,4	0,6	15	0,5
ME3c	1,0	0,4	0,5	15	0,5
ME4a	0,75	0,4	0,6	15	0,5
ME4b	0,75	0,4	0,5	15	0,5
ME5	0,5	0,35	0,4	15	0,5
ME6	0,3	0,35	0,4	15	No requirements

Table 3.4 – ME lighting categories: motorized traffic roads where luminance calculation is applicable, for dry atmospheric conditions (source EN 13201)

While for the wet condition:

	ROAD COATING LUMINANCE				DISABILITY GLARE	CONTINUITY LIGHTING
	DRY			WET		
CATEGORY	L min	Uo min.	Ul min.	Uo min	**TI% max** (+5% for low luminance sources)	**SR 2 min.** (in absence of traffic zone with proper requirements near the lane)
MEW1	2,0	0,4	0,6	0,15	10	0,5
MEW2	1,5	0,4	0,6	0,15	10	0,5
MEW3	1,0	0,4	0,6	0,15	15	0,5
MEW4	0,75	0,4	No req.	0,15	15	0,5
MEW5	0,5	0,35	No req.	0,15	15	0,5

Table 3.5 – MEW lighting categories: motorized traffic roads where luminance calculation is applicable, for mainly wet atmospheric conditions (EN 13201 source)

CE Series

These categories are applied to motorized traffic area where the luminance calculation is not possible for instance: conflict zone, commercial area and roundabout. It is even applicable to some cycle-pedestrian use when the “S” and “A” Series are not suitable.

	HORIZONTAL ILLUMINANCE	
CATEGORY	Eavg. min.maintained [lx]	Emin maintained [lx]
CE0	50	0,4
CE1	30	0,4
CE2	20	0,4
CE3	15	0,4
CE4	10	0,4
CE5	7,5	0,4

Table 3.6 – CE lighting categories: motorized traffic roads where luminance calculation is not applicable (EN 13201 source)

S, A, ES, EV Series

Categories “S” or “A” refer to cycle-pedestrian environment as for instance sidewalk or cycle-path, but also emergency lanes and other lanes separated or along the roadway, urban roads, pedestrian roads, parking areas, road inside school buildings. The choice if execute the analysis based on the horizontal illuminances (Class S) or the hemi-spherical illuminances (Class A) is given to the designer, although the UNI 11248 bring back the pedestrian area to the S class, because in Italy the analysis on the horizontal illuminance is preferable.

CATEGORY	HORIZONTAL ILLUMINANCES	
	Eavg. min. [lx]	Emin [lx]
S1	15	5
S2	10	3
S3	7,5	1,5
S4	5	1
S5	3	0,6
S6	2	0,6
S7	not fixed	not fixed

Table 3.6 – "S" lighting categories: cycle and pedestrian environments (EN 13201 source)

CATEGORY	HEMISPHERIC ILLUMINANCES	
	Ehs min. [lx]	E min.
A1	5	0,15
A2	3	0,15
A3	2	0,15
A4	1,5	0,15
A5	1	0,15
A6	not fixed	not fixed

Table 3.7 – "A" lighting categories: cycle and pedest ments (EN 13201 source)

Lighting categories "ES" refer to the survey on the hemi-cylindrical illuminances. These classes subsidiary to "S" and "A" classes when the designer consider useful in order to reduce the criminality and eliminate the unsafety sensation.

CATEGORY	Esc min. [lx]
ES1	10
ES2	7,5
ES3	5
ES4	3
ES5	2
ES6	1,5
ES7	1
ES8	0,75
ES9	0,5

Table 3.8 – "ES" lighting categories: semicylidric illuminance survey (EN 13201 source)

CATEGORY	Ev min. [lx]
EV1	50
EV2	30
EV3	10
EV4	7,5
EV5	5
EV6	0,5

Table 3.9 – "EV" lighting categories: vertical illuminance survey (EN 13201 source)

Moreover, the regulation ask to consider aspects of daytime and night-time appearance of the lighting system as well as to consider the aspects of comfort and limitation of light emission in directions not necessary, suggesting a range of topics.

SECTION THREE, PERFORMANCE CALCULATION

This third parts regarding the European legal framework, describes the convention and the calculation algorithm to adopt for obtain the caparison parameters in conformity to the EN13201-2.

The observer are one for street lane, therefore we will have an observer for n street lane. Such observer are located at the very center of the street- lane, at 1,5 meters of height and with 60 meters of distance. For each observer are calculated: i)Mean luminance of the entire carriageway; ii)General Uniformity for the entire carriageway; iii)The threshold increment for the entire carriageway; iv)the longitudinal uniformity for the centerline of the street lane of reference of the observer.

The values taken in to account are the worst taken from the different observer, those value are the value of reference. Afterwards will be calculated the threshold increments. In this third part should be underlined that, observe a given value of uniformity can become very difficult, and in order to guarantee an adequate uniformity the lighting designer have to pay more attention to the light choice.

SECTION FOUR, CALCULATION METHODS OF THE PHOTOMETRIC PERFORMANCES

This fourth part of the legislation, defines the procedures, conventions, and some suggestions for the measurement of photometric performance of a lighting system.

Provides information on tools, grids, environmental conditions and all parameters required for the implementation of the reliefs.

CHAPTER 3 – THE MAIN OUTCOME

The outcome of this chapter is to build a knowledge about the theoretical, technical and legal that concern the public lighting. In fact, it was possible to address topics relating to the main lighting measures to get an overview of theoretical knowledge appropriate to the development of the methodology explained in the next chapters. Furthermore, it was also deepened the legislative framework, European and Italian.

4. METHODOLOGY

The purpose of this chapter is to build-up a methodology able to support the entire analysis. The construction is based on some targets and assumptions useful to create a functional framework, one of those is the fact that the entire methodology is built-up according to the data available, thus the TDB become of grate relevance in this framework. Then, the steps that together compose the entire methodology will be identified. Given the nature and the large amount of data, is of fundamental importance was the use of a Geographic Information System software (here and after GIS) that allowed the management and processing of all information and the creation of the variables identified by the technical regulations in the field of public lighting. Through the use of spreadsheets these variables were subsequently managed.

4.1. TARGET

The work contained in this thesis starts from a set of fundamental assumption that will guide the work until the achievement of the targets fixed.

The public lighting of a city is a service supplied for different reasons. Initially there were a fundamental need to see inside the public environment the strictly necessary to allow the citizens to move within the city. The supplying of a service that allow to guarantee to the citizenship to carry out the daily activities even in the dark hours grew over the years and the lighting became a status for a city, a way for prove his greatness, and so were necessary light up not only the streets but also the parks and the symbol of the cities. There is a dual aspect of the public lighting system: on one hand, there is the need to increase the perception of security for the city users and for the driver that use the streets. On the other hand the public lighting in the city is used also for emphasize the great beauty that for historical reasons attract many tourist from abroad.

In this thesis, I am not going to assess the consumption of all the parts of the public lighting system, but only those aspects that make it a necessity: the safety of the city at night.

There are a lot of research that focuses on the perception of security, and mostly the crime according to the way in which is lighted-up a city.

The general target of this work, in light of the research question, is to reach a set of value that describe the different roads according to their requirements of light and their consumption derived from it. These values should be useful to have an idea, in the different step of the lighting service's deployment – from the design to the maintenance process – , a given typology of streets how much light require and consequently how much consume in terms of electric energy expressed –given the dimension of the service- in MWh and sometimes in GWh.

The categorization of the streets will be according to the lighting category, and according to the morphological and functional characteristics of the road. For the first categorization will be used the lighting category introduced by the European legislation, while for the second one, will be necessary discriminate the roads according to the presence or absence of sidewalks, their number, and the number of carriageway that sometimes describe the size of the roads. These characteristics are supposed the most responsible to the differentiation of the lighting requirements at the first level[5], and therefore will constitute the basics variables for develop a taxonomy. For doing it, it will be necessary make a strong work of data cleaning and elaboration for determinate those variables useful to the description.

All the process in this work are studied, think and applied for being scalable, and reproducible with other data in other situation. For allow this 3 characteristics to be part of the process, there is useful to construct a methodology where you can put the data and get the outcome in some step, and for obtaining that, is useful the construction of a "Black Box". The construction of the "Black Box", where is possible to insert the data and obtain the results desired is part of the target that ask for wide effort, but at the same time can bring to results that are approaching the reality. At the same time, this require a data cleaning and elaboration of other variables that do not exist, as they should stands within the database.

4.2. ASSUMPTION

ESTIMATING THE CONSUMPTION STARTING FROM THE REQUIREMENTS

The basic assumption is: given that there is a legal framework at European and national level, where is established a minimum standard of light, through the study of this standards and their application at a case study, is possible to quantify the total quantity of light needed to satisfy these standards. Through the use of the illuminating engineering and his measures is possible to shift from simple value, as for example the illuminance values required for a street, to a value that is able to establish how much light and how powerful must be those light for satisfy the minimum standard for each street.

THE LEGAL FRAMEWORK GIVES AN IDEA ABOUT THE REQUIREMENTS

The idea that the legal framework can classify in a detailed way the entire urban environment can take to a one-way work. The problem is the impossibility to foresee in detail each part of a road system in terms of public lighting. So a simplification is needed, also because the legislation is clear in this point, the luminance and illuminance values are not mandatory, the values wrote down in the legal documents quoted

[5] It is useful to remind that there are three level of designing of the public lighting. The first level, the one where we will conclude, it is a definition of a set of lighting category of reference. then after different study on the complexity of some parts of the roads there is the second level where are defined a set of designing lighting category, more precise and appropriate for specific situation, too specific for make an analysis at urban level and sometimes also at neighbor level. The third level is referred to the use of the lighting system, the expression of this level is the definition of a set of Operating Lighting Category, these category can change throughout the day because are taking into account variables like the capacity utilized of the flow and other situation that change during the 24 hours.

in the previous chapter are only a recommendation, the legislator say how to light-up, but not necessarily these values must be respected. There are so many aspects to keep in mind that thinking about writing all the prescriptions in a European legislative framework is inconceivable, so that the legislator have decided to fix a set of value classified in different category, referring to the designer the task to decide the best solution in terms of lighting.

THE URBAN SPACE CLASSIFIED – THE NOLLI MAP

The spaces where there is a need of light during the dark hour almost coincide to the public spaces. This could be sounds obvious, but a dark, or at least, a bad lighted up public space is something unconceivable today. This because of the safety perception of the pedestrian that pass through them. For this reason, in this work I have adopt the concept of Nolli Map for express the set of spaces that should be lighted up. This open to other tasks, not all the spaces are light-up in the same way, all the spaces are light-up, but moving from a given space to another one we can dealing with a change in the grade of brightness.

PRESCINDING FROM THE STRUCTURAL DIMENSION OF PUBLIC LIGHTING

This is a basic assumption. The lack of data is a problem that spread out everywhere. More than an assumption, this could be a target that anyway should be placed at the beginning. The effort of this work is to use data that every municipality should have in their data equipment, and this means avoiding the distribution of the light poles in the territory because often this information is in the hands of the agency in charge of the public lighting management. This could be a good reason for avoiding the position of the streetlight, but another one could be the fact that one of the task is the recognition of the requirements. The requirements does not start from the position or the number of the poles, but start from the need of the citizens to have a more or less bright urban space. Keeping constant the length and the lighting category, what can differentiate the requirements of light is the width of a road. This is the matter why the width is so important in this dissertation so that will be proposed two way for calculating it. The wider the road is, the highest is the quantity of light needed.

THE LIGHT POLES ARE SUPPOSED AT THE SAME HEIGHT

The last assumption open to other issues: the height of the streetlight can differ along a road. Since we're not able to determinate which road should have which height of street light, or at least, inside the different typology of motorized road, the height of the street light are fixed in 10 metres for the motorized streets and 4,5 metres for the pedestrian roads, the cycleway and the self-lighted sidewalks.

THE LIGHT EFFICACY IS CONSIDERED THE SAME FOR ALL THE TERRITORY

The value referred to the light efficacy can vary from streetlight to streetlight in practices; the big differences exist between different technologies that can grants different quantity of luminous flux maintaining constant the power used. In this thesis the light efficacy is considered as a minimum value to respect, therefore I have used a value established by the Umbria Region quantified in 90 Lumen per each watt generated (Regione Umbria, 2005). This value is crucial for calculating the consumption derived from the requirements, and this means that if we use a light that generate a light with less power. Thus have a better light efficacy than the constant 90 lm/watt, means that we're going to save few watt of power that multiplied per the hours of use and the number of light that apply the same save became a huge saving

NOT ALL THE CONSUMPTION CAN BE TRACKED

The assumption about the public space that correspond to the lighted area is true, and the fact that the different area contribute differently to the consumption, due to the different requirements (low) and due to the peddling size that relatively a category of public space take part to the lighted area. This is the case of the cycle way that are outside the urbanized area. The weight of them are so low that I have decided to skip their calculation. Anyway must be taken into account that the requirements of light of these areas are almost the same with the self-lighted sidewalk because of the use of the same typology of streetlight (in the height and in the technology) and because of their morphology, that is almost the same.

4.3. LIMITS OF THE MODEL

The purposes of this thesis, as stated before, is to recognize the lighting requirements and his derived consumption, nevertheless for having an idea at urban level, there was necessary to disregard some notions that at design level are relevant. First of all the methodology of calculation of the total flow method does not say nothing about the uniformity of illumination that is a relevant factor that can determine the unsafety of a road. Anyway, the purpose is not to design a new lighting system, the lighting classification as it stands is a good starting point on which develop a project. Secondly the quality of the data there are relevant, especially because the methodology is highly conditioned by the morphology and the characteristic of the road section more than by the functional class of it.

4.4. METHODOLOGY DESCRIPTION

4.4.1. IDENTIFICATION AND CLASSIFICATION OF THE TERRITORY TO LIGHT-UP

The first step consist on the identification of the territory on which will be applied the calculation of the light requirements. Accordingly, the choice of the territory is based on the availability of the data and should be classified for better structures the definition. In this dissertation, I have choose to split the territory of the public city in later identified in Nolli Map in: roads, composed mainly by streets and sidewalks; and other public area composed by parks and independent cycle or pedestrian path outside the roads.

4.4.2. LEGAL REQUIREMENTS AND PRESCRIPTION ANALYSIS

Once classified the Nolli Map, the second step is the investigation on the light requirements that the legal framework identifies. In this case I have identified a European legal framework that the Italian legislation have adopted in a document called UNI 11248 described in the previous chapter. This legislation referred to the light requirements was combined with the "Codice stradale" that is the Italian legislation about the roads. Both of the legislation (road typology and light requirements) are combined and simplified for the purposes of the thesis. In fact, most of the prescription are not relevant or applicable for reaching the target of the thesis. The legislative simplification, because of his logical structure, will affect the lighting categories identification's algorithm in the step four.

4.4.3. Data recognition and data cleaning

The third step sees the Data recognition and cleaning, or the collection of the minimum set of variables necessary to detect the lighting categories and apply the calculation of the total luminous flows. The first part of this step, called data mining, is the process of identification of the GIS shape files, then will be a second part of data extraction and cleaning that in practices is a process of extraction of the variables useful to the calculation. The more variables are taken into account, the more complex is the model. As will be presented in the next chapters, are proposed two versions of the same calculation and one is the evolution of the other more complex because taking into account more variables. The results of this step is a development of a Database that have inside all the variables all referred to an univocal ID geographically referred to a street elements.

4.4.4. Lighting classification of the roads

The fourth step is the quantification of the light requirements. As said before, in the methodology are displayed two algorithm that takes to outcomes similar in the logic structure, but deeply different in contents. While the simple algorithm referred only to the street side, the second one referred also to the sidewalks and so to the pedestrian dimension. The structure are similar because both takes to a classification of the roads with a lighting category and consequently an identification of a lighting index and therefor a determination of a coefficient of the illuminance value useful to classify the road and proceed with the quantification of the requirements. The other values required before calculating the requirements are the Utilization factor, better explained in the following chapters, and the depreciation coefficient established in 70%. Once known the illuminance value and the area to be light-up is possible, using the total luminous flow calculation, quantify the light requirements measured in Kilo-lumen.

4.4.5. Quantification of the light requirements

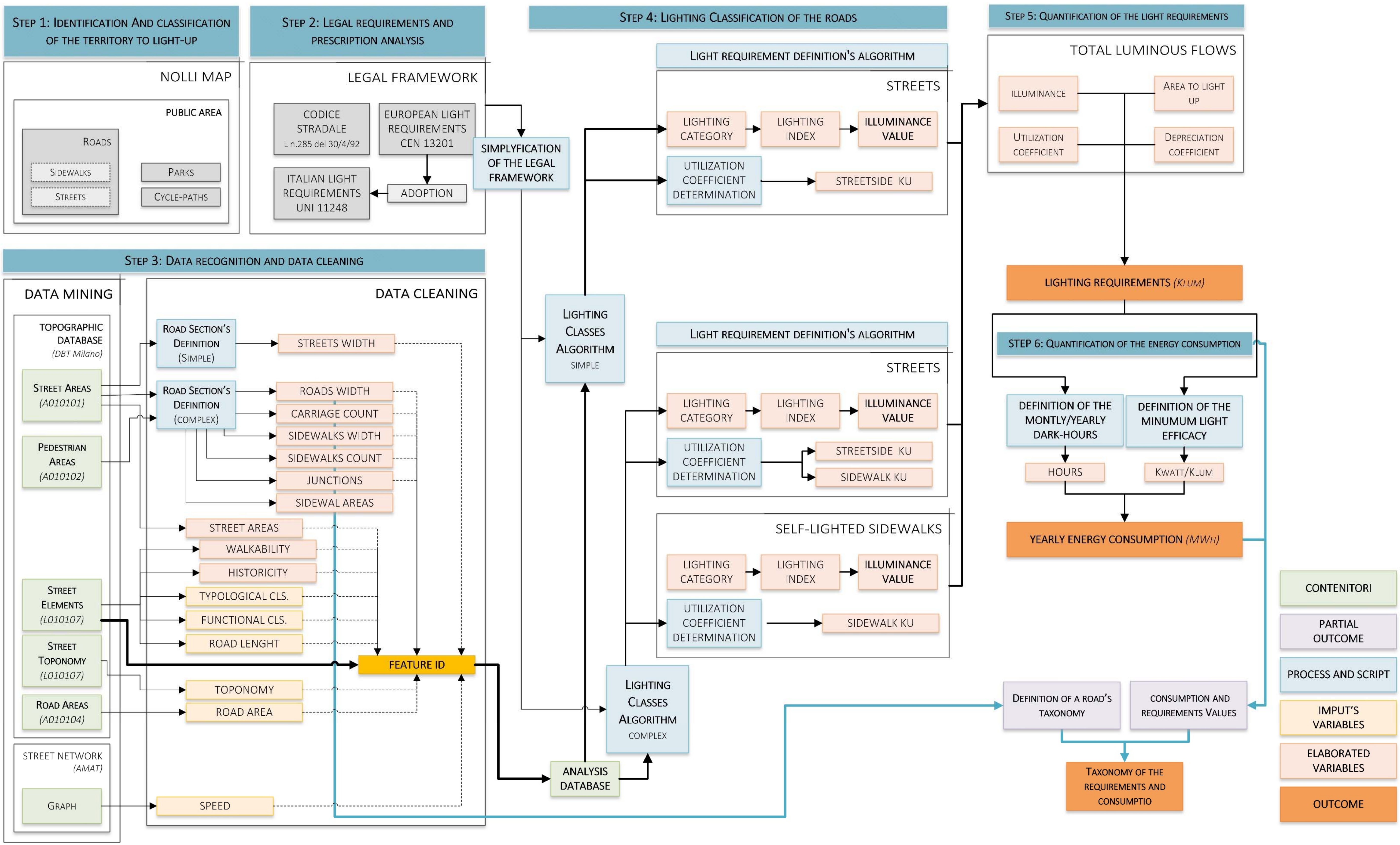
The fifth step is the determination of the light requirements. Using the Total luminous flow formula, and having the data about the illuminance value, the area to light up, and the coefficient of utilization and depreciation Is easy to calculate the requirements calculated in klm for each street element

4.4.6. Quantification of the energy consumption

The sixth step is the quantification of the light requirements energy needed to satisfy the light requirement. This final step is easy to calculate once established a light performance ratio quantified in 90 Watt per each Kilo-Lumen.

CHAPTER 4 – THE MAIN OUTCOME

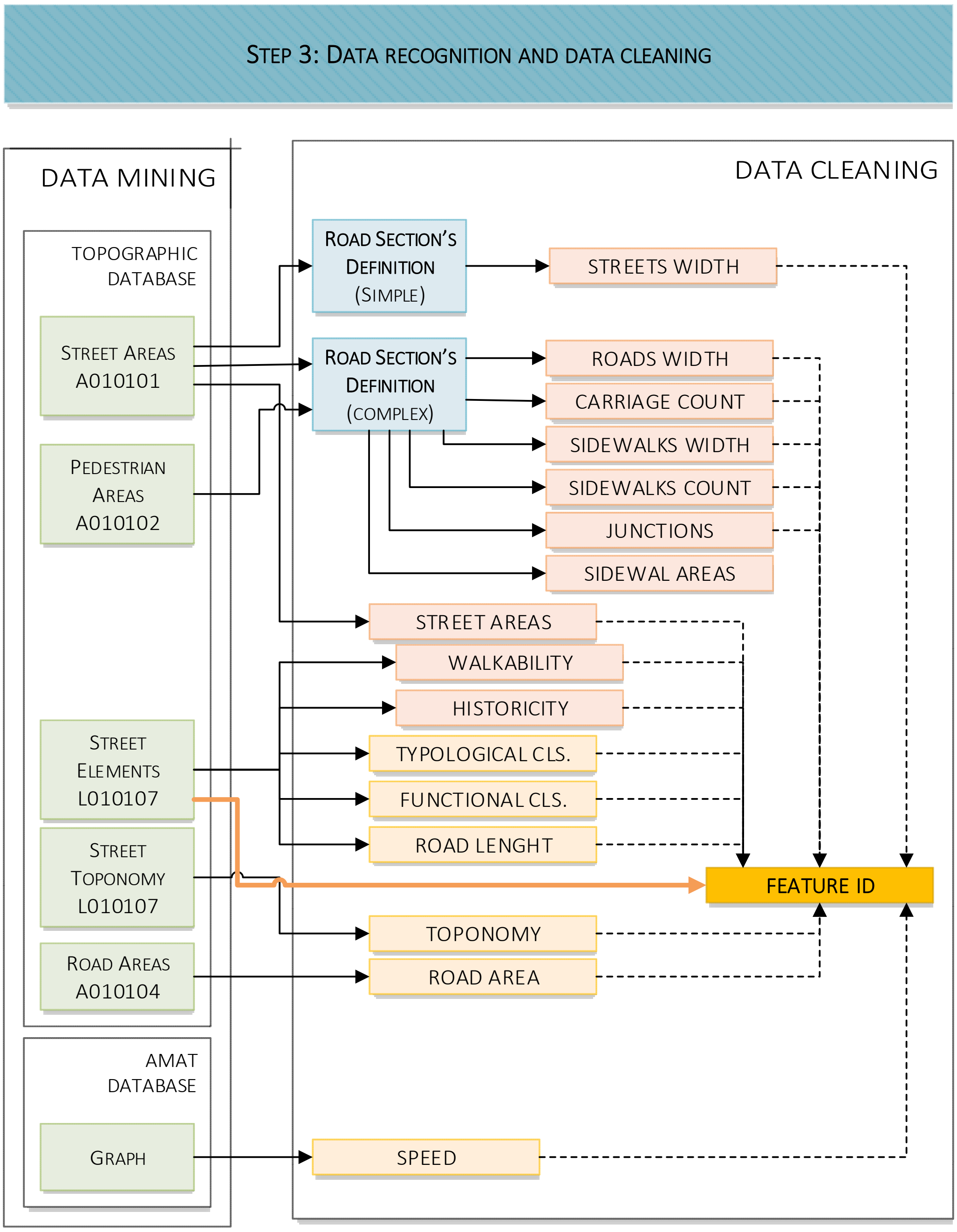
The outcome of this chapter is the construction of the methodology able to support the entire assessment of the consumption. The process must starts from few assumptions necessary in order to generalize some situation that at urban level are not manageable. The methodology have few limits in his application, certainly the outcome will not use for a detailed design of the lighting system.



Graphics 4.1 – Methodology's scheme (Own elaboration)

5. PREDISPOSITION TO THE METHODOLOGY, THE DATA ELABORATION

In this chapter will be analysed and elaborated the set of data useful to the construction of the algorithm, and therefore will be necessary carryout a set of procedure for make sure that all the variables are manageable and referred to a common ID in order to construct the database on which the algorithm works. The Analysis Database will have, besides the ID referred to the street element, the entire set of ID key of the other shape files to keep the connection with them. To have a more clear idea of how the data are directed to a database is useful to take a look in the Graphics 5.1, that are parts of the methodology explained in the last chapter.



Graphics 5.1 – Logical elaboration of the data (Own Elaboration)

5.1. THE RECOGNITION OF THE DATA REQUIRED BY THE METHODOLOGY

The data needed for carry out the process contained in the methodology regards different aspect of the roads: firstly, we have to collect data that contain those variables that classify the roads regarding their structural, functional and technical characteristic. Then is fundamental to have data regarding their morphological characteristics, in particular in this terms is relevant the width of the street, the presence of sidewalks and all those data that contain characteristics and variables that can affect the requirements of light for a given road.

5.1.1. THE TOPOGRAPHIC DATABASE (TDB) AND THE DATA USED FOR THE ANALYSIS

The Topographic Database, that in Italy is the best cartographic representation, composes the principal geographical database source used for supporting the analysis. Many layers compose this database and those used for the analysis are the follows.

A010104 STREET AREA

This shape file describe the area of the streets like an aggregate of vehicular zone, sidewalk, and small green area that often divide different carriageway inside a road like in Figure 2.2. This shape file is not the most relevant inside the analysis, anyway gives an idea which are the zones, belonging to the road system, are thus quantified and calculated the total zones that should be Light-up

A010101 STREET AREAS

Layer that describe the road surface occupied for the motorized use (car, bus, taxi, trolleybus etc.). This could be classified like the asphalted area. The total amount of this area is quantified in: 21.776.839 m_2 or 21,7 Km_2. This shape is relevant since each shape (polygon) that compose the entire file directly refer to each street elements. So that each street elements has at least one polygon referred, in this way is possible to grasp the information about the area in a relation “n to 1”

A010102 PEDESTRIAN AREA

This shape file describe the pedestrian paths and the cycle way that take part of the street and not. This means that most of the cycle path and pedestrian path (like those contained in the parks) that are outside the road system are contained in this shape file.

Clearly the information contained in this layer says a lot, anyway extract useful variables from it is an unwieldy process, in-fact the very first available variables referring the total area. This is an unmanageable information because the information we want is referred to the road trunk, for make it more clear, the information about the pedestrian area, but mostly for the sidewalks, should be referred to the road section, because if not, the value remain a stand-alone information. As presented in the methodology’s graph, this shape does not contributes to the calculation of the first Road Section Definition's but only in the second more complex and more in-depth.

L010107 – STREET ELEMENTS

The street elements' shape file is the main data container of the work. The information contained inside it makes the entire methodology working. A relevant morphological information contained is the length of the street element, then the other information referring to the typological and functional classification (D.lgs 30 Aprile 1992 n.285, o. J.) of the street that affect directly, as we will see, the lighting category. The information listed above are directly manageable, anyway, for detail them an elaboration is needed, so that through some process is possible to determinate the historicity and the walkability of a street. Finally yet importantly, the Street Elements became the main supplier of information and container of the information coming from other sources at the same time. This means that the univocal ID that each street element has inside, play a fundamental role in the construction of the database, and in particular in the joint process that are needed to grasp the data.

T030101 – STREET TOPONOMY

The Toponomy play a role of reference inside the methodology, and apart some script that use the Toponomy name of the street for recognize their function, does not enter directly in the decision process of the categorization of the roads from a lighting point of view.

5.1.2. DATA ON SPEED AND CAPACITY OF THE STREETS

The Topographic database was supported also with other geographical data. For better describe the characteristics of each road, was introduced in the black box the shape file that came from the open data distributed by the Agency for Mobility, Environment and Transportation (A.M.A.T.). The data extracted from this database were the speed and the capacity of each road.

Before talking about the process of acquisition of the data from the AMAT database, it is important to clarify the meaning of Speed and Capacity:

- Speed expressed in km/h is the velocity of outflow along each arc of street
- Capacity expressed in V_{eq} (equivalent vehicle), is the capacity of the vehicle equivalent for each arc of street in function also with the limitation like for instance the traffic lights

5.1.3. CRITICAL REVIEW OF THE DATA

The data available for the elaboration of the model in general are quite good, in the sense that, in we would have a scale of classes from one to ten of evaluation of data, I would collocate the data used for this model in the classes six. Certainly not all the city have the possibility to have the same quantity and quality of these data, in the majority of the case it is difficult to access to the Topographic Database, and it's quite difficult to find data like the AMAT database for other city.

Anyway the AMAT database, is not updated, the last update is the 2008, too far away if we would construct a dynamic model based on real traffic data.

The problem of the AMAT database is that, is not connectable via ID code with the DBT, a univocal ID code for each trunk of the road would be desirable, while in the methodology of this work it was necessary to use a spatial join with the risk to grasp wrong data making some mistake. Anyway, the validation of the spatial join was very good.

About the DBT, many criticisms have to be highlighted: firstly, many dimensional characteristics as the width of the different shape, in particular of the road, should be more precise, given that an attribute of the width in the road shapes are given, but in my opinion, the precision of this attribute is not enough. For this reason, it was necessary to use a geometrical escamotage to fine a more precise data on the street's width.

Then, it would be useful connect data that are close to the road, with the id of the road, what I mean is to refer, for instance, the sidewalk with a reference ID code, to relate them with the street elements. this because, if it was possible to know for each street trunk, the size of the sidewalk, it would be possible to know the dimensional structure of the street and build a more precise model of light requirements. Anyway, this could be considerate as suggestion to improve the model that is not so impossible to reach.

Considering the aim of the thesis, these data are useful, but for construct the variables the methodology need many steps.

5.2. ROAD SECTION DEFINITION – FIRST MODEL

Since that, the mean width of each street trunk is not given in the DBT shape file, for simplification I have calculated the width starting from properties simple to calculate. For instance, considering the archetypical structure of a streets that could be considered like a line approximately straight (of length L) with and his width could be approximate with a buffer with radius R. Now we can imagine that this width W is approximately equal to 2R. Thus, his perimeter P result approximately equal to 2W + 2L, while his area is approximately equal to W + L. Through these two equation is possible to extract the value of the width W in function of the perimeter P and the area A (two measure calculable in a GIS environment on the road sections considered:

$$\begin{cases} P = 2L + 2W \\ A = L * W \end{cases} \quad (5.1)$$

From this system of two equations of the first grade, we derive an equation of the second degree in W:

$$W^2 - \frac{P}{2} * W + A = 0 \tag{5.2}$$

Through the method of solving the second-degree equations, we obtain the average width W:

$$W = \frac{P - \sqrt{P^2 - 16 * A}}{4} \tag{5.3}$$

It is important to highlight that the previous equations fit very well with the stretched polygons with a small width (generally the case of the streets and of the sidewalks). The results of the formula could be distorted in case the square of the perimeter does not exceed 16 times the Area, having in this case the square root of a negative number.

The application of this formula were used to find the width of both the streets and the sidewalk. The width as shows before, will be useful to recognize the structure of the road

5.3. ROAD SECTION DEFINITION – SECOND MODEL

5.3.1. ASSUMPTION

The procedures that I am going to explain start from different premises and assumption.

FIRST ASSUMPTION

Firstly, the lack of information within the data collected, in particular, the missing of two relevant dimensions of the analysis of the road space: the total road width and the number of roadway, and the presence of one or more sidewalks and their relative width.

SECOND ASSUMPTION

The methodology start by the principle that a road way, composed by arc and node, has a precise direction, then, assuming those line as a point (the centre of the arc), in this precise position the road has some physical characteristic that are in conformity the entire length of the road arc.

THIRD ASSUMPTION

The results of this analysis will be applied in the methodology for estimate the light requirements and consumption, then this classification will be used as a taxonomy useful to identify the requirements and the consumption estimated for the different category of roads.

5.3.2. METHODOLOGY

Given the previous assumption, now I am briefly going to explain the step need to grasp the missing information.

First of all I need the information of the direction, and the coordinates (X; Y) in a given point of the arc (centre), and for reaching this first goal we can use the ArcGIS tool ET geo Wizard (Tchoukanski, 2004) with the conversion line to point of the shape that represent the road graph. In my case, I have used the DBT shape file named L010107.

Once used the tool we should have a situation as in the Figure 5.1, with the original shape file and a punctual shape file with the three Variables: the angle of the direction oriented towards north [ET_ANGLE], and the coordinates of the point x and y named [ET_X] and [ET_Y].

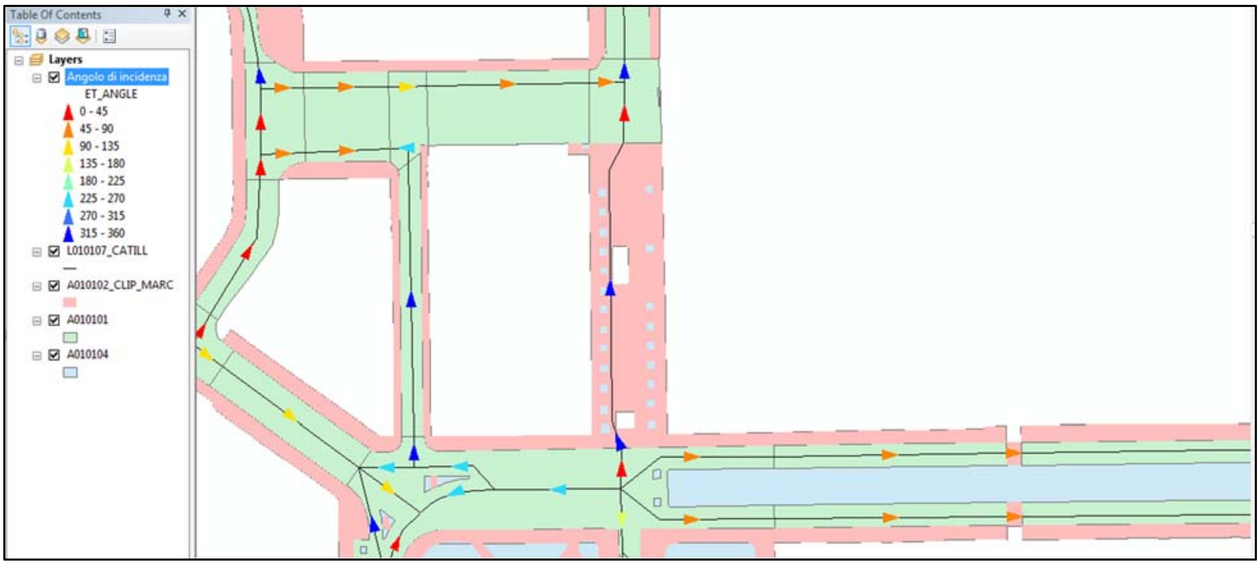


Figure 5.1 – Distribution of the centre point of the street arc with the direction attribute

After acquired the information described above, now with another tool of ArcGIS is possible to draw a line in the precise position of each node. Nevertheless, before doing that, we should create three fields in the shape file: i) a field *[LENGTH]* that contains the length of the segment that start from the centre and go for n meters in a given direction ii) two fields *[DIRECTION_1]* and *[DIRECTION_2]* that contains the angle of direction of the line. For the last two fields, given that we want two line in opposite direction exactly perpendicular to the arc, the two value calculated in the two field will be respectively:

$$DIRECTION_1 = ET_{ANGLE} + 90° \tag{5.4}$$

$$DIRECTION_2 = ET_{ANGLE} - 90° \tag{5.5}$$

Direct observation of the road, have demonstrated that the maximum width of a road in the Milan's territory is 85 meters belonging to "Corso Indipendenza" that anyway has some characteristic. Now, having the characteristic of the line we can launch the tool called: "Bearing distance to line" (Figure 5.2), that in practices ask the coordinates of the starting line [ET_X] and [ET_Y], the bearing angle [DIRECTION_2]; and the length of the segment [LENGTH], in this case I have choose a length equal to 100 meters.

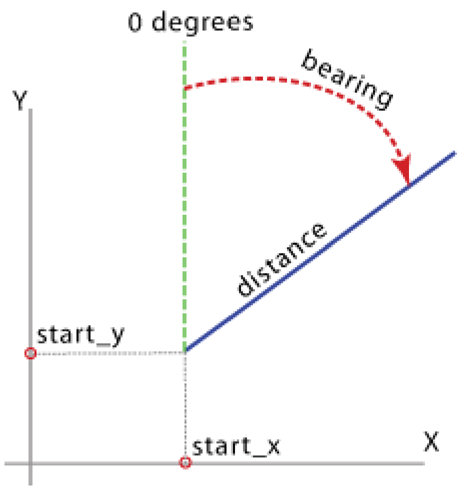


Figure 5.2 – How the Bearing Distance to Line works

Now a clarification should be done: the line drawn should have in the both direction (±90°) the same ID, and in particular, the same ID of the centre point, that anyway is the same of the road arc, so that it is easy to match the different shape files with a simple join. And even if the line will be overlapped, next will be explained how clean the plot of lines drawn after this tool

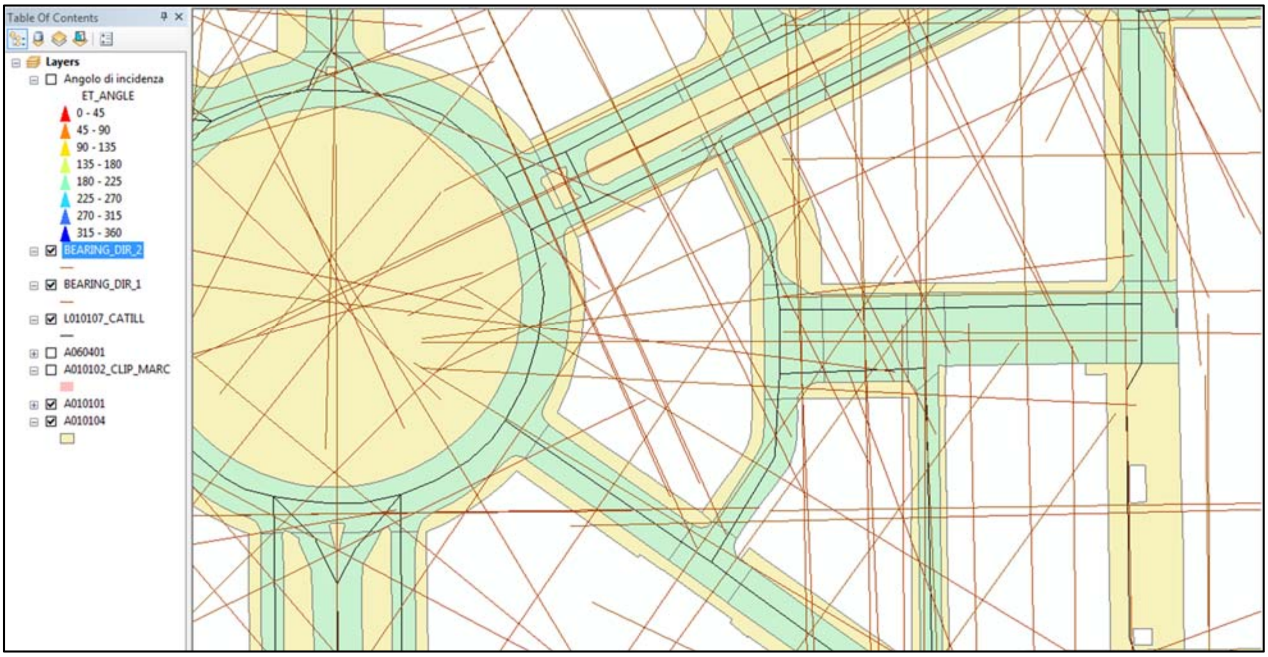


Figure 5.3 – Plot of lines after the tool execution

Now given the line are in two different shape files, I have to merge these two files in one and then dissolve it keeping the same ID of the line, so that at the end I will have a symmetrical single line with a centre line that correspond to the centreline of the arc.

Subsequently that, the main step: The clipping of the line. This step is crucial because cut the Line achieved in the last step exactly at the end of the road. For doing that, I have used the tool called "CLIP" that cut the lines with the road shape.

Now, exploding the lines cut in multipart feature and selecting the Line that intersect the original centre point, we are able to keep the right lines, the ones that belongs spatially to the centre point and discard the other lines.

Now it is possible to re-calculate the length of the segment that correspond exactly to the road width.

If the length still remain to the original, it is highly probable that the line fall in an intersection, so we can delete the lines that are longer than the widest road because are not useful to the purpose of the methodology.

The next step is useful to grasp the information about the sidewalk, and in particular the number and the dimension, to complete this task is useful to doing a spatial join between the lines and the sidewalk shape file (A010102) that has inside his attributes the information about the width of each sidewalk.

Once grasp all the information is necessary clean up and homogenize all the data for two main reason:

Firstly, the roads in some points demonstrate a wider width (up to 3 times more than the average). This is due mainly to where the line "fall", if a vertex of that line ends-up in another street area, the with will be surely affected by an error. Furthermore, among the junction the line tracked are not useful to grasp the width, because of the geometrical configuration of the junction as they stand (Figure 5.3). For these reason will be execute the following operations:

NODE COUNT FOR EACH ROAD AREA

If a given node have an area of relevance less than 250 sqm, is very likely that, this node is inside a junction because of the high density of node for square meter make true that an area is quit crowded of node. Given that, it was verified with GIS tests that there is a 75% chance to make mistake and this is unacceptable. For this reason it was choose to weight the area of relevance, multiplying for the total area of the street element and divided by the length, establishing a sort of criterion of proportion of the shape. This because is supposed that a street trunk, is similar to a long and narrow rectangle with a low ratio Area/length due to the high value of length. The resulted indicator represent the simplicity of the street element, the more simple is, and the more is the probability that, a give street elements, is a street trunk and not a junction.

$$K_s = \frac{AREA_T}{NODE_N} * \frac{LENGHT_i}{WIDTH_i} \qquad 5.6$$

The borderline value choose for declare that a given segment is a junction is: If K_s <135. This because classifying all the data in Geometrical interval[6] the lowest class has a value of 135. Now observing the effect of the classification the error decrease.

Once identified the junction with the simplicity index the next step will be carried out using Microsoft Excel.

First, there is a need to define once for the all the junction:

```
IF [KS]<135 OR
[EL_STR_TY] = "010204" (plaza) OR "010205" (roundabout) OR "010206"(crossing) THEN
        [JUNCTION] = true ELSE
        [JUNCTION] = false
END IF
```

Script 5.1
Individuation of the Junction

Once detected the junction, now we can observe the average width of the road. For doing this classification it was used the ID that correspond to the Toponomy of the street, considering the initial assumption that, a road maintain his characteristic at least along his length.

In this way, using the "Pivot Table[7]" is possible to analyse the average width of each road. Then once collected all the average per each street, it was made a discordance analysis using this formula:

$$D_i = \sqrt{\left[\frac{(WIDTH_i - \overline{WIDTH})}{\overline{WIDTH}}\right]^2} \qquad 5.7$$

The results is a set of value ranging from 0%, that means the value is consistent with the average, and 3200% that is the maximum and clearly show a problem of consistence.

A general overview of the data demonstrate that the 75% of the data are within the 100% of discordance that it is acceptable because it is possible that due to the configuration of the road the street can also change the double of his width in some cases. The value that I have considered unacceptable, are those beyond the 250% and looking at the Graphics 5.2 – Distribution of the discordance (X values

---

[6] *This algorithm was specifically designed to accommodate continuous data. It is a compromise method between equal interval, Natural Breaks (Jenks), and quintile. It creates a balance between highlighting changes in the middle values and the extreme values, thereby producing a result that is visually appealing and cartographically comprehensive. (ESRI Help Page)*

7 In data processing, a pivot table is a data summarization tool found in data visualization programs such as spreadsheets or business intelligence software. Among other functions, a pivot-table can automatically sort, count total or give the average of the data stored in one table or spreadsheet. It displays the results in a second table (called a "pivot table") showing the summarized data. Pivot tables are also useful for quickly creating unweight cross tabulations. The user sets up and changes the summary's structure by dragging and dropping fields graphically. This "rotation" or pivoting of the summary table gives the concept its name.(http://en.wikipedia.org/wiki/Pivot_table)

1=100%)Graphics 5.2 the values beyond the 250% are the 11% but if we consider that the 10.5% are junction it is clear that the discordance of the values taken into account have an average of the 10%. That means the width of the street elements differs from the average for the 10% and this is acceptable.

Once defined the Discordance, and his acceptable value, now we have to re-calculate the width for each street elements, but before we have to pinpoint some remind:

- The width considered at the beginning consider the entire width of the road without considering the number of roadway that geometrically are the street elements. It is clear that if in a road there are more than one roadway the width should be divided by the number of roadway.
- The street elements that have a value of 0 are those road that have had some mistake or simply they don't have any road that refers to this street elements (think about the cycle-path or some pedestrian streets), these streets conventionally have the width equal to the average of the streets.

Given these assumption the new width is calculated with this logic script

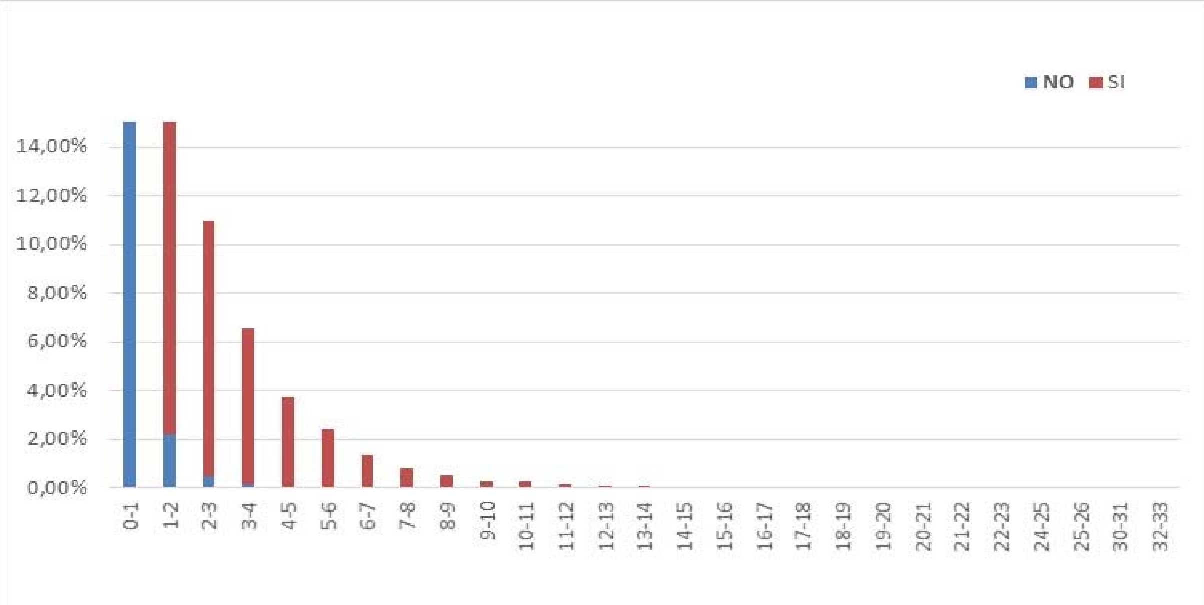
```
[WIDHT OLD] "as the width calculated with the segments"
[AVG] "as the average of the width that refers to the streets"
[DISCORDANCE] "as the relative discordance to the average of the street element's width"
[ROADWAY] "as the roadway identified per each road trunk"
[WIDHT NEW] "as the width re-calculated after the script"

IF [WIDHT OLD] =0 THEN
        [WIDHT NEW] = [AVG] ELSE
IF [DISCORDANCE] >250% THEN
        [WIDHT NEW] = [AVG] ELSE
        [WIDHT NEW] = [WIDHT OLD] / [ROADWAY]
END IF
```

Script 5.2
Definition of the Width of the roads

5.3.3. Validation

For validating the methodology, it was used the total area that results after the use of the new width multiplying per the length of each street elements.

The result after all is of 34.595.087 of square meters versus the 31.720.848 the 9% more than the reality,



Graphics 5.2 – Distribution of the discordance (X values 1=100%)

5.3.4. THE CONSTRUCTION OF A TAXONOMY OF THE ROAD SYSTEM

Once acquired the information about the number of sidewalk, the carriageway and their width, there is the need to make some order to the different characteristics building a Toponomy of the road typology in order to determinate also the lighting characteristic that each category should have, preparing the data to the calculation of the light requirements with the total flow method. Indeed now, it is possible to better describe the Utilization Coefficient because, as evidenced at page 27, the value ca be calculated for both the street-side and for the sidewalk with two different functions. The differentiation of the Toponomy was made according to the number of sidewalk and the number of carriageway. Furthermore, each category has a sub-classification that anyway is common to every category, according to the width of the street. The basic principle is, if the size of the width is beyond the 12 meters, it is possible that the streetlight can be distributed along the both side of the street. In this case, the Ku of the street it is calculated on the street width divided by two because the width of reference for each street light it is only the half. The same also for width over the 24 meters, often in this situation the streetlight for each road section can be also 4, then the width of reference is calculated dividing the street with by 4, and so on and so for.

5.4. *THE ACQUISITION OF THE ROAD AREA INFORMATION*

The information about the Area belonged to the Shape file “A010101”, and given that, for each road area belong one or more street elements (Geographical information of the Analysis Database), the information were passed on through a Spatial Join. In this case, we are making a “one to many” join process, and this means that each street elements have all the information of the street area. Nevertheless, in case we would passed on the information to the street area, we should choose if making an average, or a sum or taking the minimum or maximum value, according to the analytical process that we’re going to carry on. Is useful to underline that about 1500 records on 56000 (about the 3,2%) total street elements have not catch any data about the street area, because of this reason, on these elements is not possible to calculate anything.

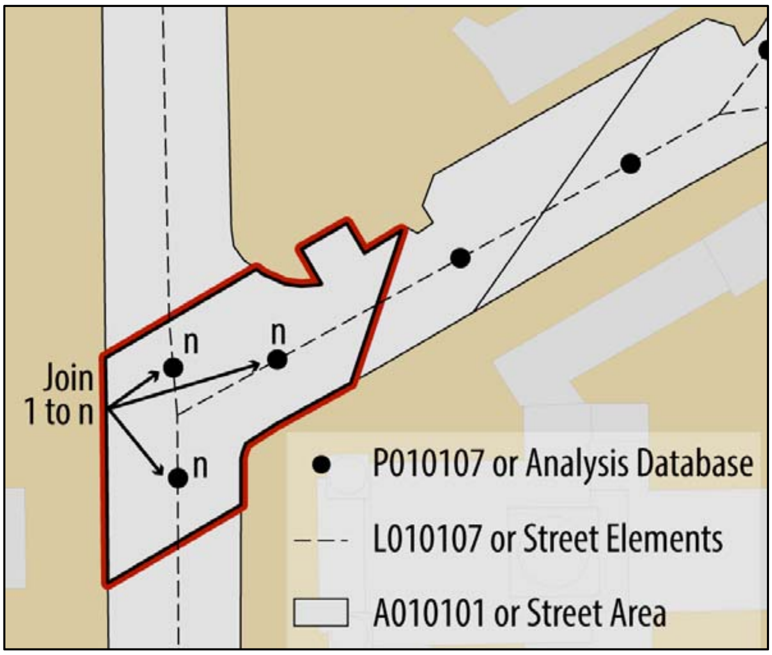


Figure 5.4 – Example of Join between the Street Areas and the Analysis Database (P010107) – (own Elaboration)

5.5. THE ACQUISITION OF THE TOPONOMY INFORMATION

This connection allow to pass on the Toponomy referred to the street names to the Analysis database through a ID code named COD_VIA content both in the two Database Tables.

The relation was one to many; this means that at one street name corresponds a number of streets elements between one and infinite.

5.6. THE ACQUISITION OF THE INFORMATION ABOUT THE SPEED AND CAPACITY

The acquisition by the DBT of the data belonging to the AMAT database is relevant to the purposes of the characterization of the street with different variables. In addition, since, use the AMAT shape file is not possible because of the different geography of the shape, this acquisition process of the speed and the capacity was made through Spatial Join in a GIS environment.

When we are making a join from line to line is difficult to acquire the data, so it was useful to fin, firstly the centroid of the L010107 (DBT Road Element Shape file), then starting with the join. Clearly, since the two-shape file have a different nature, the join have produced some mistake, but the percentage of far DBT centroid from the closest AMAT arc were very few (Less than 5%).

Like demonstrated in **Errore. L'origine riferimento non è stata trovata.**Figure 5.5 is it possible to see that the DBT not overlap the AMAT shape file, and then in Figure 5.6, is shown how the DBT shape file of the street element have acquired the Speed data (and also the capacity).

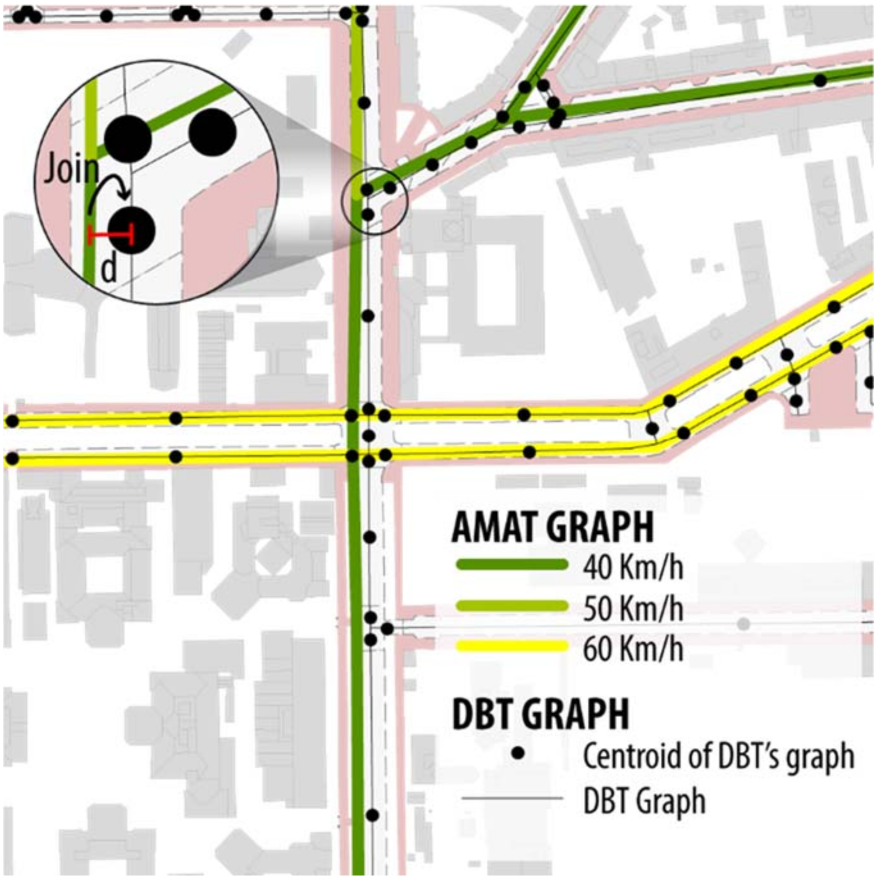


Figure 5.5 – Speed and Capacity acquisition through a Spatial Join between AMAT Graph and DBT Graph – Phase 1
(Own GIS Elaboration)

Figure 5.6 – Speed and Capacity acquisition through a Spatial Join between AMAT Graph and DBT Graph – Phase 2 (Own GIS Elaboration)

5.7. SIMPLIFICATION OF THE LEGAL FRAMEWORK

The regulation forecasts a structure of classification with precise performance and requisites.

For the purpose of this thesis I've decided to simplify this structure taking in consideration for the moment only the horizontal illumination, that anyway is the major responsible of the illumination. Because of this, from now the lighting category will be the ME, the CE, and the S. As displayed in the next tables, comparing with the tables in the paragraph 0, now some value are missing.

The Uniformity values for instance, for the purpose of the thesis are not relevant, because, since I have use a model of calculation that considers the total flow of light, it will be impossible to verify the uniformity of the distribution. Moreover, it is not taken in consideration the minimum illuminance.

CAT_GEN	CAT_ILL	L MIN		IND_ILL
ME	ME1	2	cd/m2	6
ME	ME2	1,5	cd/m2	5
ME	ME3	1	cd/m2	4
ME	ME4	0,75	cd/m2	3
ME	ME5	0,5	cd/m2	2
ME	ME6	0,3	cd/m2	1

Table 5.1 – Tables of ME lighting category with simplified values

CAT_GEN	CAT_ILL	EM		IND_ILL
CE	CE1	30	lux	6
CE	CE2	20	lux	5
CE	CE3	15	lux	4
CE	CE4	10	lux	3
CE	CE5	7,5	lux	2

Table 5.2 – Tables of CE lighting category with simplified values

CAT_GEN	CAT_ILL	EM		IND_ILL
S	S1	15	lux	4
S	S2	10	lux	3
S	S3	7,5	lux	2
S	S4	5	lux	1

Table 5.3 – Tables of S lighting category with simplified values

As demonstrated in the previous tables, what is new is the value belonging to the field IND_ILL namely illuminating index. The illuminating index is the value that correlates the different category of the EN 13201 equating the category that has the same illuminating characteristics.

For better understanding the Table 5.4, is useful to remember that, the ME categories are established with the calculation of the Luminance, that is impossible to do for the other category. Nevertheless, there is a correlation between the Luminance (L) and the Illuminance (E) when we are talking about street roads with the same, asphalted surface.

Indeed, recalling the equation of the luminance coefficient (Eq. 3.5) is clear that$E(lux) = 15 * L(cd/m^2)$, using this relation between different measure units is possible to make a correlation between the different lighting categories.

	LIGHTING INDEX UNI10439					
	6	**5**	**4**	**3**	**2**	**1**
Luminance (cd/sqm)	2	1.5	1	0.75	0.5	0.3
Category EN13201	ME1	ME2	ME3	ME4	ME5	ME6
CE	CE1	CE2	CE3	CE4	CE5	
S			S1	S2	S3	S4
Horizontal Illuminances (lux)	30	20	15	10	7.5	5

Table 5.4 – Correlation tables between different lighting categories

Consequently, the final table that has guide the entire analysis methodology. As demonstrated in the Table 5.5, the value kept for the analysis are firstly, the street identification code related with the Road Code (from A to F), for each of this correspond a Street Typology that can be describe by different capacity and different speed. Once identified the street elements by his street code, by his maximum capacity and the maximum speed of the vehicles, now it is possible to recognize the corresponding lighting category.

As can be seen, the lighting category belonging to the ME series has lose the letter that discriminating the uniformity of illumination along the street. Moreover, for each of this category correspond a lighting index from one to six, where six is the highest value with 30 lux of illuminance and one is the minimum corresponding to 5 lux. As displayed in the next step, this table is useful to construct the algorithm of classification of the reference lighting category.

COD_S	CLASS_S	CAPACITY	SPEED	CAT_ILL	E	L	IND_ILL
A_1	Extra-urban Highway	1100	150	ME1	30	2	6
	Urban Highway	1100	130	ME1	30	2	6
		1100	130	ME1	30	2	6
A_2	Highway road services	1100	90	ME3	15	1	4
		1100	70	ME3	15	1	4
	Urban Highway road services	1100	50	ME3	15	1	4
B	Main extra-urban roads	1100	110	ME3	15	1	4
	Main extra-urban road service roads	1100	90	ME4	10	0,75	3
		1100	70	ME4	10	0,75	3
C	Subsidiary extra-urban roads	600	90	ME3	7,5	0,5	2
		600	70	ME3	7,5	0,5	2
		600	50	ME4	10	0,75	3
	Subsidiary extra-urban roads with particular limitations	600	90	ME3	7,5	0,5	2
		600	70	ME3	7,5	0,5	2
D	Urban expressway	950	70	ME3	7,5	0,5	2
		950	50	ME3	7,5	0,5	2
E	Inter-district urban roads	800	50	ME3	7,5	0,5	2
	District urban roads	800	50	ME3	7,5	0,5	2
F	Extra-urban local roads (F1 and F2 types)	800	90	ME3	7,5	0,5	2
		800	70	ME3	7,5	0,5	2
	Extra-urban local roads	450	50	ME3	7,5	0,5	2
		450	30	ME4	10	0,75	3
	Urban local roads (F1 and F2 types)	800	50	S3	7,5	0,5	2
	Urban local roads: town centre, env. isles, zone 30		30	ME4	10	0,75	3
	Urban local roads: other situations		30	CE4	10	0,75	3
	Urban local roads: pedestrian areas		5	CE5	7,5	0,5	2
	Urban local roads: town centre (pedestrian, other users accepted)		5	CE5	7,5	0,5	2
	Inter-zonal local roads		50				
			30				
G	Cycle lane			S3			2
H	Particular destination roads		30				

Table 5.5 – Table of lighting classification with the performance fata for each street type

5.8. THE DEFINITION OF THE AREA OF RELEVANCE FOR EACH STREET LIGHT

Before using the total flow equation, it is important to find for each street the area of relevance for each street light. Direct observation on the different situation, have demonstrated that:

- The distance between two streetlights vary between 20 and 25 meters.
- The disposition of the street light along the street vary according the width of the street, and in particular for the street wide less than twelve meters, usually the light are distributed along one side of the

street, while for the street wide more than twelve meters the distribution is sometimes the two-side and sometimes the quincunxes.

Considering that the last two distribution, keeping the same width and distance, the area of relevance is the same.

In this way we can assume, using the logical formula, that for the street wide up to twelve meters the area is:

$$A = W * D \tag{5.8}$$

While for the street wide beyond the twelve meters:

$$A = {}^{W}/_{2} * D \tag{5.9}$$

Where W is the Width of the street and the distance is a fixed value quantified in 22.5 meters, that is the average between the two situation quoted before for the distance of the street light

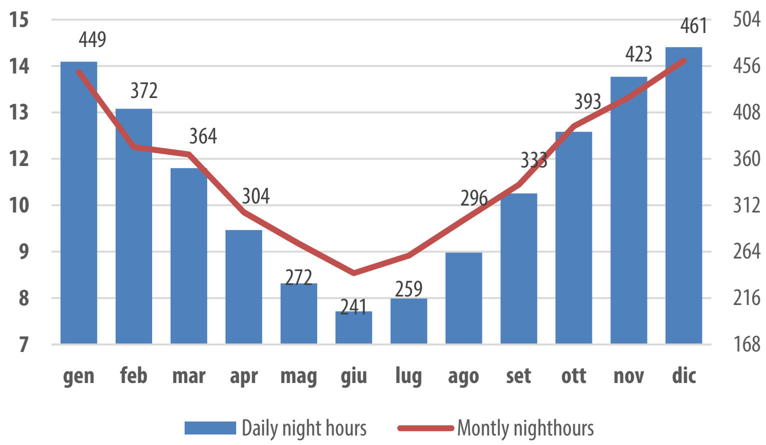
5.9. DEFINITION OF THE TEMPORAL DIMENSION OF THE LIGHTING SYSTEM

In order to calculate the consumption of a streetlight, I have supposed that this light during a year is continuously turned-on during the dark hours. The choice to evaluate the consumption during the whole year is due to the different quantity of dark hours during the twelve months. Thus for better differentiate the consumption I have choose the subdivision in monthly dark hours. Moreover, this light often is turned on 10 minutes after the sunset, and 10 minutes before the sunrise.

Taking the data on the sunrise and sunset of Milan I have calculated the total dark hours during the year that as presented in the Table 5.6 are quantified in 4174.

It's clear that the hours that the light are turned on vary according to the choice of the municipality, for instance some streets could be turned off during some night hours, some others instead can be lighted up by alternate street lights, one turned on and one turned off.

For simplification I have choose to use the whole night since we do not have the data on the ignition times of the street lighting street by the street.



Graphics 5.3– Night hours by months (Own elaboration)

MONTHS	DAILY NIGHT HOURS *(HH:MM)*	MONTLY NIGHTHOURS *(HH:MM)*
JANUARY	14:30	449:47
FEBRUARY	13:17	372:12
MARCH	11:45	364:31
APRIL	10:09	304:43
MAY	8:46	272:09
JUNE	8:03	241:40
JULY	8:23	259:58
AUGUST	9:34	296:53
SEPTEMBER	11:06	333:10
OCTOBER	12:41	393:39
NOVEMBER	14:07	423:36
DECEMBER	14:53	461:33
TOTAL	**11:26**	**4173:51**

Table 5.6 – Daily, Monthly and annually night-time hours (Own elaboration)

CHAPTER 5 – THE MAIN OUTCOME

The outcome of this chapter is a set of variables and data useful to the algorithms. The most important information elaborated in this chapter are related to the width of the streets and the roads, the Toponomy and the area of the different street trunks. Most important is the collection of the information useful to the construction of the taxonomy.

6. THE FIRST VERSION OF THE LIGHTING CONSUMPTION'S ALGORITHM

In this chapter will be explained the functioning of the first version of the algorithm that is based on a simple estimation of the light requirements of the road. The calculation will focus only on the side of the road belonging to the vehicular traffic because of the missing data about the pedestrian area. In this way this first version of the algorithm is proposed as an easy way to have a quick idea of the requirements and consequently the consumption of the streets.

6.1. LIGHTING CATEGORY IDENTIFICATION

6.1.1. VARIABLES IDENTIFICATION

Once set-up the database with the variables, it was possible to build-up the algorithm that determinates the reference lighting category. In order to sum-up the work done until now, is useful to pinpoint the data (Field from now), available in the table P010107, which allow the decision of the category:

- **EL_STR_TY** – Street typology field: defines to which zone of the vehicular area the elements refers. The characteristics defined are whether a vehicular zone belong to a carriageway in general, or belong to an intersection, to a plaza, to a circle way or to a parking lot.
- **EL_STR_CF –** Technical and functional classification field: refers to the technical-functional classification defined by the "Codice della strada" (D.Lgs. N.285 del 30.04.92). B and C are not classified in the DBT
- **TP_STR_NOM** – Street Name field: refers to the name of the street
- **SPEED** field expressed in km/h is the velocity of outflow along each arc of street
- **CAPACITY** field expressed in V_{eq} (equivalent vehicle), is the capacity of the vehicle equivalent for each arc of street in function also with the limitation like for instance the traffic lights
- **HISTORIC CENTRE** field**:** refers to the classification of the roads according to their position, inside or outside the historical centre.

Before starting the decision process, is useful to recognize the priority according to the restrictiveness of the category identifying firstly the most restrictive (First S, then CE series) and lastly the less restrictive (ME Series). Once defined the priority; it was possible to start with the process.

6.1.2. THE STEPS OF THE METHODOLOGY

STEP 1 – FIRST WALKABILITY CRITERION

If in the typology field *(EL_STR_TY),* are contained one of those characteristics:

i) *010204 – structured traffic belonging to a plaza;*

ii) *010301 – not structured traffic belonging to a parking lot;*

iii) 0104 – pedestrian road;

the lighting category *(CAT_ILL)* belonging to these roads is the "**S3**"

STEP 2 – SECOND WALKABILITY CRITERION – TOPONOMY DEDUCTION

If in the name field *(TP_STR_NOM),* are contained the words "piazz" or "giard" and, in the typology field (EL_STR_TY), are NOT contained one of these characteristics:

i) 010205 – structured traffic belonging to a roundabouts;

ii) 010206 – not structured traffic belonging to a crossing;

the lighting category *(CAT_ILL)* belonging to these roads is the "**S3**"

STEP 3 – IDENTIFICATION OF THE CONFLICT ZONES

For those roads that are not identified in the previous step if t*he Speed is < 50Km/h* and in the typology field (EL_STR_TY), are contained one of these characteristics:

iii) 010205 – structured traffic belonging to a roundabouts;

iv) 010206 – not structured traffic belonging to a crossing;

the lighting category *(CAT_ILL)* belonging to these roads is the "**CE3**"

STEP 4 – IDENTIFICATION OF THE LOW SPEED ZONES INSIDE THE HISTORICAL CENTRE

Check if one or some of the roads belonging to the "S3" and "CE3" category roads have these two characteristics:

i) Speed ≤ 30Km/h and;

ii) Are inside the Historical Centre;

If it is true the lighting category *(CAT_ILL)* belonging to these roads is the "**CE4**" if not remain the original category.

STEP 5 – IDENTIFICATION OF THE LOW SPEED ZONES OUTSIDE THE HISTORICAL CENTRE

Check if one or some of the roads belonging to "CE3" category roads have these two characteristics verified:

i) Speed ≤ 30Km/h and;

ii) Are NOT inside the Historical Centre;

If it's true the lighting category *(CAT_ILL)* belonging to these roads is the **"CE4"** if not the category remain the **"CE3"**

STEP 6 – DEFINITION OF THE ME SERIES LIGHTING CATEGORY

For those roads that are not identified in the previous steps are consequently identified in the ME Series lighting category. From now, according to the functional class will be discriminated the precise category.

i) If the *Functional class* is the *"A"* and the *Speed is ≥130Km/h* the road belong to the "**ME1**" category, while if the *Functional class* is the *"A" but* the *Speed is <130Km/h*, the road belong to the "**ME3**" category.

ii) If the *Functional class* is the *"D"* and the *Speed is ≥70Km/h* the road belong to the "**ME3**" category, while if the *Functional class* is the *"D" but* the *Speed is <70Km/h*, the road belong to the "**ME4**" category.

iii) If the *Functional class* is the *"E"* the road belong to the "**ME3**" category

iv) If the *Functional class* is the *"F"* and the *Speed is ≥70Km/h* the road belong to the "**ME3**" category, while if the *Functional class* is the *"F" but* the *Speed is <70Km/h*, the road belong to the "**ME4**" category.

STEP 7 – ATTRIBUTION OF THE LIGHTING INDEX TO THE LIGHTING CATEGORY

Once identified the lighting category, is possible to identify the corresponding lighting index following the Table 5.4:

i) If the lighting category is "S3" or "CE5" the lighting index is the "2"

ii) If the lighting category is "CE4" or "ME4" the lighting index is the "3"

iii) If the lighting category is "ME3" the lighting index is the "4"

iv) If the lighting category is "ME1" the lighting index is the "6"

From now, having identified the lighting index, is possible to recognize the need of light in terms of lux. The next step is the calculation of the luminous flux that should have the street light, necessary to guarantee the illuminance identified. For this step, I have used the calculation through the total flow method explained in the paragraph 3.1.2 at page 19

6.2. DEFINITION OF THE LIGHT REQUIREMENTS

6.2.1. ESTIMATION OF THE LIGHT REQUIREMENTS THROUGH THE TOTAL FLOW METHOD

Once detected the total yearly night-hours and the reference lighting category with their equivalent lighting index, what is known is the illuminance that the designer have to guarantee for each given road. Following the *Table 5.4*, is clear how, for each lighting category, or lighting index correspond a quantity in terms of lux.

Now the question is:

It is possible to determinate and suppose a consumption derived from the public illumination knowing the requirements of light for a given road, and therefore for the total road network?

It is clear that at this point, that the simplification made so far, could constitutes a limit of this model.

In terms of data recalling the total flow formula 3.15:

$$\Phi_{TOT} = \frac{E * A}{Ku * Kd}$$

What is known is:

- The illuminance "E" given by the illuminating index
- The area "A" for each lamp derived from different direct observation
- The K_u that is calculated using the value of the Graphics 3.1 and in particular the equation 3.16
- The K_d that is quantified in 0.7 that is the value used for the bad situation

That after the introduction of the equation of the utilization the coefficient became as follows:

$$\Phi_{TOT} = \frac{E * W * 22.5}{\left[\left(-\frac{1}{7}({}^{W}/_{H})^2\right) + \left(\frac{1}{2} * {}^{W}/_{H}\right) + (0{,}0087)\right] * 0.7} = \qquad \textit{Eq 6.1}$$

With this formula now it is possible to derive from the illuminating characteristic of each road the total lighting flux that the streetlight have to guarantee.

In order to find the total flux in terms of lumen, it is useful to underline that if, instead of using the area of relevance of each streetlight, we use the street area, the result is the same, but we cannot quantify the number of streetlights belonging to each street.

6.2.2. ESTIMATION OF THE ENERGY NEEDED TO LIGHT-UP

For estimating the power needed for lighting-up and satisfying the requirements, there is the need to apply a minimum coefficient of performance of the light. In terms of sustainability it is preferable to use lights that at constant luminosity emitted have a reduced consumption. In Italy there is no regulation that declares this coefficient, therefore we will use the coefficient established by the Umbria Region (ref). This legislation obliges to use light with an efficacy of 90 lumen/Watt (Regione Umbria, 2005), hence it is possible to calculate the minimum power that the installed light should have.

Moreover is useful to underline, that, since the 3.2% of the record, have a null value of the area, for these feature will not be possible to calculate the total flow.

$$W = \frac{\Phi_{TOT}}{90}$$ *Eq 6.2*

Once the energy demand is calculated, it is possible to derive the yearly consumption by multiplying this value times 4173, which represents the total annual dark hours.

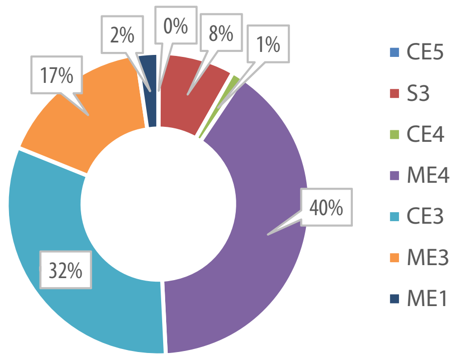
6.3. STATS AND FIGURES

6.3.1. THE DEFINITION OF THE LIGHTING CATEGORIES

Once the algorithm has been developed, the obtained results reveal to be interesting (ref fig. 6.1), almost the 70% of the street surface belongs to two categories only: the ME4 with the 37,5% of the share, and the CE3 category with the 32,8% of the share. While the first one belongs to those "D" street categories which has a speed limit of about 50 Km/h, the second one belongs to junctions and other similar zones like round-abouts, motorized plazas and so on. Pedestrian areas, instead, are quantified by the 8 percent of the total street area while the other categories, CE5, ME1 and CE4 are less than the 5 percent of the total.

LIGHTING INDEX	LIGHTING CATEGORY	LENGTH (m)		AREA (sqm)	
2	CE5	1.507	**0,1%**	14.190	**0,1%**
	S3	182.739	**8,1%**	1.513.910	**7,5%**
3	CE4	27.042	**1,2%**	179.537	**0,9%**
	ME4	895.829	**39,8%**	7.530.696	**37,5%**
4	CE3	717.221	**31,9%**	6.583.578	**32,8%**
	ME3	372.596	**16,6%**	3.396.474	**16,9%**
6	ME1	52.322	**2,3%**	862.367	**4,3%**

Table 6.1 – Distribution of the lighting category by the length and the area

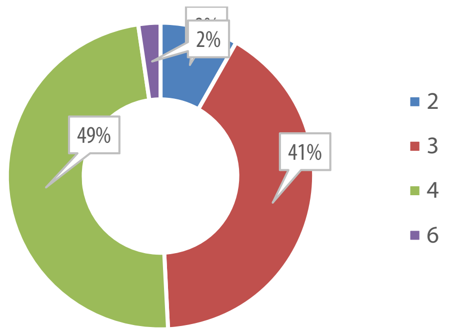


Graphics 6.1 – Distribution of the lighting category by the length

In terms of lighting index, 90% of the total area is shared by the third category, with a percentage of about 40%, and the fourth one that is almost the half of the total. In terms of brightness, this means that the half of the streets should guarantee an illuminance value of 10 lux, while the 40% of them should have 15 lux of illuminance. By the way, these are only design values, as we will see in the next part, the requirements will be determined by the morphology of the street that affect the utilization coefficient.

LIGHTING INDEX	LENGTH (m)		AREA (sqm)	
2	184.246	**8,19%**	1.528.100	**7,61%**
3	922.872	**41,03%**	7.710.233	**38,40%**
4	1.089.816	**48,45%**	9.980.051	**49,70%**
6	52.322	**2,33%**	862.367	**4,29%**

Table 6.2 – Distribution of the lighting index by the length and the area



Graphics 6.2 – Distribution of the lighting index by the length

The result on the map, showed in the next two images, is interesting for two reasons. Firstly, the distribution of the different lighting categories is homogeneous at the neighbour level, hence the correspondence between the category and the street typology works. The different function of the streets are underlined. The second reason, better shown in the Graphics 6.2 , is related to the pure accessibility of the street. It seems like that, at a first glance, the lighting classification is strictly related to the integration of the street in the graph. The main axes are classified with the highest category. There are some studies carried out in these years that move in this direction, and their findings, although related to the pedestrian flows, are quite the same (Choi et al., 2006).

6.3.2. Considerations about the outcomes

The outcome of this modelling part go beyond the initial expectations in terms of accuracy when compared to the official data of the survey published in the S.E.A.P. (ref to S.E.A.P.). Hence, these out-comes legitimate the implementation of this type of estimation at the urban scale and gives motivation to develop this work further. In fact, afterwards, I will deepen the validation by testing the model on a single street trunk and thus comparing the model to the real lighting equipment of the analysed street.

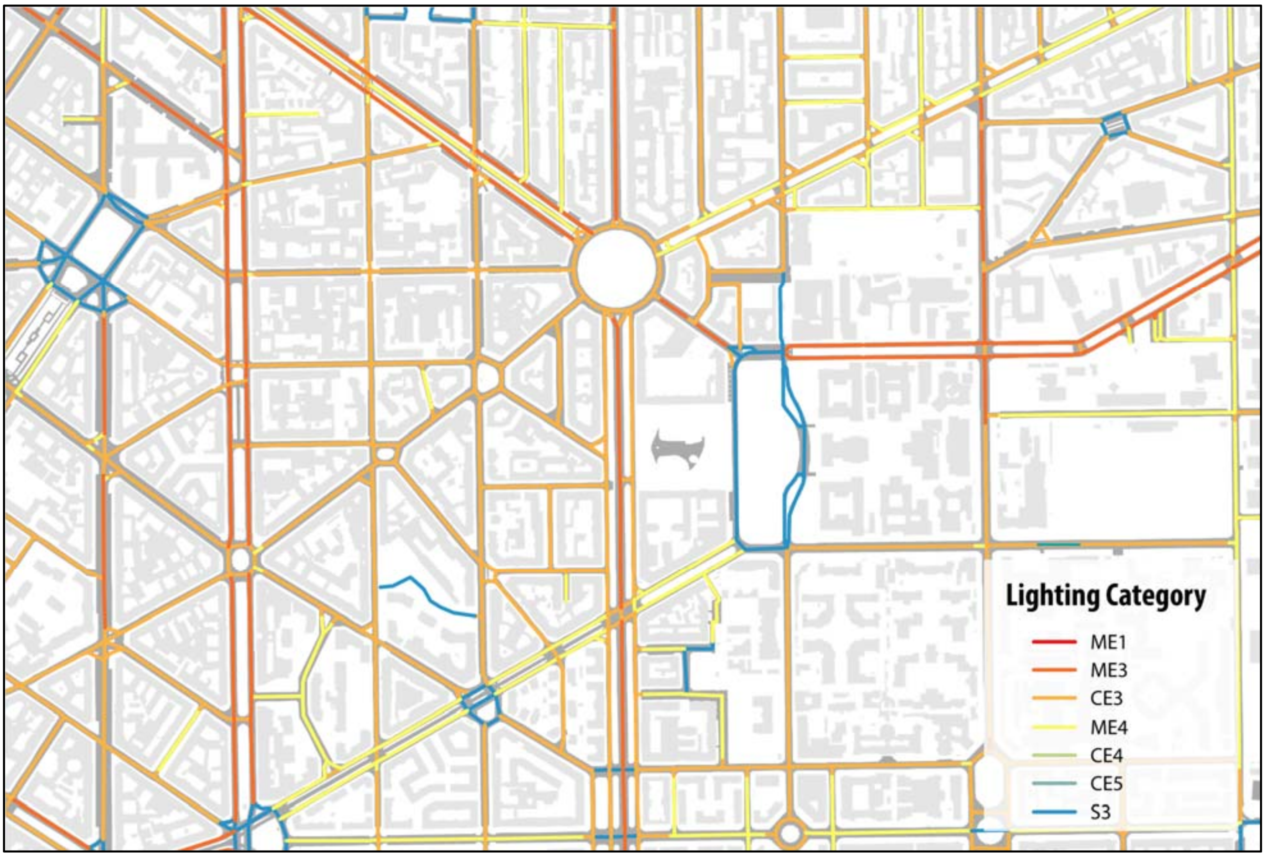


Figure 6.1 – Example of distribution of the lighting category

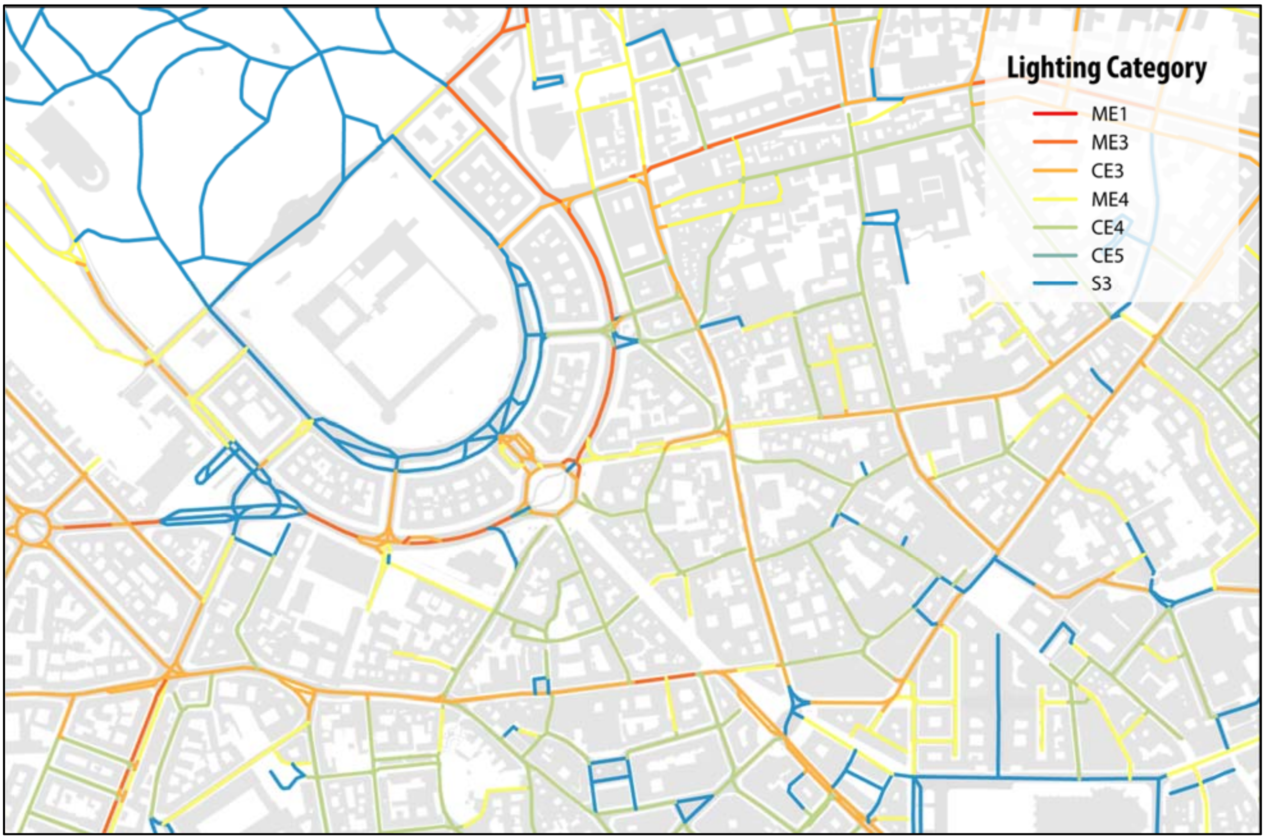


Figure 6.2 – Example of distribution of the lighting category

6.3.3. The definition of the requirements and the consumption

After the calculation of the total flow, and the calculation of the power need to guarantee this light flow, it is possible to taking a look to the results of all the steps done up to now. In order to make a resume:

- The lighting categories were identified according to the functional classification of the "Codice stradale" some variables like the typology of street, the speed, and so on and so for.
- For each lighting categories correspond a lighting index between 1 to 6, in which corresponds an Illuminance (E) value quantified in LUX
- Given the illuminance and the area of relevance of each street-light or the area of each street trunk, the utilization coefficient (K_u) and the Depreciation coefficient (K_d) it was possible to calculate the Luminous flux that the street light have to guarantee.
- Maintaining a luminous efficacy of 90lm/W, it was possible to estimate the power need to guarantee a given luminous flux in respect of the regulation.
- Given the total yearly night hours, it was possible to calculate the yearly consumption for each street trunk.

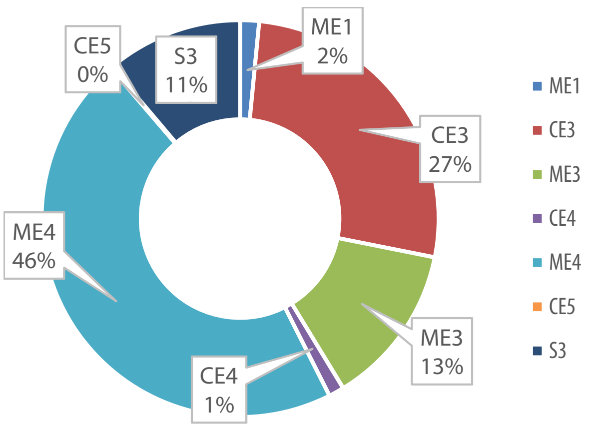
Having the data for each street elements is now possible to make some statistics about the results obtained.

As displayed in the Table 6.3 the total consumption estimated is quantified in 49,65 GWh (The real consumption estimated in the year 2005 is equal to 100 GWh). The most responsible of the total consumption are the street with lighting category "ME4" with the 47% of the total consumption concentrate in the 37,5% of the street's area, and the "CE3" with the 27% concentrated in the 32,8% of the street's area. The most impressive results is that the lighting category that have a higher lighting index, that correspond to an higher requirements of light, have the lowest unit consumption, while the lowest lighting index have an high unit consumption. This is always true for the areal unit, but according to the linear consumption, the most expensive is the "ME3" lighting category that in a year for each meters of street, consume 288 kWh, a kilometres of this kind of road consume 0.29 GWh.

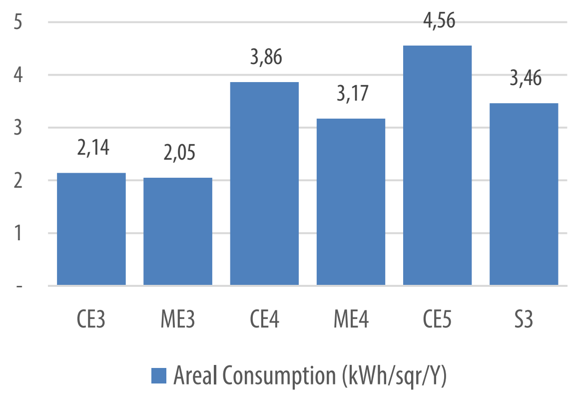
LIGHTING INDEX	LIGHTING CATEGORY	TOTAL POWER (GWH)		AREAL CONSUMPTION (KWH/SQR/Y)	LINEAR CONSUMPTION (KWH/M/Y)
6	ME1	0,77	2%	0,99	133,03
4	CE3	13,20	27%	2,14	63,16
	ME3	6,54	13%	2,05	288,93
3	CE4	0,62	1%	3,86	116,22
	ME4	22,91	47%	3,17	182,38
2	CE5	0,06	0%	4,56	50,50
	S3	5,55	11%	3,46	162,21

Table 6.3 – Stats on yearly consumption due to the illumination of the roads. Total power consumption and areal and linear consumption

Given this difference between linear and areal consumption, I have decide for the next analysis to consider the areal unit consumption as reference because of his stability and his comparability. In fact as shown in the Graphics 6.4, the areal consumption differs a lot comparing with the linear consumption.



Graphics 6.3 – Total consumption by the Lighting category



Graphics 6.4 – Yearly Areal and linear consumption of the road by the lighting category

The results geographically represented in the two pictures in the next page shows how the consumption is distributed in the territory. The value refers to the consumption per square meters, to ensure that the different roads are compared with a univocal measure. The two pictures, taken in different zones of Millan, have apparently two different results.

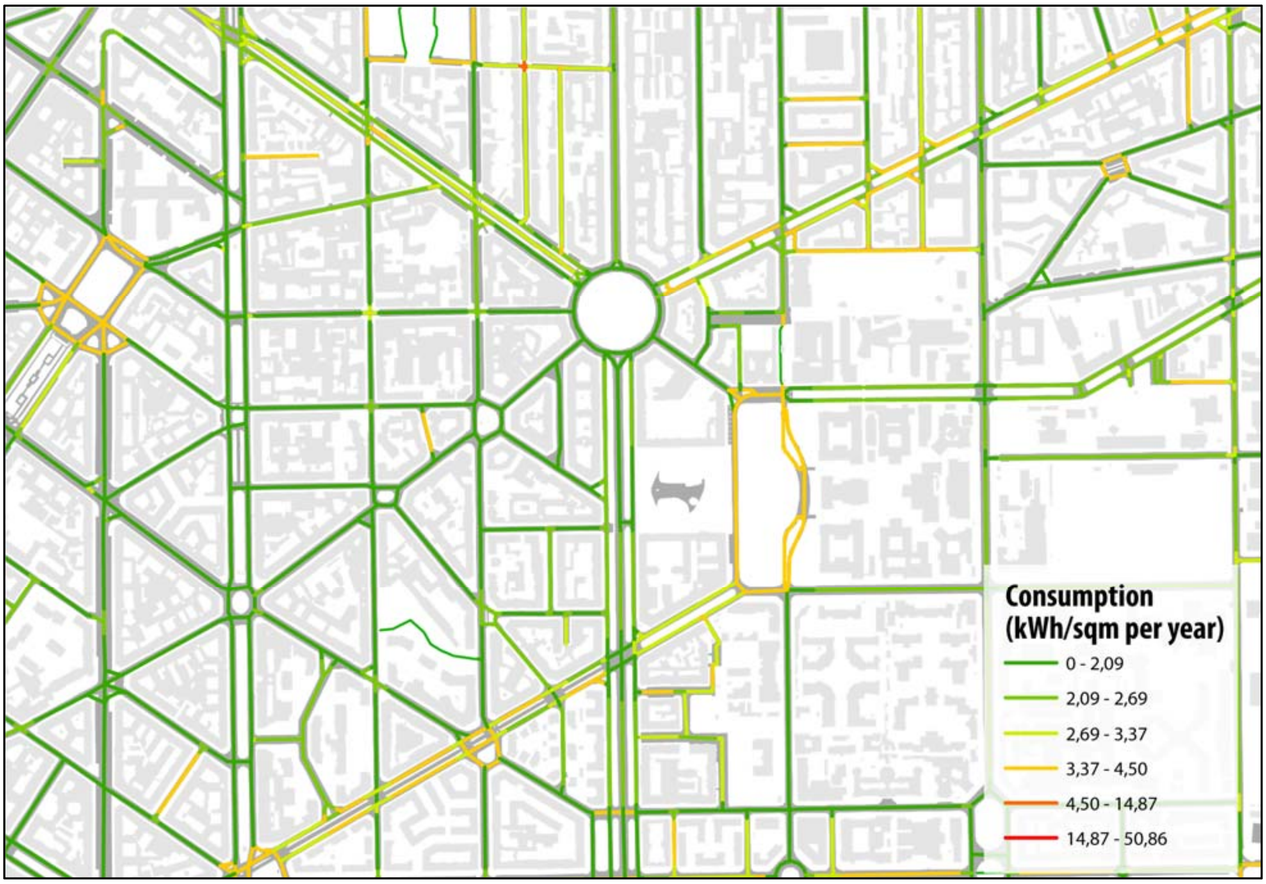


Figure 6.3 – Spatialization of the areal consumption in the Eastern area of the centre of Milan

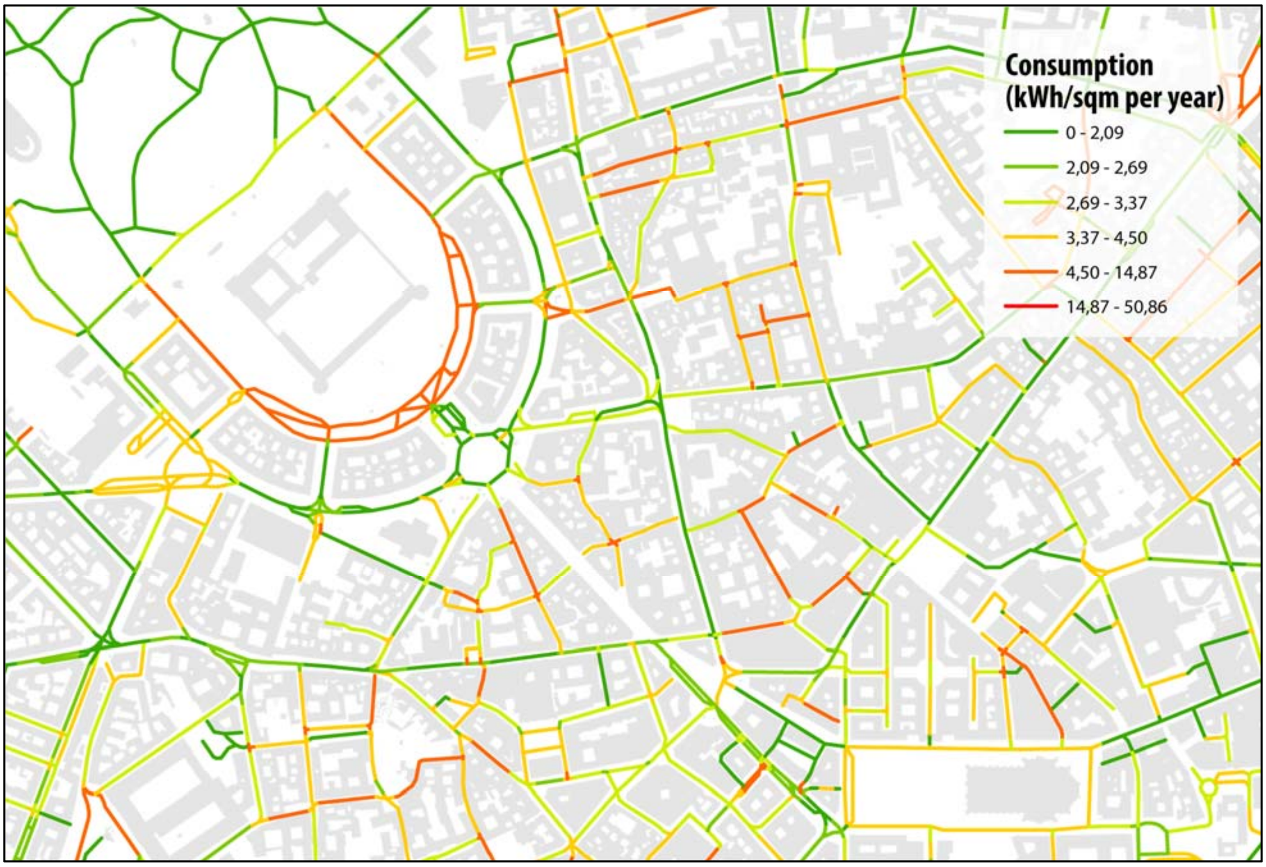


Figure 6.4 – Spatialization of the areal consumption in the centre of Milan

While in the first one, located outside of the historical centre, the consumption is quite homogeneous, the second one located in the historical centre, demonstrate a high differentiation. This is due to the morphology that, outside is more regular that in the centre. I have underlined in fact that the width affect the consumption even before than the illuminance value.

A criticism to these results is the fact that such homogeneity is unlikely at neighbour level. If we could observe a night map of the same territory taken, we perhaps appreciate a lack of homogeneity that, however, following the illuminating engineering principles, is not preferable. A road that gradually change his brightness is the best solution that a designer could achieve.

CHAPTER 6 – THE MAIN OUTCOME

The outcome of this chapter is the definition of the requirements of luminous flux and consequently the derived consumption to supply the energy necessary. The results regards only the two third of the road areas, or rather the streets. The remarkable results of this algorithm is the consistency between the initial assumption and the results obtained, that although still far from the reality, the values obtained are a first step towards an optimization of the algorithm as will be shown in the next two chapters. Now is demonstrated that is possible to reach an assessment of the consumption starting from the study of the roads in their morphology and function.

7. THE SECOND VERSION OF THE LIGHTING CONSUMPTION'S ALGORITHM

In this chapter will be presented the second version of the algorithm for the identification of the lighting categories showing up improvement and the enhancement of the physical dimension of the roads with the implementation of new information that consequently lead to different results due to the consideration of further variables. The first step will be the identification of such variables that after the construction of the algorithm will lead to the identification of the lighting categories. At the end of the chapter will be proposed a set of statistics and the results will be analysed and compared with the first version of the algorithm. Then once identified the illuminance values, such values will be used in order to calculate with the total flow method the luminous flow necessary to lit up the roads according to the requirements. Once obtained the luminous flow, it will be possible to calculate the yearly consumption starting from the assumption that all the light sources guarantee a given performance.

7.1. LIGHTING CATEGORY IDENTIFICATION

Given the amount of work that required the determination of the lighting category of the version 1.0, ' have choose to include both of the parts, also for proposing different complexity of model, that would be useful if we were in a situation of scarcity of data. In fact as will be shown later, the new variables acquired, required some days of data acquisition and data cleaning for having a successful quality of data. Moreover, the last version defines the lighting category only according to the street area, the asphalted one for being clear, and given that the street lighting, light up the whole road area (about 900 hectares more). Furthermore the Utilization coefficient, as explained in the paragraph 3.1.2 at page 29, was calculated according to the fictitious width of the single street, while now the utilization coefficient take in consideration the widths of the whole road and. In particular, take in to account also the width behind the light pole that has another function that determinates the coefficient factor.

In this second version of the methodology will be also take into account the vertical illuminances, but will not be computed for the estimation of the consumption because of the complexity of the operation. Will be therefore identified the zone where the vertical illuminances are requested according to some criterion better explained in the next paragraphs.

7.1.1. Identification Of The Variables

The variables will be classified in physical and lighting variables because the first ones are useful to identify the lighting category, and the second ones are useful to calculate the light need and the consumption

FUNCTIONAL VARIABLES OF THE ROAD

STREET TYPOLOGY

[EL_STR_TY] as "String" Street typology field: defines to which zone of the vehicular area the elements refers. The characteristics defined are whether a vehicular zone belong to a carriageway in general, or belong to an intersection, to a plaza, to a circle way or to a parking lot.

"0101" Di tronco carreggiata

- ***"010101"*** *Di tronco carreggiata - di tronco ordinario di carreggiata*
- ***"010102"*** *Di tronco carreggiata - di rampa/scivolo*
- ***"010103"*** *Di tronco carreggiata - di controviale*
- ***"010104"*** *Di tronco carreggiata - di passaggio a livello*

"**0102**" Di area a traffico strutturato

- ***"010201"*** *Di area a traffico strutturato - di casello/barriera autostradale*
- ***"010204"*** *Di area a traffico strutturato - di piazza*
- ***"010205"*** *Di area a traffico strutturato - di rotatoria*
- ***"010206"*** *Di area a traffico strutturato - di incrocio*

"**0103**" Area a traffico non strutturato

- ***"010301"*** *Area a traffico non strutturato - di parcheggio*
- ***"010307"*** *Area a traffico non strutturato - di area di pertinenza*

"**0104**" Pedonale

"**0191**" Non conosciuto

"**0192**" Non assegnato

"**0193**" Non definito

"**0194**" Non applicabile

"0195" Altro

TECHNICAL AND FUNCTIONAL CLASSIFICATION

[EL_STR_CF] - *"String"* Technical and functional classification field: refers to the technical-functional classification defined by the "Codice della strada" (D.Lgs. N.285 del 30.04.92).

0301 Autostrada

0302 Extraurbana principale

0303 Extraurbana secondaria

0304 Urbana di scorrimento

0305 Urbana di quartiere

0306 Strada locale/vicinale

0391 Non conosciuto

0392 Non assegnato

0393 Non definito

0394 Non applicabile

0395 Altro

STREET TOPONOMY

[TP_STR_NOM] as "String" Street Name that refers to the name of the street and is the result of the join between the Street elements and the Toponomy of the streets

SPEED AND CAPACITY OF THE ROADS

[STR_SPEED] as *"Integer"* expressed in km/h is the velocity of outflow along each arc of street

[STR_CAP] as *"Integer"* expressed in V_{eq} (equivalent vehicle), is the capacity of the vehicle equivalent for each arc of street in function also with the limitation like for instance the traffic lights.

HISTORICAL AND WALKABILITY CHARACTERISTICS OF THE ROADS

[HISTORIC CENTRE] as *"Boolean"* - refers to the classification of the roads according to their position, inside or outside the historical centre. This field is the result of the identification of the road belonging to the Center area of Milan, the Area 1.

[STR_WALKABILITY] as *"Boolean" refers to the street that has a walkability characteristic*

PHYSICAL VARIABLES OF THE ROAD

[STR_AREA] as "*Double*" is the area calculated on the shape file A010101 "Street Area"

STREET – MORPHOLOGICAL VARIABLES

[STR_LENGTH] as "Double" identify the length of the street

[STR_WIDTH] as "Double" expressed in meters is the width of the street (A010101)

[WIDTH_NEW] as "Double" expressed in meters is the width of the whole

STREET – FUNCTIONAL VARIABLES

[JUNCTION] as "Boolean" presence or absence of a junction that identifies the conflict zones, and is an elaboration of the complexity index and of the street typology field

[CARRIAGE] as "Integer" number that determines the number of carriage on the road sections

[CLASS_STR] as "String" is the functional class of the road

A – Urban Highway

B – Main extra-urban roads

C – Subsidiary extra-urban roads

D – Urban expressway

E – Inter-district urban roads

F – Urban local roads

SIDEWALK – MORPHOLOGICAL VARIABLES

[SIDEWALK] as *"Integer"* number that determines the presence in a given street element the number of sidewalks on the road sections

[AVG_SIDEWALK] as *"Double"* average of the sidewalks width in the road section

[MIN_SIDEWALK] as *"Double"* minimum value of the sidewalks width in the road section

[MAX_SIDEWALK] as *"Double"* maximum value of the sidewalks width in the road section

[SUM_SIDEWALK] as *"Double"* Sum of the total sidewalks width in the road section

LIGHTING VARIABLES OF THE ROAD

STREET

[EV] as *"Boolean"* identify the necessity of vertical illuminances

[CAT_ILL] as *"string"* is the lighting category identified for a given street element

[IND_ILL] as *"integer"* is the lighting index assign to a given lighting category

[ROAD_WIDTH_RELEVANCE] as *"Dou*ble" is the road area width of relevance that affect the K_{utr}

[KU_R₁] as *"Dou*ble" is the coefficient of utilization for the road facing the street side

[KU_R₂] as *"Dou*ble" is the coefficient of utilization for the road facing the sidewalk side

[K_D] as *"Dou*ble" is the coefficient of depreciation

[LAMP_WIDTH] as *"Dou*ble" is the width of reference used for calculating the utilization factor

[LUX] as *"Integer*" is the minimum quantity of LUX to guarantee on a given street element

[AREA_LIGHT] as *"Dou*ble" is the area considered to light-up

[STR_TOT_FLOW] as *"Dou*ble" is the results in "klm" of the total flow formula, necessary to guarantee the light requirements of the street-side

[STR_POWER] as *"Dou*ble" is the quantification of energy necessary to light-up a given street element for achieve the requirements established.

[STR_CONSUMPTION] as *"Dou*ble" is the annual power consumption calculated in **"***MWh"*

SIDEWALK

[SIDEWALK_SELFLIGHTED] as *"Boolean*" state if a given road element has a sidewalk that, given his width" need a self-lighting system

[SIDEWALK_WIDTH_RELEVANCE] as *"Dou*ble" is the sidewalk width of relevance that affect the K_{uts}

[SIDEWALK_AREA] as *"Dou*ble" is the area considered to light-up

[KU_S] as *"Dou*ble" is the coefficient of utilization for the sidewalk

[SID_TOT_FLOW] as *"Dou*ble" is the results in "klm" of the total flow formula, necessary to guarantee the light requirements of the sidewalk

[SID_POWER] as *"Dou*ble" is the quantification of energy necessary to light-up a given sidewalk belonging to a given street element.

[SID_CONSUMPTION] as *"Dou*ble" is the annual power consumption calculated in **"***MWh"*

[TOTAL CONSUMPTION] as *"Dou*ble" is the total annual power consumption for both the sidewalk and the street, calculated in **"***MWh"*

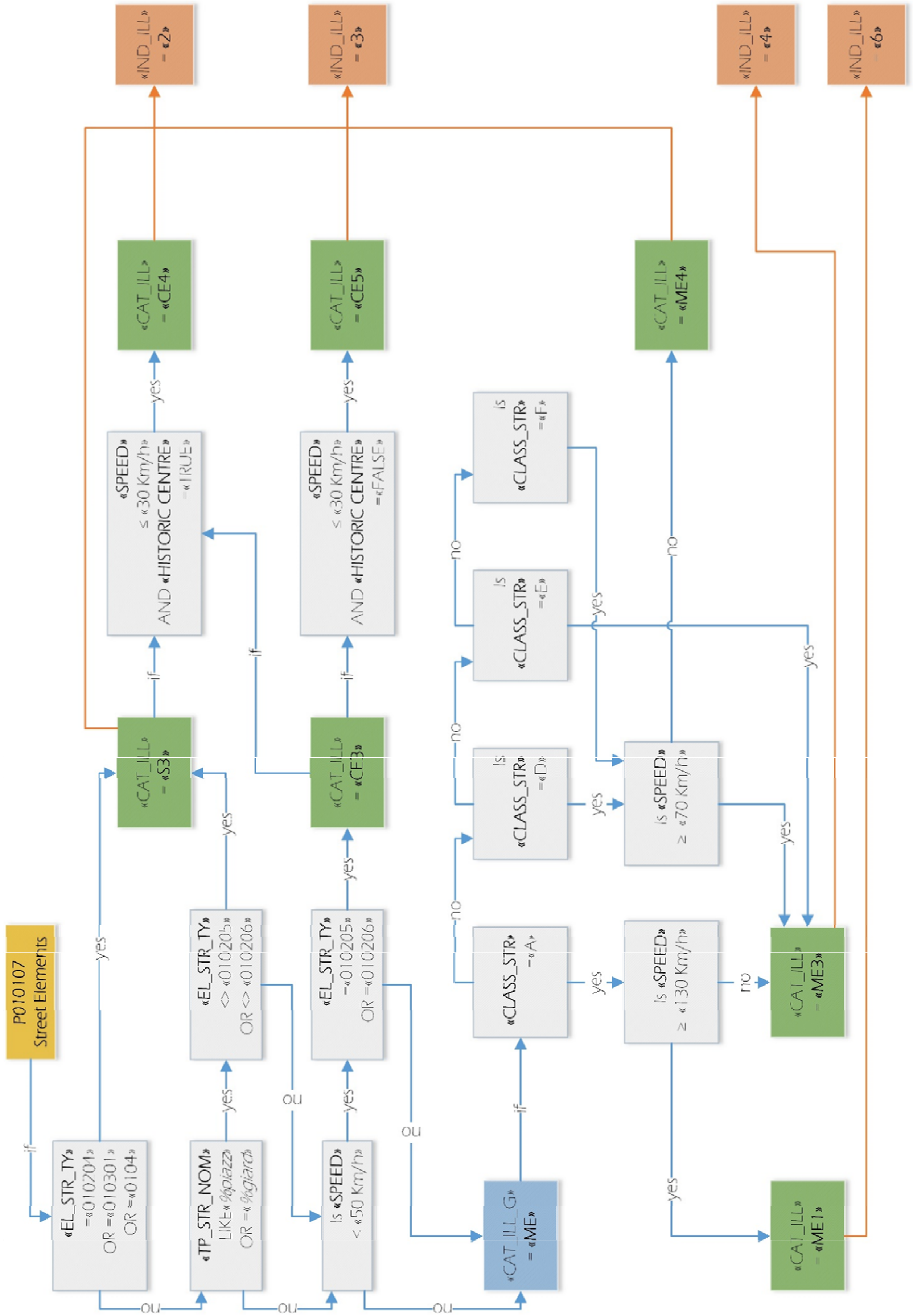


Figure 7.1 – Logic scheme of the Algorithm

7.1.2. Definition Of The Lighting Categories

STEP 1- DETERMINATION OF FURTHER FUNCTIONAL VARIABLES THAT AFFECT THE LIGHTING CATEGORY

In this first part, is determinate if a given street element have two fundamental properties: firstly, if according to other functional variables, a road have a walkability function, and then if the street elements fall in the historical centre.

```
IF [TP_STR_NOM] = %PIAZZ OR [TP_STR_NOM] =%GIARD THEN
        [STR_WALKABILITY] = "TRUE" ELSE "FALSE" AND
IF [EL_STR_TY] <> "010205" AND IF [EL_STR_TY] <> "010206" AND IF [EL_STR_TY] = "010204"
THEN [STR_WALKABILITY] = "TRUE" ELSE "FALSE"
END IF
```

Script 7.1
Determination of the walkability

With this logical syntax, it's been established that if a street element contain in his name "piazz" or "giard" and according to the Typological field of the Street element in the DBT is a plaza the value is true, if not is false.

```
IF [ID_ZONE] = 1
THEN    [HISTORIC CENTRE] = "TRUE" ELSE "FALSE"
END IF
```

Script 7.2
Determination of the historical relevance

The logical syntax above, establish if a given street elements is inside the zone 1 of Milan, Inside the "Cerchia dei Bastioni", the street elements is inside the historical centre.

STEP 2- DEFINITION OF THE LIGHTING CATEGORY SERIES

```
IF [EL_STR_TY] = "0101" OR [EL_STR_TY] = "010101" OR [EL_STR_TY] = "010102"
OR [EL_STR_TY] = "010103" OR [EL_STR_TY] = "0102" OR [EL_STR_TY] = "010307"
THEN    [CAT_ILL_SERIES]= "ME" ELSE
IF [EL_STR_TY] = "010205" OR [EL_STR_TY] = "010206" OR [JUNCTION] =1 OR [CLASS_STR] ="F"
THEN    [CAT_ILL_SERIES]= "CE" ELSE
IF [EL_STR_TY] = "010301" OR [EL_STR_TY] = "0104" OR [STR_WALKABILITY] = TRUE
THEN    [CAT_ILL_SERIES]= "S"
END IF
```

Script 7.3
Definition of the lighting category series

With this logical script, I have identified the lighting category series, and now I'm going to clarify which specific lighting category is.

STEP 3- DEFINITION OF THE LIGHTING CATEGORY OF REFERENCE

```
SELECT CASE [CAT_ILL_SERIES] = "ME"
FOR [CLASS_STR] = "A"
        IF [STR_SPEED] ≥ 130 THEN [CAT_ILL] = "ME1" ELSE
        IF [STR_SPEED] < 130 THEN [CAT_ILL] = "ME3"
        END IF
END FOR
FOR [CLASS_STR] = "D"
        IF [STR_SPEED] ≥ 70 THEN [CAT_ILL] = "ME3" ELSE
        IF [STR_SPEED] < 70 THEN [CAT_ILL] = "ME4"
        END IF
END FOR
IF [CLASS_STR] = "E" THEN [CAT_ILL] = "ME3" ELSE
END IF
FOR [CLASS_STR] = "F"
        IF [STR_SPEED] ≥ 70 THEN [CAT_ILL] = "ME3" ELSE
        IF [STR_SPEED] < 70 THEN [CAT_ILL] = "ME4"
END IF
END FOR
END SELECT CASE
```

Script 7.4
Individuation of the ME lighting category of reference

With the script above, we have identified which specific lighting category belonging to the ME series, now I am going to identify the category belonging to the CE series.

```
SELECT CASE [CAT_ILL_SERIES] = "CE"
        IF [STR_SPEED] ≤ 30 AND [HISTORIC_CENTRE] = TRUE
        THEN [CAT_ILL] = "CE4"
        END IF
        IF [STR_SPEED] ≤ 30 AND [HISTORIC_CENTRE] = FALSE
        THEN [CAT_ILL] = "CE5"
        ELSE [CAT_ILL] = "CE3"
        END IF
END SELECT CASE
```

Script 7.5
Individuation of the CE lighting category of reference

With the script above, we have identified which specific lighting category belonging to the CE series, now I am going to identify the category belonging to the S series.

```
SELECT CASE [CAT_ILL_SERIES] = "S"
[CAT_ILL] = "S3"
END SELECT CASE
```

Script 7.6
Individuation of the S lighting category of reference

The script above is relatively simply because in the majority of the case, if the lighting category series is the "S", then the lighting category of reference will be the "S3"

Once identified the lighting category of reference, there is the case in which one street elements could belong to different lighting categories, in this case will be followed a priority according to the most restrictive category. In fact, the S series taking into account the fact that a street element has a walkability function, so, for instance, if a road is both "S3" and "ME4" the lighting category will be the "S3". Therefore, the order of priority is 1) "S" series; 2) "CE" Series; 3) "ME" Series.

With this last logic function, I have defined once for the entire Lighting category for each road. Now following the Table 5.4 at page 61, is possible to attribute a lighting index to each lighting category and therefore establish a precise lighting requirement quantified in LUX. The information about the illuminance, is useful for the next steps because will be used in the total flow formula for calculating the luminous flux necessary to light up the road.

7.2. ALGORITHM FOR THE QUANTIFICATION OF THE ENERGY NECESSARY TO LIGHT UP THE STREETS

The difference between this method and the method explained at the 6.2 at page 67, is in the quality of the data used. While in the first version the junction were identified only according to the DBT attributes, now the junction are identified with different procedures explained in the 5.3 at page 51. Thanks to this methodology, it was possible also to construct a taxonomy of the typology of the road according to the sidewalk and the carriage. This taxonomy has a double function: firstly, is now possible to better differentiate the calculation of the light requirements for each typology. Secondly the taxonomy is a kind of set of pattern, and once calculated the light requirements and the energy necessary to satisfy this need, it will be possible to quantify, for example, for each kilometres of road of a given typology, which is the minimum light requirements.

Moreover, this second version has a double potential: on one hand, the area of reference calculated is now the entire road (street, Pedestrian Island, sidewalk, and often some small green area that divide the carriage). On the other the sidewalk now are quantified in their width and area, so, given that often some sidewalk are self-lighted, a calculation of the light requirements of these sidewalks is useful.

7.2.1. Quantification Of The Light Requirements For The Streets

WIDTH OF RELEVANCE

For elaborating the light requirements, a refinement of the differentiation of different road typology is useful, in spite of the direct observation. The street light often are located along one side, sometimes along the two side of the street, and rarely the street have four street light that light up the street. For this reason, before calculating the Utilization coefficient is useful to establish whether a street has one strip of street-light or more. In the first case the utilization coefficient will be calculated according the entire width, in the second case, if a road has the street light disposed along both the side, the half of the width calculates the utilization coefficient. In order to solve this, I have introduced this script:

```
SELECT CASE [STR_WIDTH]
FOR [STR_WIDTH] > 12M
THEN [LAMP_WIDTH] = [STR_WIDTH]/2
END FOR
END SELECT CASE
```

Script 7.7
Definition of the width of relevance

AREA OF RELEVANCE USED FOR CALCULATING THE LUMINOUS FLUX

The area of relevance, is that one that contribute to the calculation of the total flux, in practices is the area that should be lighted up, and for this reason it is important to determinate a good quality of the area that for each road section has a light requirements. The information about the area that we have are the area of the entire road that is derived multiplying the width per the length[8], the street area that correspond to the street elements, and the sidewalk area.

```
IF [JUNCTION] = 1 'condition in which the street element is a junction'
THEN [AREA_LIGHT] = [ROAD_AREA]
        IF [ROAD_AREA] = 0
        THEN [AREA_LIGHT] = 0 'a first condition necessary to avoid negative area'
        IF ( [ROAD_AREA] - [SIDEWALK_AREA] ) < [STR_AREA]
        THEN [AREA_LIGHT] = [STR_AREA] 'a second condition necessary to avoid negative area'
        IF [SIDEWALK_SELFLIGHTED] = 1
        THEN [AREA_LIGHT] = [ROAD_AREA] - [SIDEWALK_AREA]
        ELSE [AREA_LIGHT] = [ROAD_AREA]
END IF
```

Script 7.8
Definition of the area of relevance

[8] It is useful to remember that for the Road Area, the information about the area is not related to the street elements, for this reason, the only method for calculating the road area in a given street element, is to multiply the width per the length.

The most complicated issue in the recognition of the area that are in charge of the total flow formula, is that, sometimes the sidewalks get out of the road, hence it could happen that the road area is less than the sidewalks area (For instance the plaza). In this case there is the need to state, if this problem hap-pens, to take the first area that we are sure is correct, and in our case is the street area that is calculated on the shape file in a GIS environment.

UTILIZATION COEFFICIENT DETERMINATION (KU_R)

Once all the variables are defined, the last step before the calculation of the total flow, is the determination of the Utilization coefficient. The utilization coefficient for the road is double, a first KuR1 calculated on the street width, and a second coefficient called KuR2 calculated on the sidewalk width. The total Ku_R is the sum of both the coefficients.

```
[KU_R1] =-0,1505*(([STR_WIDTH]/10)^2)+0,5256*([STR_WIDTH]/10)+0,0087
[KU_R2] = -0,1067*(([MAX_SIDEWALK]/10)^2)+(0,2667*([ MAX_SIDEWALK]/10)
```

Script 7.9
Determination of the street's Utilization coefficients

QUANTIFICATION WITH THE TOTAL FLOW METHOD

At this point it is possible to proceed with the calculation of the total flow, all the variables, area, illuminance value, and the different coefficients are calculated, and with the help of the formula below, it is possible to calculate the quantity of kilo lumen (klm) that each street must have in order to satisfy the requirement. It is useful to remember at this point, that the resulting value is referred to the luminous flux that the sum of the street light have to guarantee. For instance, if a road, after the calculation of the total flow has a re-quirement of 100 klm, and a given street light has a luminous flux quantified in 15 klm, we have to divide the requirements by the luminous flux of each street light, and in this case it is 6.7, this means that for guaranteeing the satisfaction of the requirements, we have to install at least s street lights, because 6 are not enough. This is only a design problem, but in order to clarify the dimension and the measure that we are using, it is useful to underline that.

```
[STR_TOT_FLOW] = ( [ROAD_AREA]* [LUX] / ( [KU_R1] +[KU_R2] ) / [KD] )/1000
```

Script 7.10
Determination of the total flow using the total flow method

7.2.2. QUANTIFICATION OF THE LIGHT REQUIREMENTS FOR THE SIDEWALKS

Once the Total Flow required by the street side has been calculated, it is necessary to calculate the require-ments of light of the sidewalks. Before explaining the procedures, that anyway is similar to the street side, it is useful to remember that the calculation explained in the next paragraphs belong to those sidewalks that have their own system of illumination. These parts of the streets, here and after called 'self-lighted sidewalk', are those parts that, because of its width or because of the quantity of pedestrian flows need an independent lighting system. Briefly, the procedures are similar to the street, but in the calculation of the utilization factor, I have used a height of 4.5 meters, that is the most used height of the sidewalk light.

SIDEWALK'S PHYSICAL AND LIGHTING DIMENSIONS OF RELEVANCE

The calculation of the total flows of the sidewalks, is calculated on the shape file A010102, file in which the information about the average width of each sidewalk, and its area is contained. Given that, now it is possible to calculate all the Utilization Coefficient for each sidewalk maintaining a height of the lamp of 4.5 meters. Hence, for instance, if a sidewalk is 5.5 meters width, the ratio height/width is about 1.2.

Latest, what is missing, is the quantity of lux necessary to light-up each single sidewalk. For this part of the road it is not necessary to have a discrimination as in the street side, because it is supposed that the sidewalks are homogeneously lighted-up. The choice of lighting class suitable for this purpose is the class "S3" utilized in the part of the road where there is a high presence of cycle path and a high walkability. The illuminance that corresponds to this class are quantified in 7.5 lx. Knowing that also the illuminance is constant, I am going to explain the calculation of the Utilization Coefficient of the sidewalks and then the total flows of the street side.

UTILIZATION COEFFICIENT DETERMINATION

Now is possible to calculate the Utilization Coefficient of the sidewalks using the formula of the Utilization coefficient, in this case, differently from the Ku of the street side, we have only one Utilization Coefficient, calculated only through the sidewalk, and the formula is:

```
[KU_S] =-0.1505*(([SID_WIDTH_REL] /4.5)^2)+0,5256*([SID_WIDTH_REL] /4.5)+0.0087
```

Script 7.11
Determination of the sidewalks' Utilization coefficient

QUANTIFICATION WITH THE TOTAL FLOW METHOD

Knowing the $Ku_{S\ it}$ is now possible to quantify the requirements of light through the calculation of the total flow. Firstly, the script that calculates that, starts with an essential condition: if the sidewalk needs an own lighting system the condition is true, then it is possible to calculate the formula, if it is false, the value quantified in klm is 0, and the sidewalk receive the light from the street-light.

```
IF [SID_SELFLIGHTED] = 1
THEN
[SID_TOT_FLOW] = [SIDEWALK_AREA] *7,5 / [KU_S] /[KU_D] / 1000
ELSE [SID_TOT_FLOW] = 0
```

Script 7.12
Quantification of the total requirements of the sidewalks trough the total flow method

QUANTIFICATION OF THE TOTAL FLOW REQUIRED FOR LIGHT UP THE ENTIRE ROAD SYSTEM

Given that the calculation are already done for the sidewalks and for the streets, the total requirements it is a sum of both of the roadside.

[TOT_FLOW] = [STR_TOT_FLOW] + [SID_TOT_FLOW]

Script 7.13
Quantification of the total flow required for light up the entire road system

7.2.3. Quantification Of The Energy Need To Satisfy The Light Requirements For The Entire Roads

TOTAL ENERGY REQUIRED FOR LIGHT UP THE STREET FOR ONE YEAR

The total energy needed, estimated in Megawatt per hour (from now MWh), are calculated dividing the Total requirements by 90. This is the value adopted and recognised as the minimum lighting performance value calculated as a ratio lumen per each watt of power. This means that, if a street that requires 90 lumen for being lighted-up, the street light used should not overcome 1 watt of power, while less is desirable.

[TOTAL POWER] =[TOT_FLOW] / 90 /1.000.000

Script 7.14
Total energy required for lighting up the street for one year

At the end the result is divided by 1.000.000[9] because the value is given in Watt, while we need to express the value in MWh because of the dimension of the values.

TOTAL ENERGY CONSUMPTION FOR ONE YEAR

The results of the energy needed is quantified in MW; this value explains how powerful the entire lighting system should be, but it does not say anything per se, or at least it says little about the consumption. The missing information, is the duration in which those lights are turned on which corresponds approximately to the nighttime hours (for more information please refer to chapter 5.9 at page 63). Given that, the calculation of the total yearly consumption will be calculated as follows:

[TOTAL CONSUMPTION] = [TOTAL POWER] * [YEARLY NIGHTHOURS]

Where 4.137 are the total yearly dark-hours referred to the Milan's area. The total consumption is expressed now in MWh

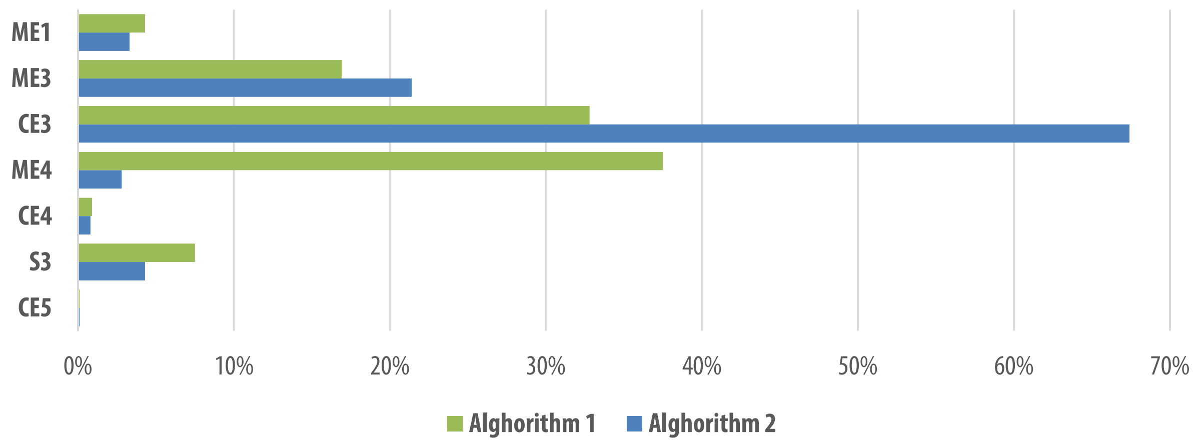
[9] *1.000.000 Watt equal to 1 MW*

7.3. STATS AND FIGURES

7.3.1. RESULTS ON THE DISTRIBUTION OF THE LIGHTING CATEGORIES

The results of the second version of the algorithm that identifies the lighting categories with different variables and scripts, demonstrate deeper changes from the first one. Anyway, it is difficult to have a more precise comparison, because the total area considered in the calculation differs, because in the first methodology the sidewalks are not considered. Nevertheless, from a relative point of view, observing the percentages some consideration can be done:

The "CE5" category is the only category that does not present significant changes, so it has been the same amount of the previous algorithm (relative and absolute). The "S3", instead, being at the 4,3%, are almost the half than the first algorithm, while the CE4 have been decreased by the 10%, and so there are not any big changes. The categories that have experienced the deepest change are the ME4 and the CE3, but, while the first one has loos almost the 90% of his area, passing from the 37% to the 3% the second one has doubled its area shifting from the 33% to the 67% that is exactly the two-third of the whole road area. The ME3, have seen an increase of the 26% more, but in absolute terms have doubled its area. The ME1, lastly, does not change so much, they are still less than the 5% of the total area.

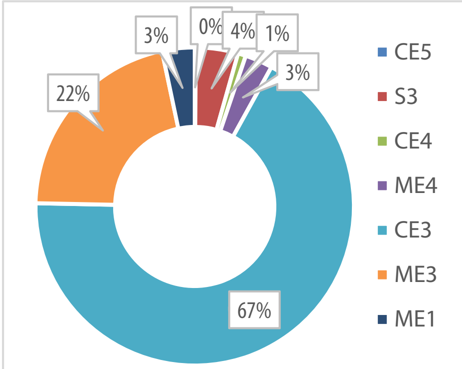


Graphics 7.1 – Changes in the quantity per each lighting category by applying the two proposed calculation methodologies

In the Graphics 7.1 the changes in the relative quantity of road areas per each category are presented, the main differences are in the "CE3" and "ME4" category.

LIGHTING INDEX	LIGHTING CATEGORY	LENGTH (m)		AREA (sqm)	
2	CE5	1.530	**0,1%**	22.932	**0,1%**
	S3	119.960	**5,3%**	1.410.775	**4,3%**
3	CE4	28.512	**1,3%**	265.245	**0,8%**
	ME4	49.608	**2,2%**	904.107	**2,8%**
4	CE3	1.652.959	**73,5%**	21.912.739	**67,4%**
	ME3	349.015	**15,5%**	6.949.826	**21,4%**
6	ME1	47.671	**2,1%**	1.069.611	**3,3%**

Table 7.1 – Distribution of the lighting category by the length and the area

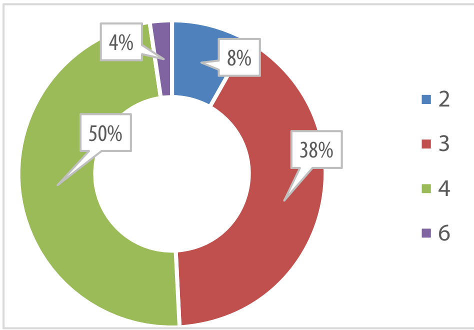


Graphics 7.2 – Distribution of the lighting category by the area

While the distribution among the lighting category is much differentiated, the distribution among the lighting index is relatively homogeneous. As we can see in the Table 7.2 the 90% of the road area is distributed among the third and the fourth lighting index, that in terms of illuminance means that this quantity has an illumination value that shifts from 7,5 and 15 lux. Going more in depth, the two indexes have respectively the 38% of the total road area for the index 3 and about the 50% for the index 4. The other two, instead have a little quantity of road area dedicated: 7,5% for the second index that is the lowest one, and 4,3% for the index six that is the highest one. This means that in terms of distribution of the illuminance values the territory results quite homogeneous, as we can see in the next pictures.

LIGHTING INDEX	LENGTH (m)		AREA (sqm)	
2	184.246	**8,19%**	1.528.100	**7,61%**
3	922.872	**41,03%**	7.710.233	**38,40%**
4	1.089.816	**48,45%**	9.980.051	**49,70%**
6	52.322	**2,33%**	862.367	**4,29%**

Table 7.2 – Distribution of the lighting index by the length and the area



Graphics 7.3 – Distribution of the lighting index by the area

The most important results coming from the pictures below are that the category seem to have a close relation with the importance of the road. For instance, the road inside the block seems have almost the same lighting category, while for the main streets, the category attributed have a higher value of illuminance consistently with their function and with the criterion established in the algorithm.

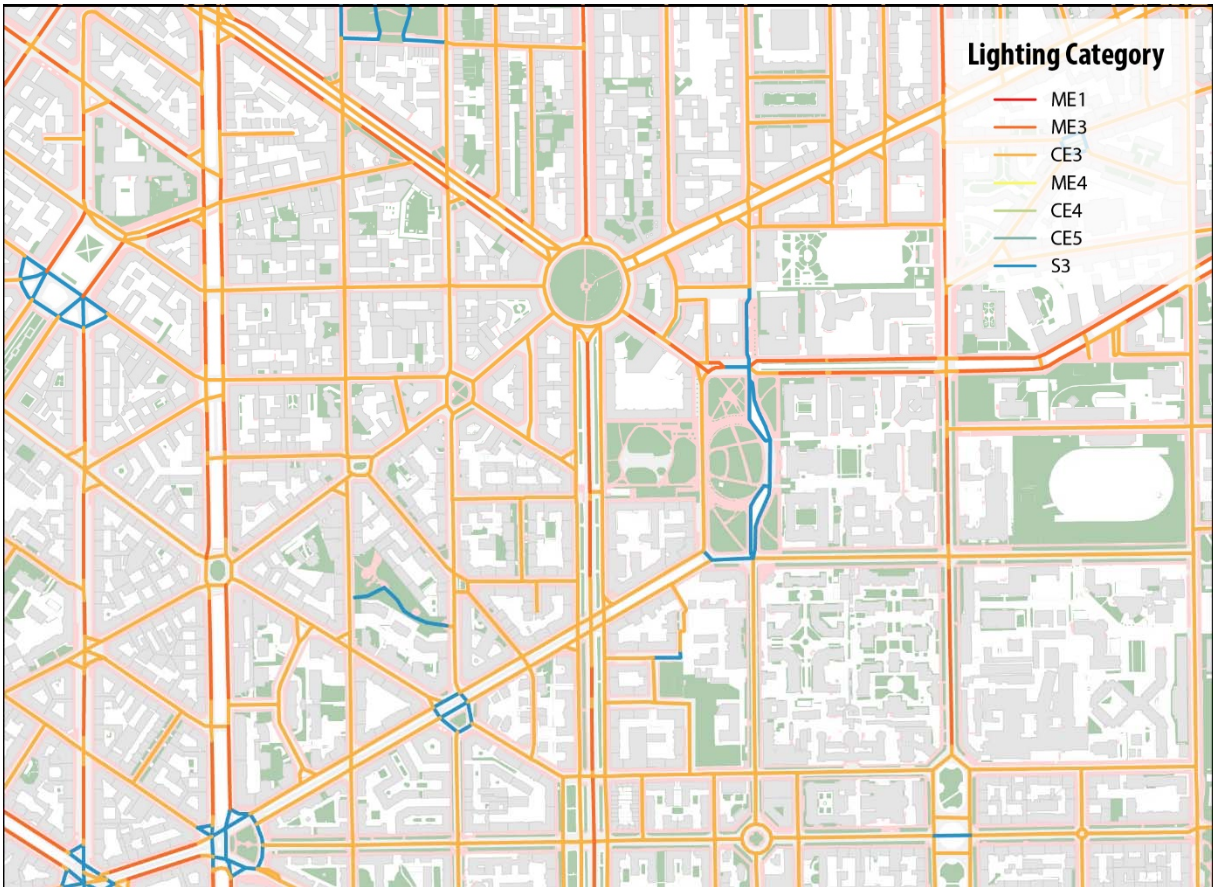


Figure 7.2 – Example of distribution of the lighting category on the Piazza Leonardo area with the algorithm 2.0

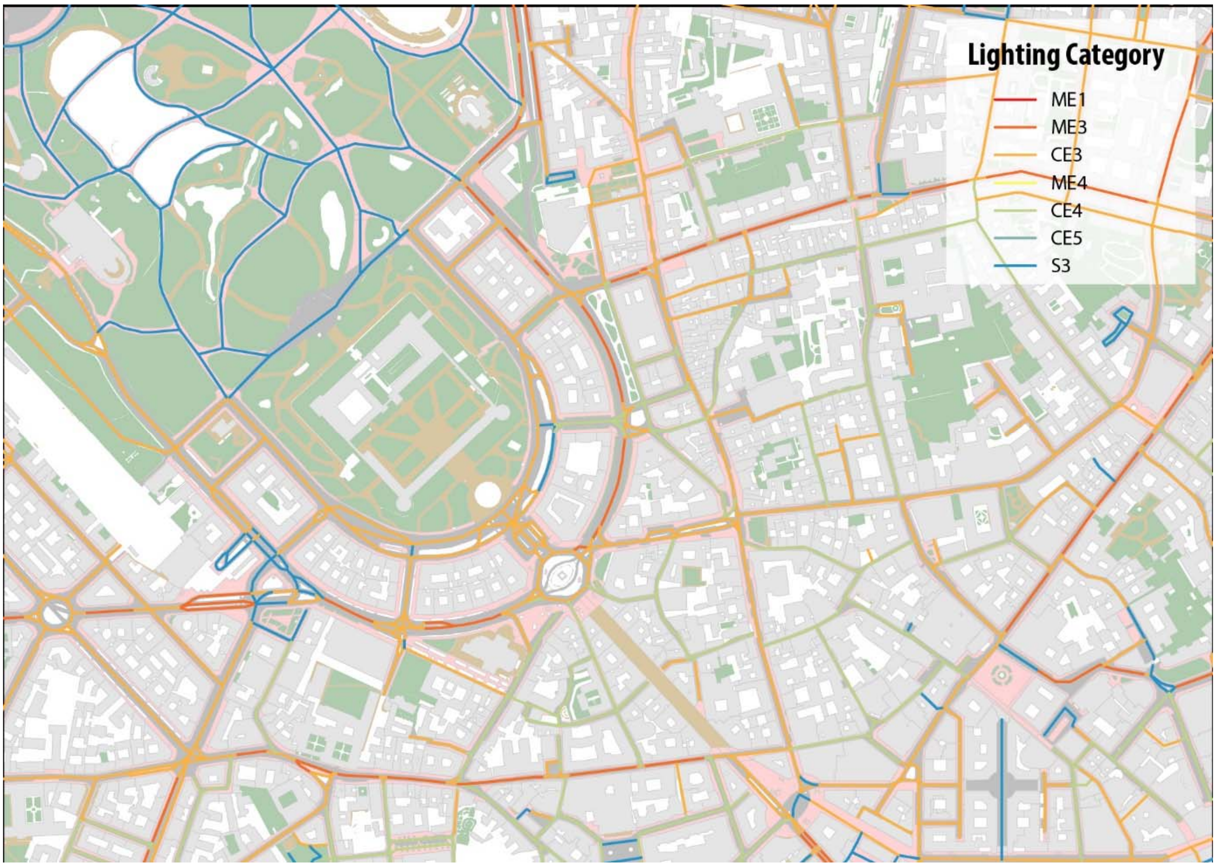


Figure 7.3 – Example of distribution of the lighting category on the Piazza Castello area with the algorithm 2.0

7.3.2. Results On The Consumption

After the calculation of the light requirements, and the consumption derived from, in this second version of the algorithm it seems that the figures are approaching the real data of the 2005 declared in the Sustainable Energy Action Plan (Comune di Milano, 2009) documents. Clearly the value it is only a point of reference, since it has been almost ten years ago. Nevertheless, the things changes slowly in the public lighting field. In fact, only now, some changes are ongoing, for instance the changes in the technology used for light up the streets, while until a couple of years ago the technology used was the same as that of twenty years ago.

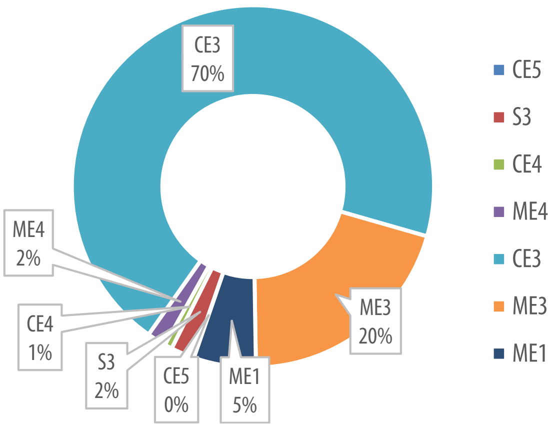
The Sustainable Energy Action Plan documents, at the chapter 5.4.3 declare a consumption of electricity for the public illumination in the year 2005 of 108 GWh, comparing this value to the results of the analysis summarized in the Table 7.3, that are quantified in MWh[10], it is clear that the two values are close with an underestimation of about 83%. From this value are missing two parts of the public illumination that are not calculated, the parks and the cycle-path outside of the roads.

LIGHTING INDEX	LIGHTING CATEGORY	TOTAL YEARLY CONSUMPTION (MWH)	
6	ME1	4.998	5,5%
4	CE3	62.837	69,7%
	ME3	18.315	20,3%
3	CE4	607	0,7%
	ME4	1.534	1,7%
2	CE5	28	0,1%
	S3	1.892	2,1%
TOTAL		**90.211**	**100%**

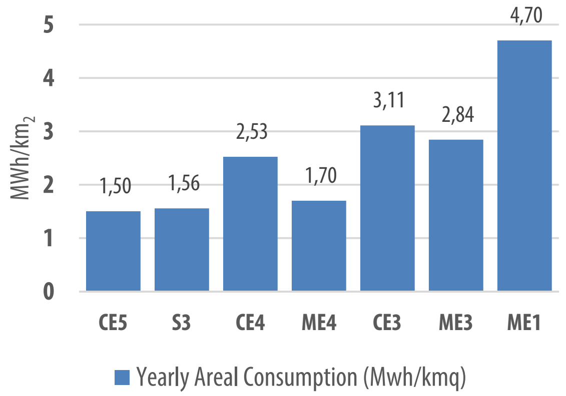
Table 7.3 – Stats on yearly total consumption due to the illumination of the roads.

Observing the Table 7.3 and the Graphics 7.4 its possible see at a glance, which are the ravenous categories in terms of absolute energy consumption. Those two illustrations, anyway, are the results of the quantity in terms of square kilometres per each category, just to remind, the CE3 category that is the responsible for 70% of the consumption, looking the Table 7.1 at page 90, the same category is the 67,4% of the total street surface of the Milan Municipality. Just to get a better idea, which are the hungriest categories, at the first place we have the ME1, which is the category to which the highways belong. At the second place we find the CE3, or the category of the crossing, roundabout and other street-typologies that have a high degree of risk of accident.

[10] 1000 MWh are equal to 1GWh



Graphics 7.4 – Total consumption by the Lighting category (expressed in %)



Graphics 7.5 – Yearly Areal and linear consumption of the road by the lighting category

The geographical distribution of the requirements and consumption, resulting from the first version of the algorithm, showed a more even distribution. In particular, the maps of consumption are evident parts of the city and from the morphological and functional point of view, in terms of energy are more demanding. From the second algorithm, therefore more detailed results come out, especially because they contain the requirements and consumption for the part of the pedestrian sidewalks. In fact, the algorithm by identifying the self-lighted sidewalks, and sidewalks along the streets, the requirements and consumption of 33% of the road surface have been estimated, where it is worth remembering that, by these surfaces we intend the whole part of the public space both accessible to vehicles and pedestrians.

This is one of the main reasons for this diversification of consumption also along the same road. In this way, to wide sidewalks and wide streets will correspond higher consumption, affecting much more than the lighting category identified. This diversification of the requirements and consumption allows a better identification of these values within a taxonomy developed based on morphological characteristics of the road.

Regarding the images of the spatialization of consumption, as it is evident in this case, the road junctions are mostly responsible for higher consumption levels with respect to the road sections. Intersections, squares and roundabouts are evident in the spatial distribution of consumption. Equally evident are the parts of the city by large pedestrian areas that increase the demand light.

In the detail of Figure 7.7 comparing it the same portion of territory, and by the use of the first algorithm, it is evident how the consumption proves accentuated than in the intersections in the streets themselves.

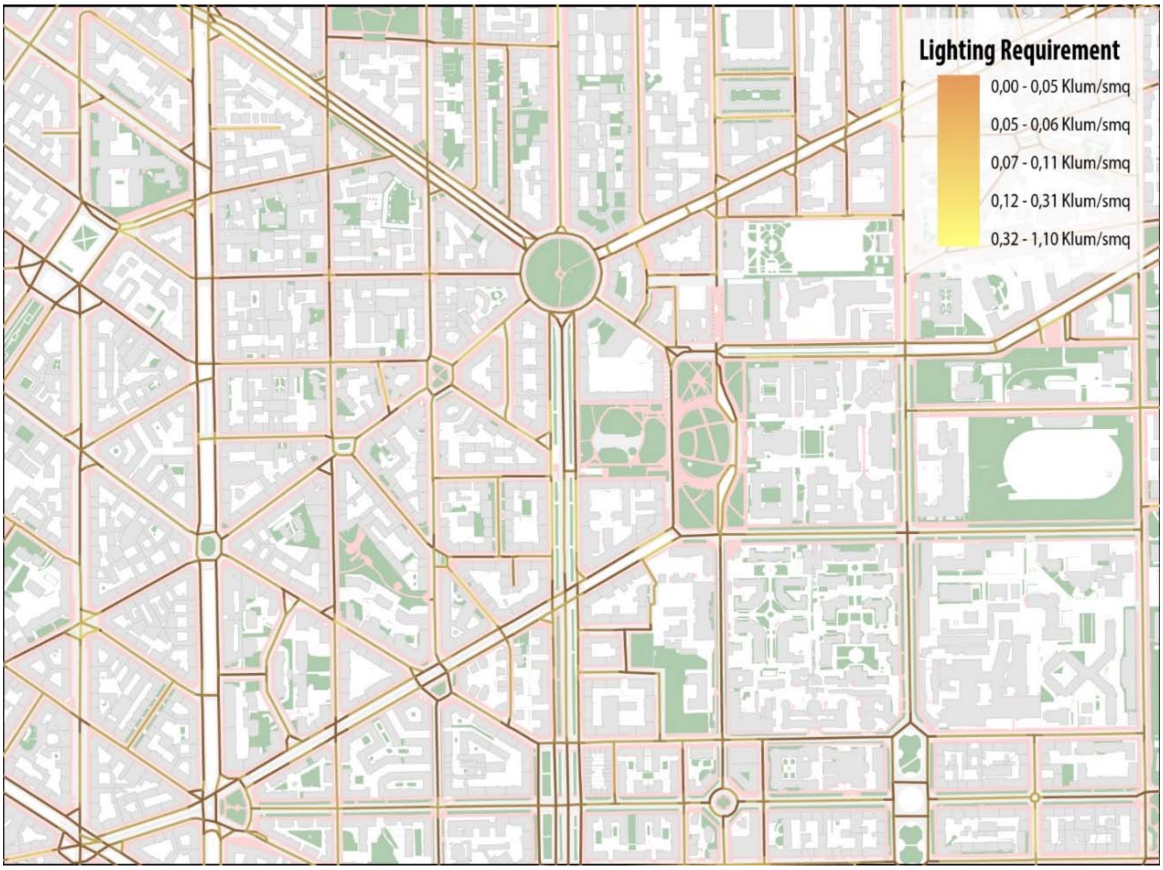


Figure 7.4 – Spatialization of the lighting requirements in klm (kilo lumen) in the Eastern area of the centre of Milan

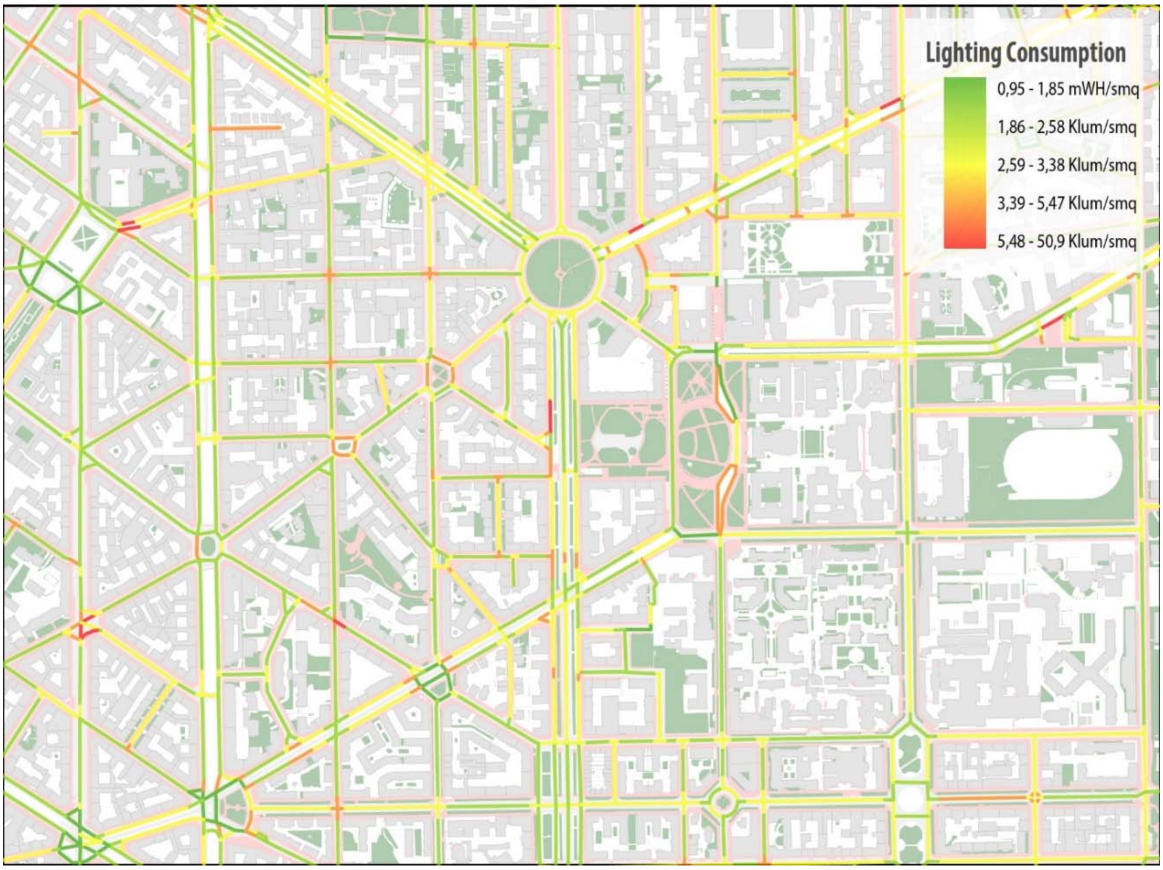


Figure 7.5 – Spatialization of the areal consumption in the Eastern area of the centre of Milan

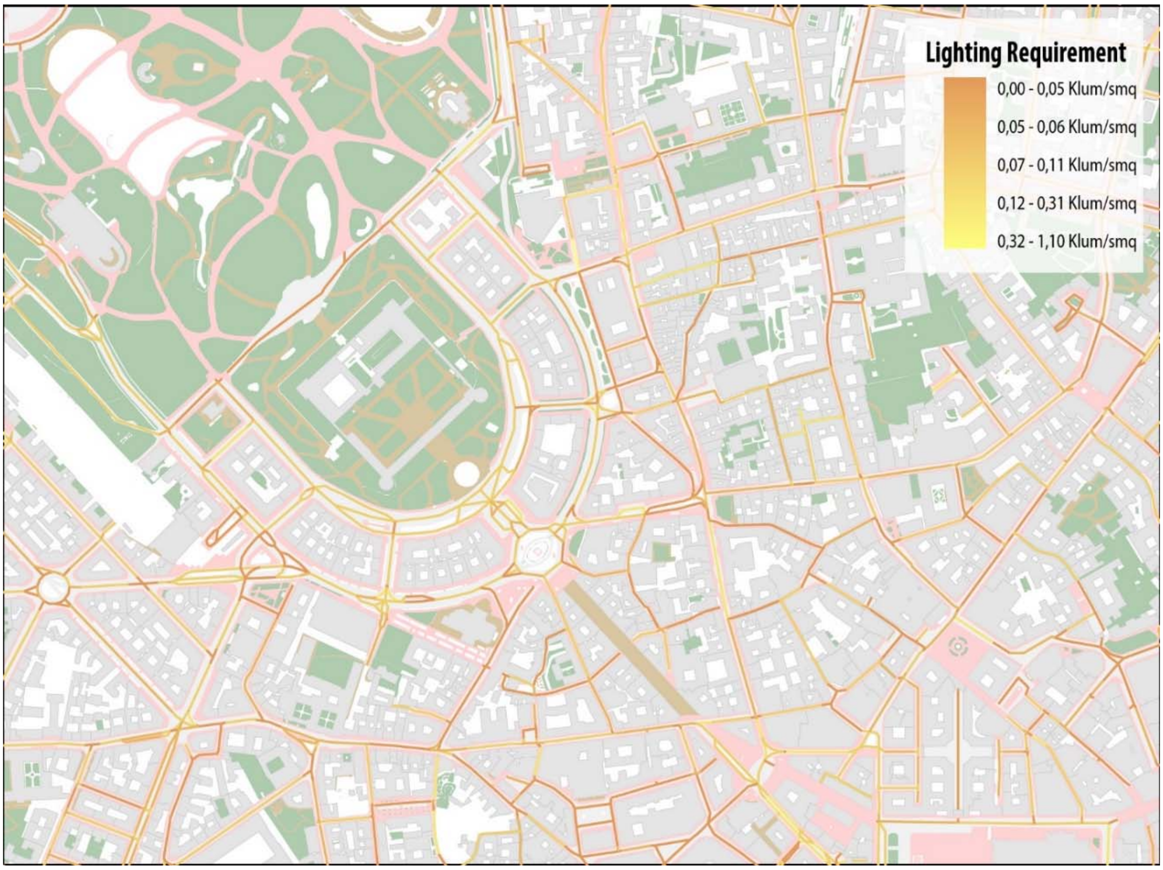


Figure 7.6 – Spatialization of the lighting requirements in klm (kilo lumen) in the Piazza Castello Area of Milan

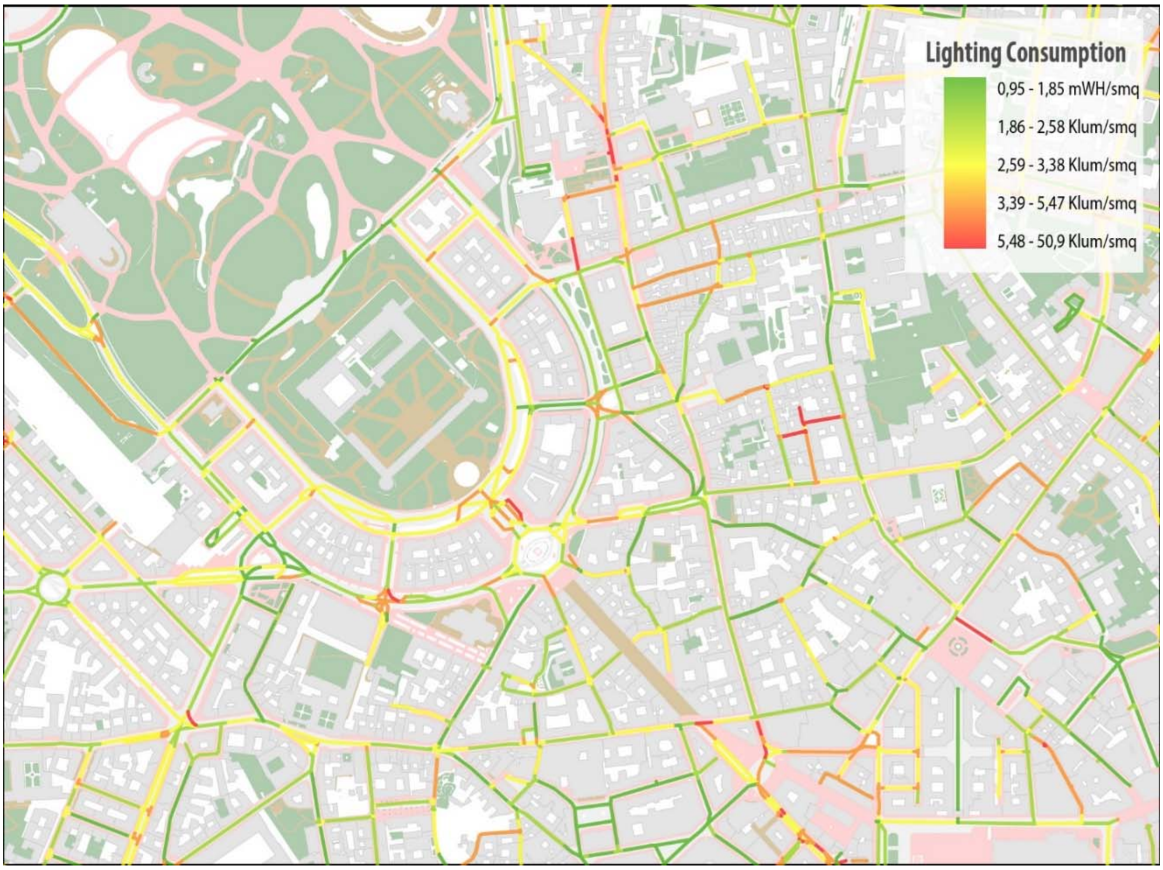


Figure 7.7 – Spatialization of the areal consumption in the Piazza Castello area of Milan

CHAPTER 7 – THE MAIN OUTCOME

The outcome of this chapter is the definition of the requirements of luminous flux and consequently the derived consumption to supply the energy necessary. The results regards this time both the streets and the pedestrian area calculating the lighting requirements also on the missing 33% of the last version. The results showing up a big difference, since the consumption estimated reach the 85% of the reality, but the best results is the estimation of the luminous flux necessary to satisfy the requirements that reach the 95% comparing with the reality. This is due to the area referred to, as stated before, but also due to the new algorithm. Moreover, the Utilization factor vary according to the width of the road, showing up the differences inside the same road.

8. RESULTS OBTAINED AND INTERPRETATION OF THE OUTPUT

In this chapter, the results will be analyzed and interpreted according to the taxonomy identified in the previous chapter. Then also a validation of the results comparing them with the official real data obtained from a survey will be proposed.

Nowadays, in a world increasingly inclined to control consumption that has to try to avoid waste, analysis and estimation of consumption at the urban level become of fundamental importance because these are the ones that concern all of us. When, however, there arises the problem of analyzing a citywide phenomenon which in itself has some peculiarities that are different and require different levels of detail, an appropriate level of abstraction and simplification is needed. In order to look at the results with the right point of view it is useful to summarize where we started, what goals we had seat, and then measure the results.

The challenge of this work was to identify and estimate the power consumption for public lighting at urban level. Of course it would have been much easier to take the count of street lights, check the technology of light sources mounted, and multiply the power developed for the monthly and annual hours of use.

In most cases, this analysis is not possible at the urban level. The challenge then was to study the city, from streets and its morphological and functional characteristics, to assess a wide range of features and using lighting calculations, first find the light requirements, and then derive consumption. The methodology used to address this research, it is halfway between a naïve method and a technical and scientific method.

Despite the simplistic idea of interpreting something very complex as the management of lighting calculations on the streets, the results obtained at the urban level in my opinion are of good quality and they tell us a lot about what can be done at the city level for anticipating the lighting calculations made by employees in the sector to estimate the costs of a given street.

The awareness that certain characteristics of a road, whether morphological or functional change and determine variation of light requirements demanded by users, it is crucial in the design of urban environments to give more attention to energy savings. Of course, we are talking about a small component of the total energy balance of a city. It can be argued that urban space has variables with low uncertainty, so much so that action on urban space to reduce energy consumption derived from the public lighting it could be a choice that will cost you more than the benefits. Something different than the established functions that potentially have a greater incisiveness on costs, instead of changing the vehicular and pedestrian flows.

The issue of management of public lighting will be managed and detailed in the third part, for now in this final section of the second part, we will analyze the results of the needs and consumption derivatives after calculation by the algorithms. In order to better interpret these results, we propose a taxonomy based on morphological characteristics such as width of the streets, sidewalks and the presence of their number, and the number of lanes.

8.1. CONSUMPTION ACCORDING TO THE TAXONOMY OF THE ROADS

8.1.1. CRITERIONS AND ASSUMPTIONS OF THE TAXONOMY

At this point, given the results obtained, it is useful to bring to a dimension easily legible and sufficient to use from a planning point of view. What is needed therefore, is to deal with the size of the morphological and functional, of course, is that of which the urban planner is concerned. The objective of this chapter is therefore to identify a classification, and obtain values regarding their requirements and energy consumption of a taxonomic category identified. The priorities identified relate to the classification in order:

1. Identification of roadways that make up the road, given that according to the number of carriageways you can easily correlate the functional classification of the road is important to classify the roads first of all according to this variable;
2. The absence or presence, by counting the number of sidewalks and pedestrian zones present in a given road section;
3. The width of the entire road section, because I believe to be an important variable in terms of needs light a wide road from the point of view of the width of its cross section, will be more demanding from the point of view of light.

The taxonomic structure then can be classified with the identification code "CSW" where "C" is the number of roadways; "S" is the number of sidewalks. For each of the taxonomies identified, the following aspects will be taken into analysis:

1. The total length of the road segments measured in km and their relative amount with respect to the total;
2. The average light requirements measured in klm / Km indicates that the luminous flux required to illuminate a kilometer of road segment length, which is important since it represents the value of the road project;
3. The annual energy consumption measured in MWh/km, which indicates the annual energy consumption of the minimum[11] necessary to meet the needs of light referred to in point 2.

After identifying the taxonomic categories and the respective values of demand and consumption, the categories are detailed on the basis of the width of the road section by dividing the categories by 12 to

[11] It is useful to remember that for the estimation of the consumption it was taken in to account a lighting efficiency for about 90 w/lum, that, in the case of the use of new technology of lighting sources, this value can decrease.

12m. In this way each taxonomic category will be deepened by a further 5 categories of width 12 meters each.

8.2. MAIN FINDINGS

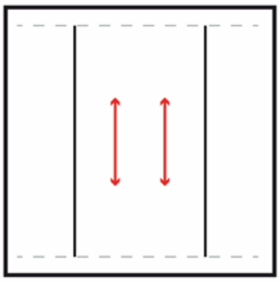
The information collected inside each category of the taxonomy can be used for a double purpose: firstly the information about the requirements can be used as a target value for the lighting project, or at least, can be used as a reference value. Moreover the classification according to the width of each category, can help to allow this kind of uses of the taxonomy, considering it like an abacus. On the other hand, the taxonomy could be used like a catalogue to use for assessing quickly the consumption of a given street, taking as reference the dimensions and the characteristics.

The main findings of the interpretations of the results according to this taxonomy are the followings:

- The macro category most responsible on the municipality of Milan for the overall lighting requirements are the roads with one carriageway, the simplest one, with an overall requirements equal to 84%,
- Inside the category with 1 carriageway we can find the most responsible micro category on the municipality of Milan for the overall lighting requirements that one with 2 sidewalks, the most common in the residential area.
- The overall consumption for this category is 948.000 klm that is the 56% of the overall requirements.
- Talking about the unit consumption, the most exigent category is contained in the micro category with one carriageway and 2 sidewalks plus 1 or more pedestrian islands. Most of them have a width between 24 and 48 meters and have a requirements equal to 2.100 klm per each kilometre, with a peak of 3.200 klm/Km for the roads with a width between 48 and 85 meters. Now the highest, in absolute, category that have the highest unit requirements of light are the roads inside the category with 1 carriage and 2 sidewalks that have a width greater than 85 meters. There we can reach the 3.900 klm per each kilometres but anyway, those roads are a total of 1 km.

8.2.1. One carriage Roadway

No sidewalk

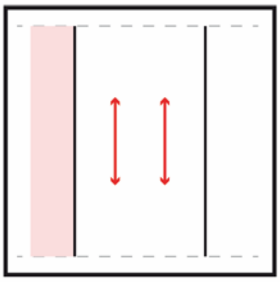


323,8 Km
14,9%

Width (m)	Lenght (Km)		KuR	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	237,6 Km	10,2%	30%	480	22
12 - 24	61,0 Km	3,4%	33%	1.100	52
24 - 48	21,2 Km	1,1%	34%	1.970	91
48 - 85	3,8 Km	0,2%	36%	3.200	148
>85	>1 Km	0%	40%	2.280	105

770 KLum/km
36 MWh/km

1 sidewalk

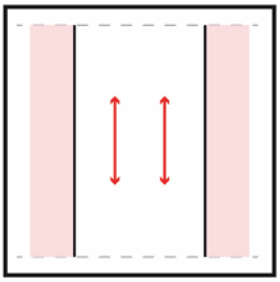


207,4 Km
11,7%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	83,7 Km	4,2%	31%	520	24
12 - 24	95,9 Km	5,5%	34%	860	40
24 - 48	25,0 Km	1,8%	35%	1.600	75
48 - 85	25 Km	0,2%	34%	2.800	128
>85	>1 Km	0%	37%	2.200	105

900 KLum/km
42 MWh/km

2 sidewalks

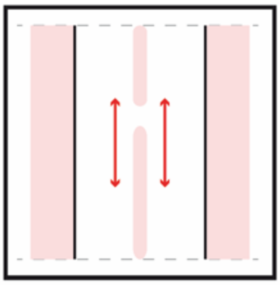


861,9 Km
51,5%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	154,55 Km	8,8%	29%	600	28
12 - 24	501,4 Km	28,5%	34%	880	41
24 - 48	181,2 Km	12,4%	34%	1.630	76
48 - 85	23,9 Km	1,7%	35%	2.800	130
>85	1 Km	>0,1%	36%	3.900	181

1.100 KLum/km
50 MWh/km

2 sidewalks and 1 or more pedestrian island



14,6 Km
0,90%

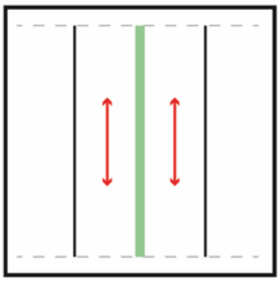
Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	-	-	-	-	-
12 - 24	2,5 Km	>0,1%	33%	1.100	52
24 - 48	8,0 Km	0,5%	34%	1.970	91
48 - 85	3,4 Km	0,2%	36%	3.200	148
>85	>1 Km	>0,1%	40%	2.280	105

2.100 KLum/km
100 MWh/km

Figure 8.1 – One Carriage Roadway taxonomy (Own elaboration)

8.2.2. Two carriage Roadway

No sidewalk

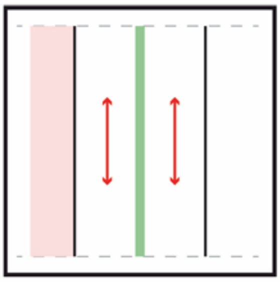


56,3 Km
3,1%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	16,3 Km	1,3%	33%	560	26
12 - 24	30,0 Km	1,3%	35%	1.390	64
24 - 48	10,0 Km	0,4%	34%	2.550	118
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

1.200 KLum/km
55 MWh/km

1 sidewalk

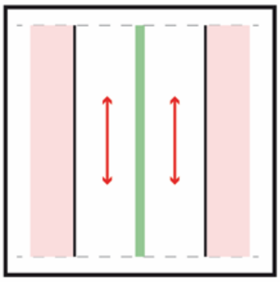


33,3 Km
2,2%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	17,0 Km	1,1%	32%	460	21
12 - 24	13,0 Km	0,9%	34%	880	40
24 - 48	3,3 Km	0,2%	35%	1.490	69
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

740 KLum/km
34 MWh/km

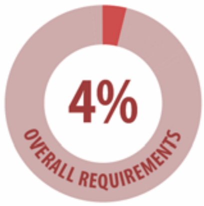
2 sidewalks



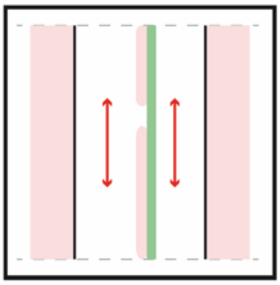
85,6 Km
6,2%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	20,1 Km	1,3%	33%	530	23
12 - 24	56,9 Km	4,2%	33%	900	41
24 - 48	8,5 Km	0,7%	34%	1.460	67
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

890 KLum/km
41 MWh/km



2 sidewalks and 1 or more pedestrian island



25,0 Km
1,9%

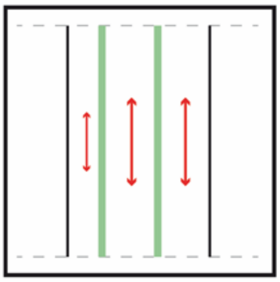
Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	2,7 Km	0,2%	33%	530	24
12 - 24	12,7 Km	1,0%	33%	1.000	46
24 - 48	9,6 Km	0,8%	34%	1.530	76
48 - 85	>1 Km	>0,1%	39%	2.260	105
>85	-	-	-	-	-

1.200 KLum/km
56 MWh/km

Figure 8.2 – One Carriage Roadway taxonomy (Own elaboration)

8.2.3. Three Carriage Roadway

No sidewalk

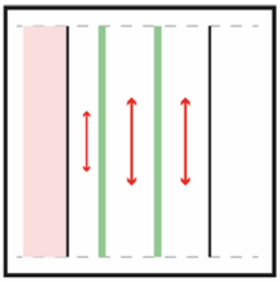


15,9 Km
1,0%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	8,9 Km	10,2%	34%	510	24
12 - 24	6,1 Km	3,4%	36%	1.290	60
24 - 48	>1 Km	>0,1%	37%	1.400	65
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

910 KLum/km
42 MWh/km
1% Overall requirements

1 sidewalk

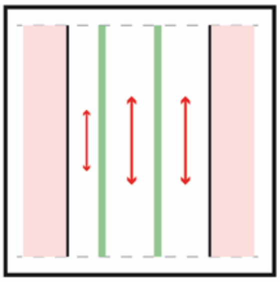


8,8 Km
0,6%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	4,4 Km	0,3%	32%	470	22
12 - 24	3,9 Km	0,3%	35%	930	43
24 - 48	>1 Km	>0,1%	36%	1.500	69
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

750 KLum/km
35 MWh/km
<1% Overall requirements

2 sidewalks

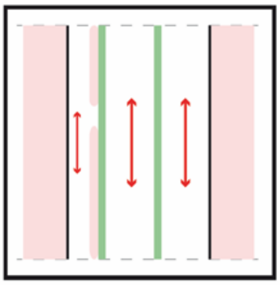


40,2 Km
2,7%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	13,8 Km	0,8%	31%	530	25
12 - 24	25,3 Km	1,7%	33%	810	38
24 - 48	1,0 Km	0,1%	35%	1.360	63
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

740 KLum/km
34 MWh/km
2% Overall requirements

2 sidewalks and 1 or more pedestrian island



18,3 Km
1,1%

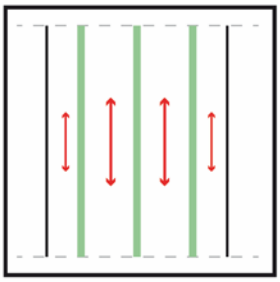
Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	3,5 Km	0,3%	32%	560	26
12 - 24	13,1 Km	0,7%	33%	860	40
24 - 48	1,7 Km	0,1%	36%	1.370	64
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

840 KLum/km
39 MWh/km
1% Overall requirements

Figure 8.3 – One Carriage Roadway taxonomy (Own elaboration)

8.2.4. Four or more carriage Roadway

No sidewalk

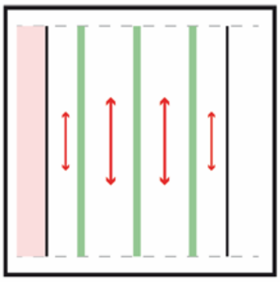


4,2 Km
0,4%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	2,4 Km	0,2%	33%	650	30
12 - 24	1,8 Km	0,1%	34%	1.330	60
24 - 48	-	-	-	-	-
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

910 KLum/km
42 MWh/km

1 sidewalk

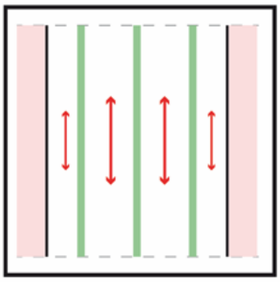


1,6 Km
0,2%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	>1 Km	>0,1%	35%	550	25
12 - 24	>1 Km	>0,1%	34%	740	34
24 - 48	-	-	-	-	-
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

620 KLum/km
29 MWh/km

2 sidewalks

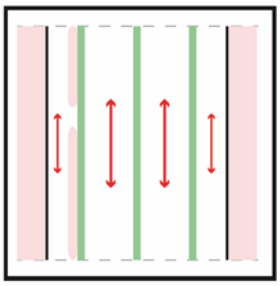


20,6 Km
1,3%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	12,5 Km	0,7%	32%	510	24
12 - 24	8,1 Km	0,5%	33%	780	36
24 - 48	-	-	-	-	-
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

620 KLum/km
29 MWh/km

2 sidewalks and 1 or more pedestrian island



8,8 Km
0,6%

Width (m)	Lenght (Km)		Ku_R	Light Req (KLum/Km)	Light Cons (MWh/km)
<12m	3,8 Km	0,2%	29%	510	24
12 - 24	4,4 Km	0,3%	18%	840	39
24 - 48	>1 Km	>0,1%	37%	1.270	56
48 - 85	-	-	-	-	-
>85	-	-	-	-	-

700KLum/km
32 MWh/km

Figure 8.4 – One Carriage Roadway taxonomy (Own elaboration)

8.3. VALIDATION OF THE MODEL

8.3.1. REAL CONSUMATINE IN A TRUNK O VIA PONZIO

The results achieved, according to the purpose of the thesis, are interesting for different matters. Firstly, now it is possible to have a vision of the basic light requirements all around the city, secondly because the database containing the information about the lighting category and index, can be a solid base that can be used for construct a model of management of the public lighting.

Nevertheless, a comparison with the reality is useful to check and find the weakness of the model and re-calibrate the different step. Using the data available on the Piazza Leonardo's area[12], it was possible to make some figures on the real consumption on some streets of this area. In this paragraph I'll focus on a trunk of Via Ponzio, that is a street behind the Politecnico di Milano. The Table 8.1 quantify the total number of the street light, with the description of the typology of light used to light-up the different area of the road. In fact, as can be seen, for the sidewalk are used mercury-vapour lamps that often are used for pedestrian street and sidewalk because they have some characteristic that allow reaching some requirements of those area. Then for the road are used lamp with sodium vapour lamps that are the common light use for the vehicular zone of the street with different power according to the performance that have to guarantee on the different zones of the streets. For instance in via Ponzio, for the crossing are used light with sodium vapour lamps. , with a power of 250 W, while for the street, are used power of 150 W. This is common because, as explained in the previous chapters, the crossing have to guarantee a lighter view during the night-hour because of the risk of accident.

Given this premises, the total streetlight quantified in the reality are 39 for the street, plus 2 for the crossing with a total of 41 street light. The model built have quantified a total of 45 street light, a closer results with the reality because the model have calculated the 9.7% more than the reality and this is explained by the fact that, the area of relevance of the street used are almost the same.

The things are changing in the data of the Luminous flux and the power used. In the reality, if we take the value that Enel give about the technical details of the light (Enel, 2001), they declare a luminous flux for each light quantified in 14 klm for the NaAP 150, and 27 klm for the NaAP 250. Multiplying these values per the number of streetlight, the quantity of total luminous flux of the street is equal to 600 klm. If we compare with the total luminous flux calculated with the model, the estimate of the actual values exceed 80% of the values calculated in the model, and this means that the model estimate almost the half of the requirements really satisfied, therefore the reality double up the model.

[12] *Census of the localization and typology of the street light on Via Cenisio, Via Ponzio, Piazza Leonardo and other streets close to them*

The same is true for the Consumption, because the power used are 150 W for 39 streetlights, and 250 W for 2 streetlights localized over the crossing, the total power used is 6.350 W.

Assuming an use for 4.173 hours per year (value estimated for the night hours see the previous chapter), the total amount of power used is quantified in 26.499 kWh per year, while the estimation of the model, supposing a light efficacy of 90 lm per W, is quantified in 15.376 kWh per year. Comparing the value, as with the luminous flux the reality exceed 72% the value calculated with the model.

Typology of lamp used	Zone	Street Light	Area of Rel.	Power W	Total power (W)	luminous flux (lm)[13]	Total luminous flux (klm)	lm/mq (LUX)	Annual Consumption (MWh)
Hg 125	Sidewalk	39	205	125	4.875	6.300	245,7	31	20,3
NaAP 150	Street	39	163	150	5.850	14.000	546,0	86	24,4
NaAP 250	Crossing	2	784	250	500	27.000	54,0	34	2,1
	Street				**6.350**		**600,0**		**26,5**
	Road				**12.650**		**845,7**		**46,9**

Table 8.1 – Requirements (green) and Consumption (red) calculated with the census of the streetlights of a trunk of Via Ponzio

8.3.2. Validation of the first model

FEATURE_ID	LARGH m	SPEED km/h	LENGTH m	AREA sqm	LIGHTING CATEGORY	LIGHTING INDEX	LAMP NUMB.	TOTAL FLOW (lm)	YEARLY CONS. MWh/y
000000000044	13,16	40	150,40	1.979	CE3	4	13,4	97.698	4,52
000000000556	13,04	40	246,92	3.221	CE3	4	21,9	160.054	7,41
000000004151	13,32	50	63,39	844	ME3	4	5,6	41.304	1,91
000000035086	11,29	40	15,12	171	CE3	4	0,7	5.954	0,27
000000035089	11,29	40	15,14	171	CE3	4	0,7	5.954	0,27
000000035092	11,35	50	11,36	355	ME3	4	1,4	12.338	0,57
000000039247	9,24	50	10,24	110	ME3	4	0,5	4.278	0,19
000000039249	9,24	50	10,25	110	ME3	4	0,5	4.278	0,19
AVERAGE	**11,49**	**45**		**69,99**	-	-	-	-	-
TOTAL			**523**	**6.960**	-	-	**45**	**331.859**	**15,38**

Table 8.2 – Requirements (green) and Consumption (red) estimated of the same trunk of Via Ponzio

Thinking about the result achieved comparing it with the reality it is clear that something is missing. Wondering why these values are so different, some answer could be find out in the values used.

First, a clarification must be done in order to remember the data that results from the model, the lighting category resulted are category of reference, and this means that these are the minimum requirements to be satisfied. Indeed, after this phase, a more precise study in terms of risk assessment should be done in order to being able to say if a given road needs a lighter category or not.

[13] (Enel, 2001)

Another relevant point is that, the data used on the technical details of the light shows the value of the nominal luminous flux, and this means that this value could be different, often less than the value declared. Indeed, as shown on the technical detail (Enel, 2001: p. 12) at the point 3.4.1.2 is given as follow: "The validation of the lighting characteristics. The luminous flux must be greater than 90% of the nominal value at the test conditions specified in Standard IEC 60662."

This means that, since the first use, the light could have the 90% of the nominal luminous flux

8.3.3. Validation of the second model

The results of the second model are closer than the first one. This is probably due to several factors: on the one hand, the main difference lies in the increase in the area under consideration, and this in itself contributes to an increase of one third compared to the first. I Furthermore, the new algorithm has contributed to a better identification of road junctions which are normally more exigent from the point of view of light. This in terms of lighting, represents an increase of twice the illuminance for areas occupied by the junctions.

At this point, observing the results of Table 8.1 against values achieved with the second model and summarized in Table 8.3 for those who regards the reference section of road, it can be noted that the requirements approaches strongly to the luminous flux delivered to the status of fact, an increase of 3% compared to the reality. Regarding the consumption, the comparison is more difficult because in the survey phase values were used as a lighting efficacy greater than those used in the models, which then translate into less consumption. However, the comparison shows 40.4 MWh estimated by the model, compared to 47 MWh calculated using survey data. This leads to the values of the model to be underestimated by 85% compared to reality.

FEATURE_ID	AREA	STREET LIGHTING REQUIREMENT (klm)	SIDEWALK LIGHTING REQUIREMENT (klm)	STREET CONSUMPTION (MWh)	SIDEWALK CONSUMPTION (MWh)	TOTAL LIGHTING REQ. (klm)	TOTAL LIGHTING CONSUMPTION (MWh)
000000000044	3196	250,73	34,59	250,73	1,60	285,32	13,22
000000000556	7395	422,80	0,00	422,80	0,00	422,80	19,59
000000004151	1372	104,89	13,56	104,89	0,63	118,45	5,49
000000035086	171	8,93	0,00	8,93	0,00	8,93	0,41
000000035089	171	8,93	0,00	8,93	0,00	8,93	0,41
000000035092	355	15,27	0,00	15,27	0,00	15,27	0,71
000000039247	110	6,42	0,00	6,42	0,00	6,42	0,30
000000039249	110	6,42	0,00	6,42	0,00	6,42	0,30
TOTAL	**12879**	**824,39**	**48,14**	**824,39**	**2,23**	**872,53**	**40,43**

Table 8.3 – Requirements (green) and Consumption (red) estimated of the same trunk of Via Ponzio

Obviously, for the whole series of reasons listed before, the reference value, to which we will truly realize, is the requirement that constitutes the design value and a reference point on which to develop actions of energy efficiency. Regarding consumption, we must take into account that the illumination is not uniform throughout the night, this uncertainty asks great difficulties in the estimation of consumption themselves.

However, to have a general feedback that applies throughout the municipality, it is necessary to take into account the power consumption, since their estimate was made in 2009 during the preparation of the SEAP and refers to the consumption of 2005, almost 9 years ago.

The report estimated at 2005 overall consumption of nearly 105 GWh, equivalent to 105,000 MWh, while in the model were estimated 90GWh of energy needed to illuminate all areas considered. Again, the model is underestimated by 85% compared to the actual consumption, the same as the comparison value in the validation phase with respect to a road segment.

Despite the underestimation, I believe that the values obtained are important and could make a strong contribution in creating awareness to the planner that certain actions constitute costs of urban development and needs from the point of view of public lighting.

The work done in this part, however, leaves more developments and insights, and have already developed a following, more detailed is evidence of the fact that implementations by new factors to be taken into account are possible in order to make the model as reliable as possible.

CHAPTER 8 – THE MAIN OUTCOME

In this chapter are displayed the results coming from the second version of the algorithm, validating them with surveys carried out in the real environment demonstrating the closeness of the model to the reality. Moreover, there are proposed some values useful to suddenly understand the requirements and the likely consumption of a given road according to some characteristics identified in the taxonomy such as the presence of sidewalks, the number of carriageway, and finally the width of the street.

PART III
PUBLIC LIGHTING AND THE VISUAL DIMENSION OF THE CITY

1. ABSTRACT OF THE SECOND PART

ITALIANO

La dimensione percettiva dell'essere umano che vive e osserva la città è stato ben approfondito negli ultimi 30 anni, e le ricerche condotte vedono l'utilizzo di strumenti sempre più efficaci che ci forniscono informazioni preziose su come la città può essere percepita e vissuta. Questi studi sono stati condotti finora per scopi legati più alla dimensione architettonica della città, e raramente condotti per ottenere delle informazioni che riguardano l'illuminazione pubblica. Per questa ragione è stato ritenuto opportuno effettuare delle sperimentazioni su un caso studio per poter effettuare delle considerazioni. La metodologia di indagine in questo caso parte da una ricerca teorica per esplorare i limiti tecnici delle analisi, successivamente sono state effettuate delle prove sul caso studio ottenendo determinati indicatori. Il significato di questi indicatori successivamente viene spiegato fornendo una possibile interpretazione in chiave illuminotecnica. Queste interpretazioni sono state sviluppate all'interno di questa tesi con lo schema indizio-ipotesi di sviluppo futuro, con lo scopo di porre le basi per successive ricerche e approfondimenti su particolari indizi che sono stati colti in seguito alle analisi dei risultati. Rispetto alle aspettative iniziali l'esperimento ha avuto dei risultati non completamente soddisfacenti, ma ritengo opportuno approfondire determinate tematiche poiché il campo di esplorazione in sé è molto vasto e indizi interessanti sono stati raccolti.

ENGLISH

The perceptual dimension of the human being who lives and observes the city has been well investigated in the past 30 years, and research conducted sees the use of increasingly efficient tools that provide us with valuable information on how the city can be perceived and experienced. These studies have been conducted so far for purposes related to the architectonical dimension and rarely conducted to obtain information regarding public lighting. For this reason it was considered appropriate to conduct experiments on a case study in order to make some considerations. For this reason it was considered appropriate to conduct experiments on a case study in order to make some considerations. The survey methodology in this case starts with a theoretical research to explore the technical limitations of the analysis, then tests were carried out on the case study to obtain certain indicators. The meaning of these indicators is then explained by providing a possible interpretation in lighting. These interpretations have been developed within this thesis with the outline clue-hypothesis for future development, with the aim of laying the groundwork for subsequent research and insights on specific clues that were taken following the analysis of the results. Compared to the initial expectations of the results the experiment was not completely satisfactory, but I think certain issues to be investigated because the field of exploration itself is very vast and interesting clues have been collected.

2. INTRODUCTION

In the previous part, how it is possible to infer the need for a night light the size of morphological and functional public spaces considered has been studied.

In the previous part, it has been studied how it is possible to infer the need for a night light the size of morphological and functional public spaces considered.

The results showed that, the need for lighting at night is a condition dictated by different circumstances: on one hand, there is the need to create a safe road in order to improve visibility, and therefore a condition linked to nocturnal mobility; on the other hand, there is the need to create conditions of perceived security by pedestrians.

In this part will be presented experimental explorations of trying to link the perceptive dimension of urban space and public lighting. The goal is to looking for clues that may suggest methods to enlighten the public space using tools that nowadays are available which allow analyzing the public space from the point of view of perception. Several studies conducted over the years have shown a close correlation between the indicators and the resulting increase or decrease of pedestrian flows.

This is one of the clues that inspired me to perform explorations in this field. The structure of this section, being experimental is constituted by a first theoretical exploration of searches available to date, and a subsequent operational phase where the results will be displayed and analyzed. For each of these results will be proposed the interesting insights that I think highlighting the key points of the results obtained by interpreting them in terms of public lighting.

A basic premise is that, the analysis are carried out, due to the fundamental principle of operation of the instruments used, assuming a public space fully illuminated. At first glance this may seem paradoxical, since the analysis is conducted as if the observer had the power of sight very deep, while at night the observer clearly has severe limitations compared to the day. As will be explained later, however, the indicators resulting from these analyzes describe phenomena that explain how the user moves within a city, also explain the difficulties inherent visual urban space, namely those difficulties arising from the presence of obstacles. These clues suggest how we can calibrate the luminous flux of the lamps to improve the visibility in an area with a strong presence of obstacles, or increase them where indicators suggest there-not the presence of hotspots subject to increase cash flow.

2.1. RESEARCH QUESTION

Given the above assumptions the objective of this section of the thesis is to looking for clues in the analysis of space syntax we suggest how to light the public space, especially where it comes to be analyzed to look for the appearance perceptive observer. There are possible developments of research in the field of visual graph analysis related to public lighting? It is possible to infer the needs light and consequently the possible consumption by analyzing the resulting indicators?

2.2. CHAPTER INTRODUCITON

CHAPTER 4 – LITERATURE ON URBAN LIGHTING

This section deal with a literature about the relation between the street lighting and the safety perception of the citizenship. The section 4.1 focuses on the topic of 'where to light for pedestrians' through considering typical pedestrian tasks and the size of the visibility field appropriate for those tasks. Section 4.2 expands on this by considering the visual experience of pedestrian lighting with respect to the purposes and effects over the complete area.

CHAPTER 5 – SPACE SYNTAX AND THE VISUAL GRAPH ANALYSIS

In this chapter will be introduced theory and tool about the Space Syntax theory and the Visual Graph Analysis. The purpose is to create the basis for an analysis on a case study.

CHAPTER 6 – THE ANALYSIS AND THE INTERPRETATION OF THE RESULTS

The analysis carried out through the software Depthmap led to the calculation of indicators that relate to "Space Syntax" and in particular the "Visual Graph Analysis". In this section, the main objective is to try to interpret the values obtained for the lighting based on the theoretical context of the research outlined in the previous chapter. At first sight, the results are not yet satisfactory, however, will highlight key points and possible insights that could give interesting results.

3. STATE OF THE ART

3.1. SCIENTIFIC REASERCH

The visual dimension of the observer that walk or drive during the night is something that a lot of researcher have studied. Motorists require lighting that will make obstacles on the carriageway visible and provide advance guidance to allow route navigation (Lester, 2010), while for the pedestrian according to Caminada and van Bommel (1980) "the lighting in a street should permit of mutual recognition […] and provide sufficient visual information […] while he or she is still a reasonable distance away". In the 1960s Edward Hall, an anthropologist, investigated the distances between people at which they feel comfortable, and developed four 'zones of proximity' that depend on the nature of the social context and added that low illumination of an environment could increase the spacing of these zones. Some research indicates that facial recognition in 'day lighting conditions' normally occurs up to 22 metres away (Oc, Tiesdell, 1997) while for the night time condition occurs up to 7 meters. Overall, factors for determining suitable visibility fields for pedestrians include the nature of movement of the pedestrians and the general level of illumination. Likely user familiarity with the area and likely user activities or interactions could also be considered. Oc and Tiesdell (1997) report that there are limits to which lighting may affect actual and perceived rates of criminal and antisocial behaviours[…] the authors still consider that environmental interventions, such as lighting, may address people's levels of fear.

The studies about how the urban environment is perceived by an observer starts by over 30 years, when Benedikt theorized the isovist with a research at the end of the 70s. In his studies proposes an instrument useful to describe the spatial characteristics of an environment and his perception by the users. Some researches indicate that space syntax index—integration—is closely related to human spatial behaviour. This suggests that space syntax methods could be of use in studies of urban lighting plan since it needs to be considered pedestrian space use pattern in urban area.(Choi et al., 2006)

3.2. CASE STUDY

The case study, as presented in the Figure 3.1 is localized in an eastern part of the city within the Area 3. The size of the area taken in consideration is a square with a side of 1,2Km. The area contain the entire campus Leonardo of Politecnico di Milano. The choice of the size is due to the elaboration by the software, the larger the area more time is required for processing, and given that such area is divided by a matrix of 4x4 meters, the time requested for the elaboration took almost four days straight.

Figure 3.1 – Localization of the case study

The position of the area is interesting because of the different pattern that we can find inside, in fact, being across the historical center and a more peripheral zone, the morphology of the built environment has created different situation, shaping different public spaces as well. Moreover this part of the city is well known and widely studied, and because of this was possible a better interpretation of the results.

4. LITERATURE ON URBAN LIGHTING

This section deal with a literature about the relation between the street lighting and the safety perception of the citizenship. The section 4.1 focuses on the topic of 'where to light for pedestrians' through considering typical pedestrian tasks and the size of the visibility field appropriate for those tasks. Section 4.2 expands on this by considering the visual experience of pedestrian lighting with respect to the purposes and effects over the complete area.

4.1. VISIBILITY FIELD FOR THE OBSERVER

For safety and navigation, the visibility field required by pedestrians is much smaller than that required by motorised road users. Motorists require lighting that will make obstacles on the carriageway visible and provide advance guidance to allow route navigation. Generally, this requires a viewing field corresponding to a travelling time of 5–10 seconds(Lester, 2010).

Compared with motorists, pedestrians can be much more responsive to obstacles, and only require lighting that will give a few seconds of visibility of such objects to enable safe passage with no physical injury. The 'few seconds' visibility can be related to the travelling speed of the pedestrians – for example, a few seconds at a likely pedestrian walking speed of 80 metres per minute corresponds to a forward visibility range of approximately 4–6 metres.

Obstacles to safe physical pedestrian negotiation of an area are most likely to be on or near the walking surface – for example, loose material or changes in level (although other 'higher' obstacles, such as overhanging branches, should also be considered). Lighting of 'physical obstacles' and the 'ground level' must create the few seconds of visibility field required by pedestrians for physical safety. Where meeting obstacles is more likely, such as on a stairway, or where pedestrians are moving faster, such as on a running route, a greater quantity of ground-level illuminance is appropriate. Once the amount of ground preview time is defined, the lighting can be technically specified to provide that visibility field.

4.2. SOCIAL ZONES AND COMFORT DISTANCES

With respect to personal security, pedestrians require lighting to enable visibility of other people who are approaching, or in the vicinity, from a reasonable distance away. Pedestrians must be able to judge whether an oncoming person is friendly, indifferent, or aggressive in sufficient time and space to make any appropriate response. According to Caminada and van Bommel (1980):

> *The lighting in a street should permit of mutual recognition before coming almost face to face and provide sufficient visual information regarding a person anywhere on the street while he or she is still a reasonable distance away. This has to do with the feeling of*

security. The point is to define a 'reasonable distance' as well as what is meant by 'sufficient visual information'.

The range of visibility field required for acceptable pedestrian perceptions of personal security is greater than the range required for their physical safety. Much pedestrian lighting guidance incidentally illustrates alignment with this approach by commonly considering personal security as the critical determinant of pedestrian lighting requirements. Other sources provide more formal evidence and a range of suggestions for the size of visibility field required.

As cited in works by Raynham (2004) and Caminada and van Bommel (1980), in the 1960s Edward Hall, an anthropologist, investigated the distances between people at which they feel comfortable, and developed four 'zones of proximity' that depend on the nature of the social context, as shown in Figure 4.1

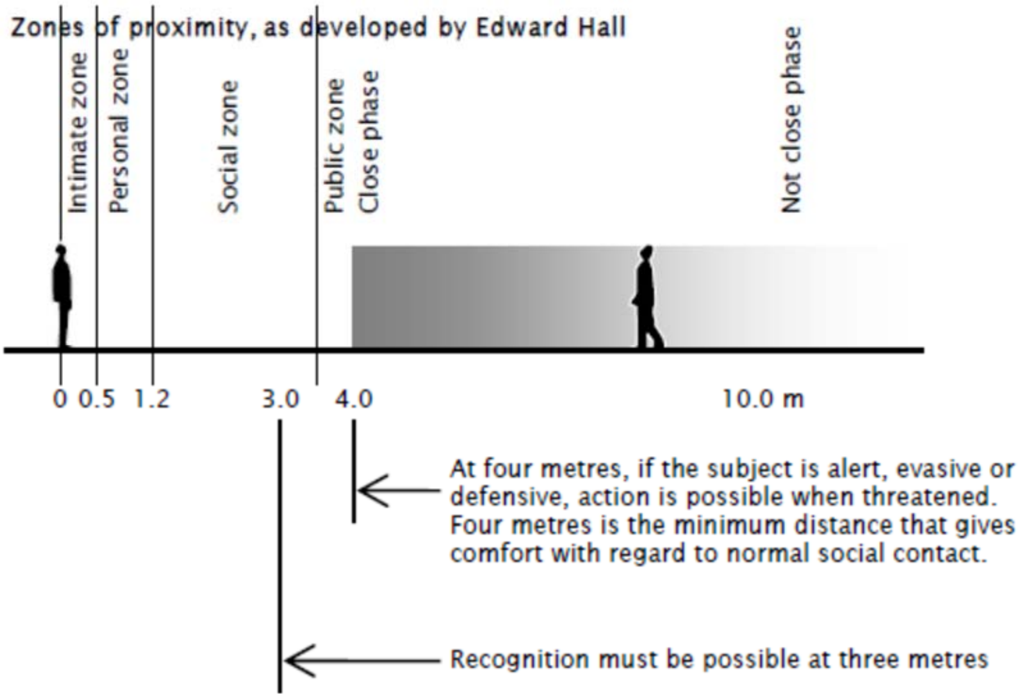


Figure 4.1 – Intimate zones

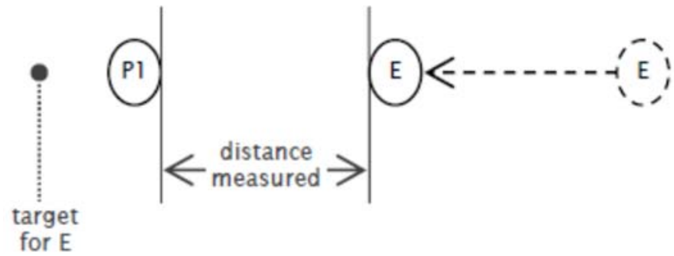
The 'intimate zone' is within approximately 0.5 metres and applies for social contacts – eg embracing, touching, or whispering.

- The 'personal zone' is 0.5–1.2 meters apart – interactions among good friends occur within this range.
- The 'social zone' is 1.2–3.5 meters apart – interactions among acquaintances occur within this range.
- The 'public zone' is outside of 3.5 meters, and divided into two phases of 'close' (3.5–10 metres) and 'not close' (starting at 10 meters).

Hall added that low illumination of an environment can increase the spacing of these zones.

Based on the work of Hall and some experimental investigation, Caminada and van Bommel (1980) suggest that an ideal facial recognition distance would be 10 metres, at the point of transition between the 'not close' and 'close' phases of the public zone. A recommendation for the minimum distance for facial recognition is about 3 metres.

Some research indicates that facial recognition in 'day lighting conditions' normally occurs up to 22 metres away (Oc, Tiesdell, 1997). 'Once this distance is reduced below 15 metres, the space in which [pedestrians] have time to react to avoid trouble, or simply an undesirable situation, becomes reduced beyond comfortable levels.' Other research (Fujiyama et al., 2005)included an experiment where participants stood stationary while being approached by another pedestrian, as illustrated in Figure 4.2. The experimenter pedestrian continued to walk towards each participant until the participant indicated they were uncomfortable because of the close distance between them and the oncoming pedestrian. The experiment was repeated under five different lighting conditions.



MINIMUM COMFORT DISTANCE
One experimenter (E) walks towards a participant (P1). As the experimenter approaches the participant, the participant indicates the point when they feel uncomfortable because of the closeness of the approaching experimenter. The distance between participant and experimenter at that point is recorded as the minimum comfort distance.

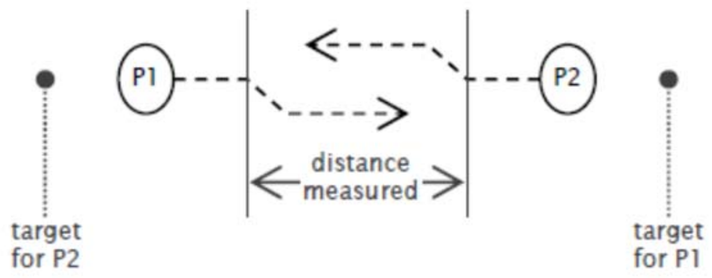
Figure 4.2 – Experiment setup for establishing 'minimum comfort distance' (Fujiyama et al., 2005)

Under 'day lighting conditions' the 'minimum comfort distance' was found to be around 4 metres, and under 'night lighting conditions' the 'minimum comfort distance' ranged from just over 4 metres up to 5.2 metres at the lowest illumination level tested.

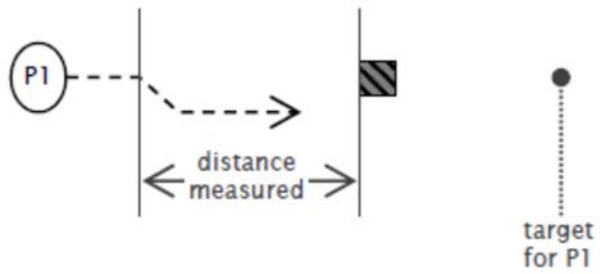
The 'minimum comfort distances' identified in the study, where the subject (participant) was stationary and the other person (experimenter pedestrian) was moving, are larger than the equivalent distances found in other studies where both the subject and the other person are stationary (Fujiyama et al., 2005). Fujiyama et al suggested the explanation 'that the perception of pedestrians in motion is different from that of stationary people'.

Fujiyama et al also used their laboratory situation to investigate the collision-avoidance and obstacle avoidance behaviours of pedestrians under different levels of illumination. Participant pedestrians were set walking towards a target with their path being in line with another oncoming pedestrian, or an obstacle.

Experimenters recorded where participants started their avoidance manoeuvre with a deviation from their 'direct' path. The two setups are illustrated in Figure 4.3



COLLISION AVOIDANCE DISTANCE
Two participants (P1 and P2) walk towards each other, each on their direct path to their target.
As the participants approach each other, at some point, a participant veers from their direct path.
The distance between the two participants at that point is recorded as the collision avoidance distance.



OBSTACLE AVOIDANCE DISTANCE
One participant (P1) walks towards an obstacle that lies on the participant's direct path to their target.
As the participant approaches the obstacle, at some point, the participant veers from their direct path.
The distance between the participant and the obstacle at that point is recorded as the obstacle avoidance distance

Figure 4.3 – Experiment set up for establishing 'collision avoidance distance' and 'obstacle avoidance distance'(Fujiyama et al., 2005)

Under 'day lighting conditions' the 'collision avoidance distance' and the 'obstacle avoidance distance' was each around 5.5–6.0 meters. Under 'night lighting conditions' the 'collision avoidance distance' was 8–9 meters, and the 'obstacle avoidance distance' was 6–7 meters.

It cannot be determined whether this finding implies that pedestrians relate to 'other pedestrians-as obstacles' differently from how they relate to 'objects-as-obstacles', or whether it is further evidence of the finding from the 'minimum comfort distance' work, that people relate to stationary obstacles (i.e. objects or other pedestrians) differently from moving obstacles.

Overall, factors for determining suitable visibility fields for pedestrians include the nature of movement of the pedestrians and the general level of illumination. Likely user familiarity with the area and likely user activities or interactions could also be considered.

4.3. LIGHTING AND PERSONAL SECURITY

Issues relating to personal security generally do not arise when considering lighting for motorists. However, pedestrians must feel secure while walking.

The effect of lighting on perceptions of personal security, and the effect of lighting on the incidence of criminal and antisocial behaviours, have been researched. The following discussion of references shows that the relationship between public lighting and personal security is complex.

4.3.1. Crime and 'personal security'

The term 'crime' can be used to cover an extremely wide range of behaviours that could affect pedestrians, ranging from serious offences such as muggings and assaults of pedestrians, through to antisocial or 'public nuisance' acts of loitering, boisterous behaviour and verbal intimidation.

Measuring crime that affects pedestrians can be difficult. Reported crime against pedestrians is more likely to be of the nature of physical attacks or confrontational robberies. Incivilities may be more common and not reported, yet still bear great influence on perceptions of personal security.

Many sources, including IDA (2002), define lighting in the context of personal security for pedestrians as 'lighting that provides a feeling of comfort or freedom from worry for the pedestrians using the lit area'.

Quintet and Nunn (1998) researched 'the impact of street lighting on calls for police service'. Their findings have been qualified by the idea that quantifying crime via the number of calls made to the police by pedestrian users of an area could overlook other incidents that affect pedestrians' perceptions of personal security. Nevertheless, Quintet and Nunn found that 'some of the effects of street lighting are crime specific' – for example, the introduction of lighting to an area can affect burglary rates differently from, say, the incidence of assault. They said: 'Assessments of the impact of lighting should create crime categories that are substantively meaningful to the question at hand.'

As well as issues of appropriately defining 'personal security' and 'crime', definitive information on the effect of public lighting on personal security may be further obscured by the focus on residential areas in a lot of research on the relationships between personal security and lighting. Also, some studies on the effects of pedestrian lighting on risk and fear are inconclusive because of the confounding effects of simultaneous changes to a variety of lighting aspects, or implementation of the lighting changes occurring within a package of other physical measures (Clark 2002).

4.3.2. General issues relating to lighting and personal security

Understanding the relationship between public lighting and personal security is complex, as the following sample of references shows:

Oc and Tiesdell (1997) report that there are limits to which lighting may affect actual and perceived rates of criminal and antisocial behaviours, as these behaviours can be considered to have root social causes that cannot be addressed through interventions in the physical environment. However, the authors still consider that environmental interventions, such as lighting, may address people's levels of fear.

If public lighting is installed, Oc and Tiesdell caution that public lighting should not be relied upon, in isolation, to successfully prevent criminal or antisocial behaviours – to increase its chance of having any effect;

it must be installed along with other complementary features. Lighting of an area may also need to be supported by other measures to ensure legitimate use of the space and light, rather than the lit area becoming vulnerable to attracting undesirable antisocial behaviour or uncivil loitering.

Oc and Tiesdell also note that public lighting does not appear to lessen crime rates over wide areas, but may have more impact when used to target small and specific areas of concern. Where newly installed or upgraded lighting reduces the incidence of crime or antisocial behaviour in a specific area, planning and instruments to cater for the possible displacement of these activities should be considered.

From a review of studies on public lighting and crime, Clark (2002) states that artificial light at night tends to allay the fear of crime, but its effects on the actual risk of crime have not been robustly demonstrated.

In the late 1970s, the US Department of Justice commissioned a comparative analysis of past and ongoing street lighting projects. The study concluded that 'although the paucity of reliable and uniform data and the inadequacy of available evaluation studies preclude a definitive statement regarding the relationship between street lighting and crime', it still found that 'while there is no statistically significant evidence that street lighting impacts the level of crime, especially if crime displacement is taken into account, there is a strong indication that increased lighting – perhaps lighting uniformity – decreases the fear of crime' (Tien et al 1979).

From 'a systematic review of the effects of improved street lighting on crime', Farrington and Walsh (2002) found that 'improved street lighting led to significant reductions in recorded crime'. To explain how improved street lighting produced this change, Farrington and Welsh suggest that 'a theory of street lighting focussing on its role in increasing community pride and informal social control may be more plausible than a theory focussing on increased surveillance and increased deterrence'.

The Australian Capital Territory Government (2000) states that lighting works to enhance feelings of personal security when there is a strong chance that someone will see any illicit activity. If this is not likely, lighting can actually make it easier to commit a crime. This concept of visibility and surveillance is also referred to by Ramsey and Newton (1991). The authors comment that pedestrian lighting can be used to complement other crime-prevention techniques, particularly through its positive effect on visibility. For example, the effectiveness of natural surveillance from members of the public and monitoring by CCTV cameras relies on adequate lighting.

5. SPACE SYNTAX AND THE VISUAL GRAPH ANALISYS

The space syntax theory is based on the fact that any urban area can be represented as a matrix of connected spaces, and that mathematical properties of this matrix can be measured using computer simulations. Ben Hiller introduce for the first time the concept of Space Syntax in the 1976. The terms Syntax call back the construction rule of a sentence and the set of modular relation between parts that constitute a plot. Hiller explain that syntax means "a set of elementary objects, relations, and operation capable of being combined to form rule structures" (Hillier et al., 1976). The space attribute indicates clearly that such objects, are spatial elements, and that such relation between them are the results of their localization. Here and after named Space Syntax have been made a huge number of study characterized by the primary target of the spatial relation between territorial elements.

In this chapter will be introduced theory and tool about the Space Syntax theory and the Visual Graph Analysis. The purpose is to create the basis for an analysis on a case study.

Valerio Cutini on his book (Cutini, 2010) make a recognition of the main elements that compose the space syntax theory, that are common on every single operational techniques, are the follow five point:

1. the urban space have an essential role of the settlements processes, or better an essential role on the phenomena that occur on it;
2. the assumption of the urban grid, as primary grid where the settlements processes occurs;
3. the oriented interest on the existent spatial relation between elements that composes the urban grid, rather than their structural assets or on the morphological consistency;
4. the hypothesis of the existence of a natural movement, defined as portion of the movement-function of the configuration of the urban grid; with a connecting role between the same grid and the localization of activities;
5. the fundamental role that on the relation between elements of the grid plays the visual perception of the urban spaces, of which derives a topological approach to the study of his configuration.

As part of the operational techniques that have been developed over the years, the main are the axial analysis and the Visibility Graph analysis, the first more related to the original vision of Hiller, and the second that is a subsequent development that is theorized from the early 90s.

The conceptual basis are the same: the genesis of settlements of an urban area is determined from the methods in which his public space is used, and in particular from the criteria in which the flows of movements are distributes along the trunk of his grid. Consequently, the way a city user is moving inside is determined by the way he visually perceives the urban space.

The difference from the other techniques is the way in which the urban space is decomposed. The principal elements of the VGA, central points of his conceptual construction, is not an aerial or linear elements of the grid, but rather one single point inside it (Turner et al., 2001). Taking the urban public space as it stands, each point is identified as the possible localization of a user/observer of the grid; starting from this grid, he will move inside guided by the way he perceive other points, that could or not could be possible destinations of his shifts.

To each points results associated a portion of urban public space, from him visually perceivable composed by a set of point directly visible called isovista analytically described through the expression:

$$V_x = \{v \in D: v\ is\ visible\ from\ x\} \qquad 5.1$$

From a chronological point of view, the concept of isovist is already theorized by a research of Benedikt at the end of the 70s. In his studies the isovist is proposed as an alternative operational instrument then the usual geometrical notions useful to describe the spatial characteristics of an environment and his perception by the users (Benedikt, 1979)

Figure 5.1 – Example of isovist from a point (Red), in grey the visible urban space; in white the occulting area; in black the obstacles.

As displayed more clearly in the Figure 5.1, the definition of an isovist underline the effects of the disposal of material elements, for instance buildings, fences, blocks, on the definition of the isovist.

As for the line of the axial max, the vertex of the visibility graph, the results of the analysis is the definition of a set of parameters, which the value is attributed through the elaboration of the model. The parameters resulted after the analysis will constituted the set of variables that will describe the urban configuration. (Turner, 2001)

5.1. HOW CAN ISOVIST CAN GUIDE THE DESIGN OF PUBLIC ILLUMINATION

Once an axial map is obtained, it can be used as the basis for calculation of various relational properties of the geometry of an environment. The second stage of the process involves transcribing the axial map as a graph where nodes represent lines and edges depict their relations of intersection. The properties of this graph can then be measured in various ways. The process described above introduces a simple measure of 'depth', which is the most important concept in the syntactic analysis. Depth is measured in steps and corresponds to a topological measure of distance in the graph, which differs from a concept of metric distance. The depth between two adjacent axial lines of spaces is 1.

RESEARCH ABOUT THE SOCIAL SPATIAL BEHAVIOUR

Some researches indicate that space syntax index—integration—is closely related to human spatial behaviour. In particular, two are relevant here. First, there appears to be a consistent relationship between spatial integration in the axial map and observed human movement flows in urban areas—all other things being equal, the more integrated the line the greater the traffic (Hillier et al., 1993). Second, there appears to be a consistent relationship in urban areas between spatial cognition and syntactic integration (Kim, Penn, 2004). Specifically, a pedestrian movement rate can be forecasted with other syntactic results from space syntax analysis. Several researches (Hillier, 1996) (Read, 2001) have been conducted to show the comparisons between measured pedestrian movement rates and spatial integration. This suggests that space syntax methods of representation and measurement of spatial configuration could be of use in studies of urban lighting plan since it needs to be considered pedestrian space use pattern in urban area.(Choi et al., 2006)

5.2. THE TOOL

The software used is Depthmap, a program designed to perform visibility graph analysis of spatial environments. The tool enables a user to perform VGA on both building and urban environments, allowing the user to perform the kind of analysis proposed by Turner et al.. Depthmap allows the user to import layouts in 2D DXF format and to fill the layout with a rectilinear grid of points which will constitute the base of the analysis. Once set up the grid, the program is able to perform the analysis. In our case the analysis took almost 4 days just to set-up the map and obtain the Local and Global Indicators of a square area of 2,4 km of side. The results obtained through this program are then exported in GIS shape file in order to better analyse the results. In-fact the visualization of the results inside the program are limited to a classification of the values comparable to the "equal interval" classification of the ArcGIS classification tool. In order to better underline the differences inside the map, we will classify the results of each indicators using both the “Natural Breaks” and the “Geometrical Intervals” yet explained in the first part, that are the most useful classification tools able to underline even the minimal difference. In fact, as can be seen in the Figure 5.2 below, the indicator demonstrated is the Clustering Coefficient, comparing them with the Figure 6.8 is possible to grasp more information from the GIS classification than the Depthmap ones.

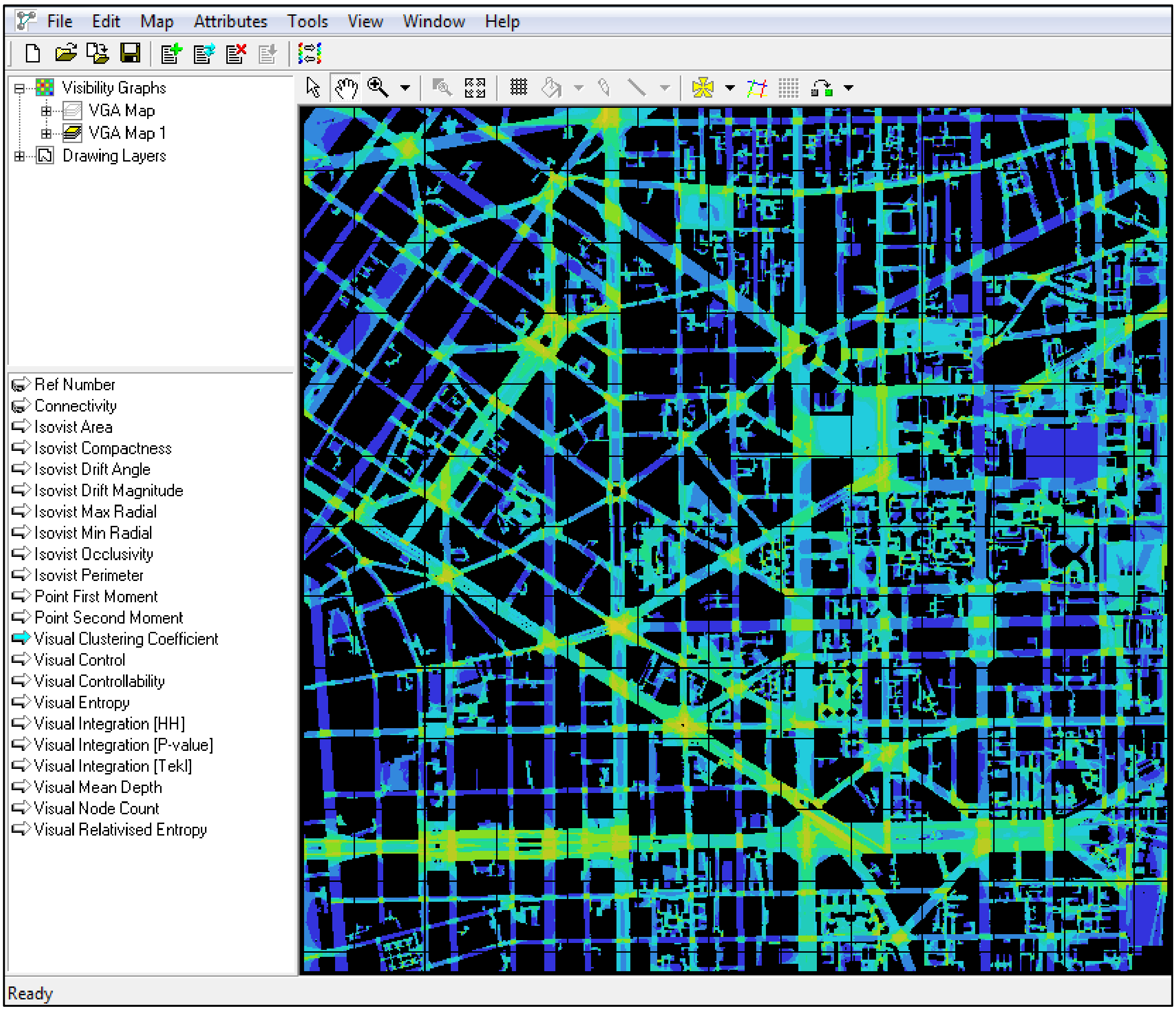


Figure 5.2 – Example of the user interface of the software Depthmap showing the “Clustering Coefficient” and the indicators already calculated.

6. THE ANALYSIS AND THE INTERPRETATION OF THE RESULTS

The analysis carried out through the software Depthmap led to the calculation of indicators that relate to "Space Syntax", and in particular the "Visual Graph Analysis". In this section, the main objective is to try to interpret the values obtained for the lighting based on the theoretical context of the research outlined in the previous chapter. At first sight the results are not yet satisfactory, however, will highlight key points and possible insights that could give interesting results.

6.1. ISOVIT INDICATORS

6.1.1. ISOVIST AREA

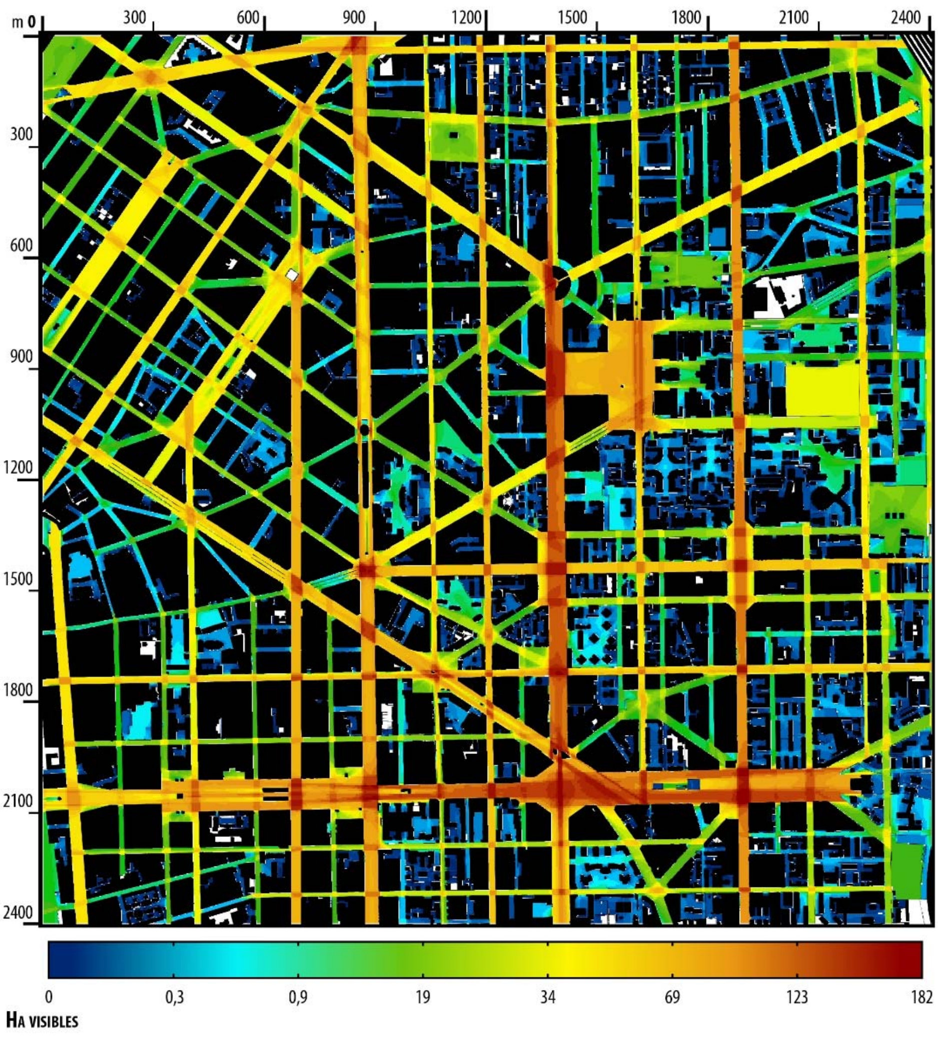


Figure 6.1 – Isovist area

MEANINGS

Ax — Area of the polygon visible from a given point of view of the space.
"The area of the isovist at a point x." (Benedikt, 1979)

POSSIBLE INSIGHTS

The isovist area indicator shows the map where the field of view is broader, highlighting in a certain way, the central areas. In fact, as you can see from the map in the Figure 6.1, the road junction stand having color tending to dark red, while areas of poor visibility are highlighted with lower values. From a lighting point of view this indicator loses its value because the assumption of us during the night, this field of view would certainly be reduced. However, the fact that he had highlighted key points, as they seeing a high number of points on the map, following the concept points are mutually visible, it means that the places marked by high values also correspond to those that are potentially visible from different points of map. This is an important concept for urban footprint as the places characterized by these high values are often the most characteristic, and are an important reference point for those who move during the night. Therefore, it can be assumed that these areas are subject to increase in the value of luminous flux to facilitate the orientation of the pedestrian or motorist.

6.1.2. Isovist Perimeter

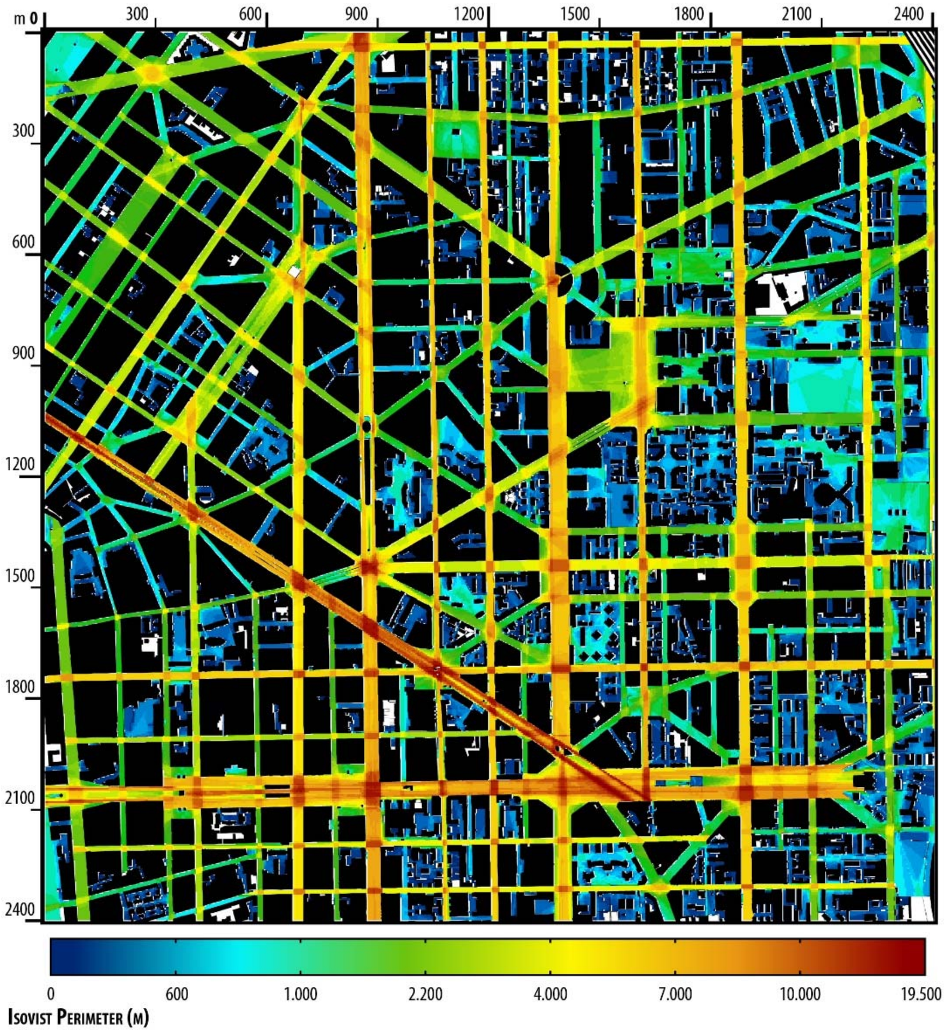


Figure 6.2 – Isovist perimeter

MEANINGS

P_x Perimeter of the polygon visible from a given point on the space.

"The length of the visible boundary" (Benedikt, 1979)

POSSIBLE INSIGHTS

The indicator named "Isovist Perimeter" quantifies how many meters of obstacles are visible from a given point asbestos. In addition to determining all indicated for the indicator "Isovist Area" for obvious reasons, this value suggests and introduces a new concept: the obstacle. To a high value of visible perimeter corresponds in fact a potential distraction for drivers high as it could be distracted by what is happening in his field of vision. Of course this is a hypothesis to be verified, however, the experiments could be conducted, possibly by combining both values of perimeter and area.

6.1.3. CONNECTIVITY OF THE SIGHT POINT

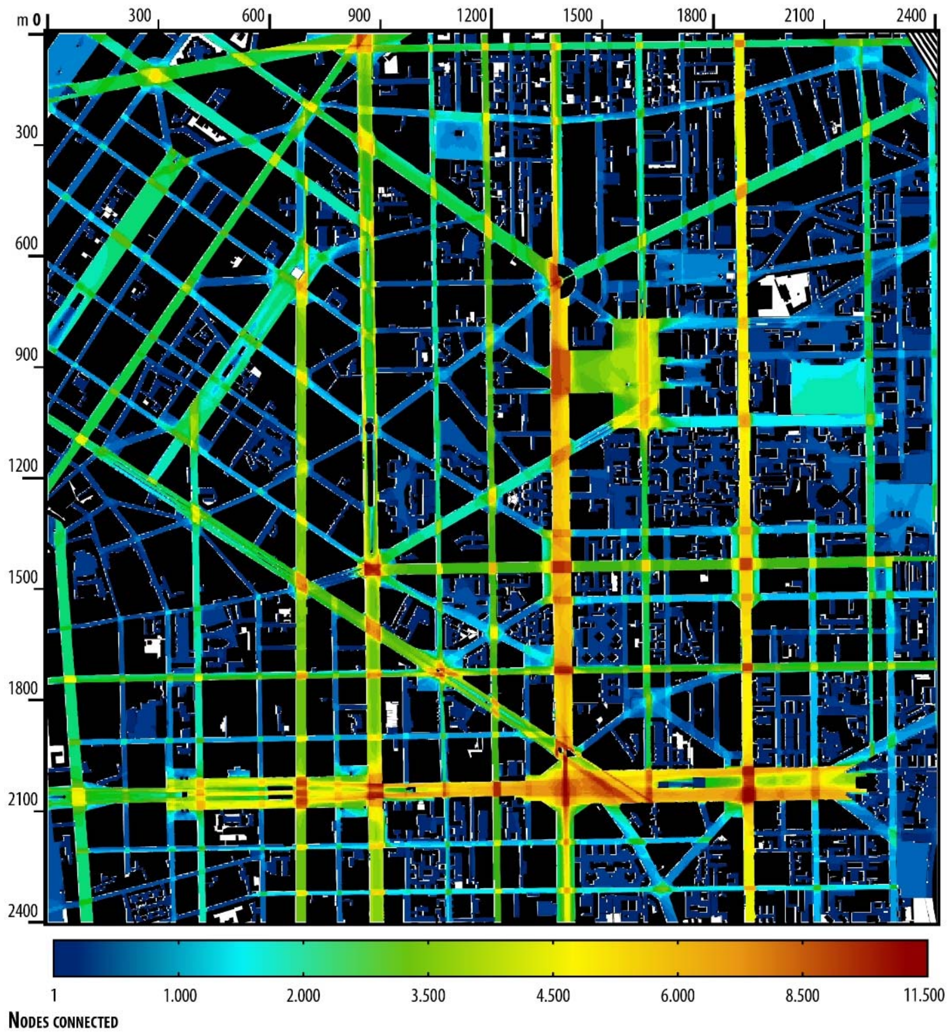


Figure 6.3 – Connectivity coefficient

CONNECTIVITY

The connectivity is defined as the number of lines, or vertex in the case of the VGA, directly connected to a given line or vertex. The connectivity of a vertex is so equal to the number of vertex that has a depth equal to one respect to the vertex considered. (Hillier, Hansen, 1984)

POSSIBLE INSIGHTS

As a coefficient of pure connectivity, showing points of the map that was already highlighted in the indicator area, but I believe it appropriate to refer the possible developments of this indicator in section 6.2.4 where the integration factor that is a normalized value of the connectivity factor is explored.

6.1.4. Isovist Compactness

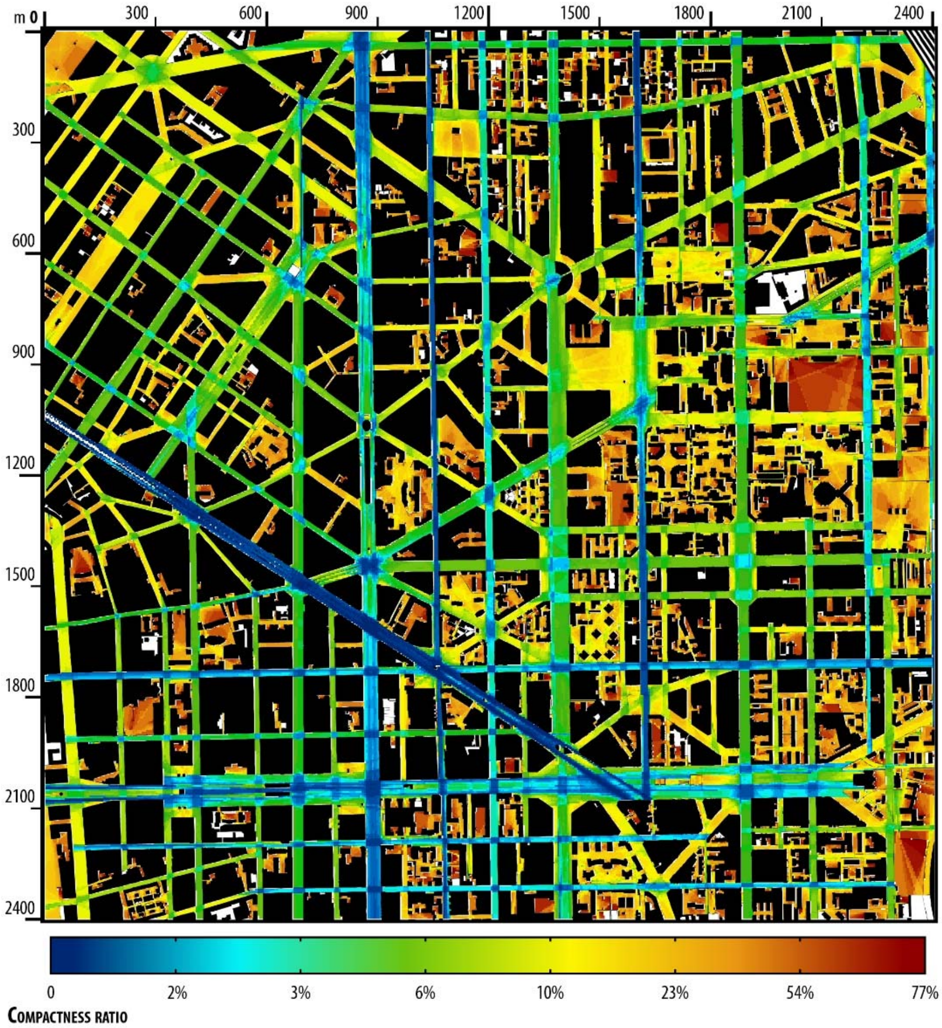


Figure 6.4 – Isovist Compactness

COMPACTNESS

Analogy of the isovist shape to a circle. (Pebbles et al., 2007)

POSSIBLE INSIGHTS

The compactness value shows the areas of the city where the view is not "disturbed" by various types of obstacles. To high values correspond areas of the city which have similar characteristics in terms of views. On the map, these are often localized in the inner zones of the block, as though indicating a safe and controlled environment. The key points that I think worth stressing here are particularly the great avenues, where clearly show low values of compactness. This highlights the fact that some avenues are "bothered by many intersections or other obstacles with a high fragmentation that contributes to the lowering of the compactness of the isovist. These avenues will require higher levels of illumination due to the increase of the risk factors that can lead to unsafe conditions in the area under consideration.

6.1.5. Isovist Maximum Radial Distance

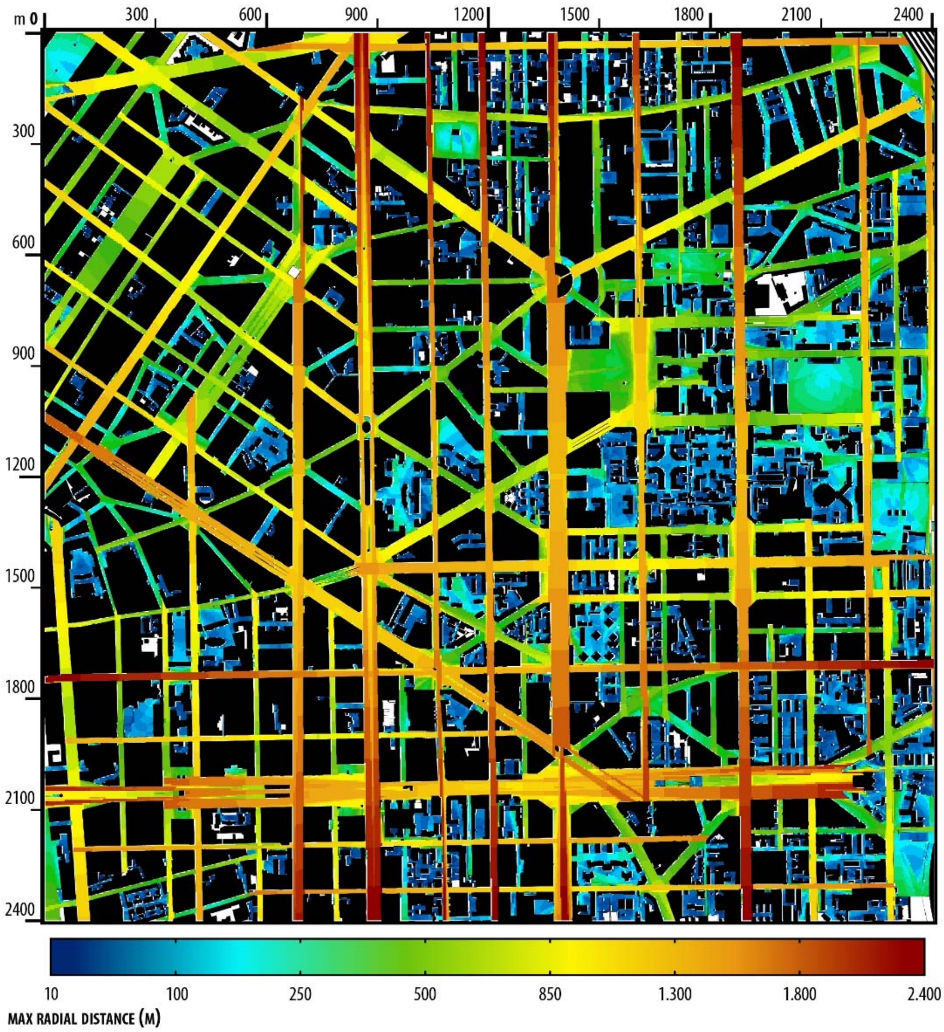


Figure 6.5 – Isovist Maximum Radial Distance

RADIAL DISTANCE

d_{max} *"Maximum or farthest distance which can be seen from the vantage point, the minimum distance and the average distance"* (Batty, 2001)

POSSIBLE INSIGHTS

The values of "Radial Distance" alone have an irrelevant meaning, it is indeed unlikely, at least for the maximum distance, that the user is able to seeing during the night over a certain depth. As an indicator may indicate, even if it would not be appropriate, the presence of very long avenues and at the level of pedestrian traffic means a higher attractiveness for these flows. Nevertheless high values of distance (with the exception of open spaces) higher mean distance of pedestrians traveling to the places where they prefer to walk, or perimeters, so it is unlikely that pedestrians can be found in these areas. For further information and future developments, however, please refer to section 6.2.6 which is the result of an interesting integration between the two.

6.1.6. Isovist Minimum Radial Distance

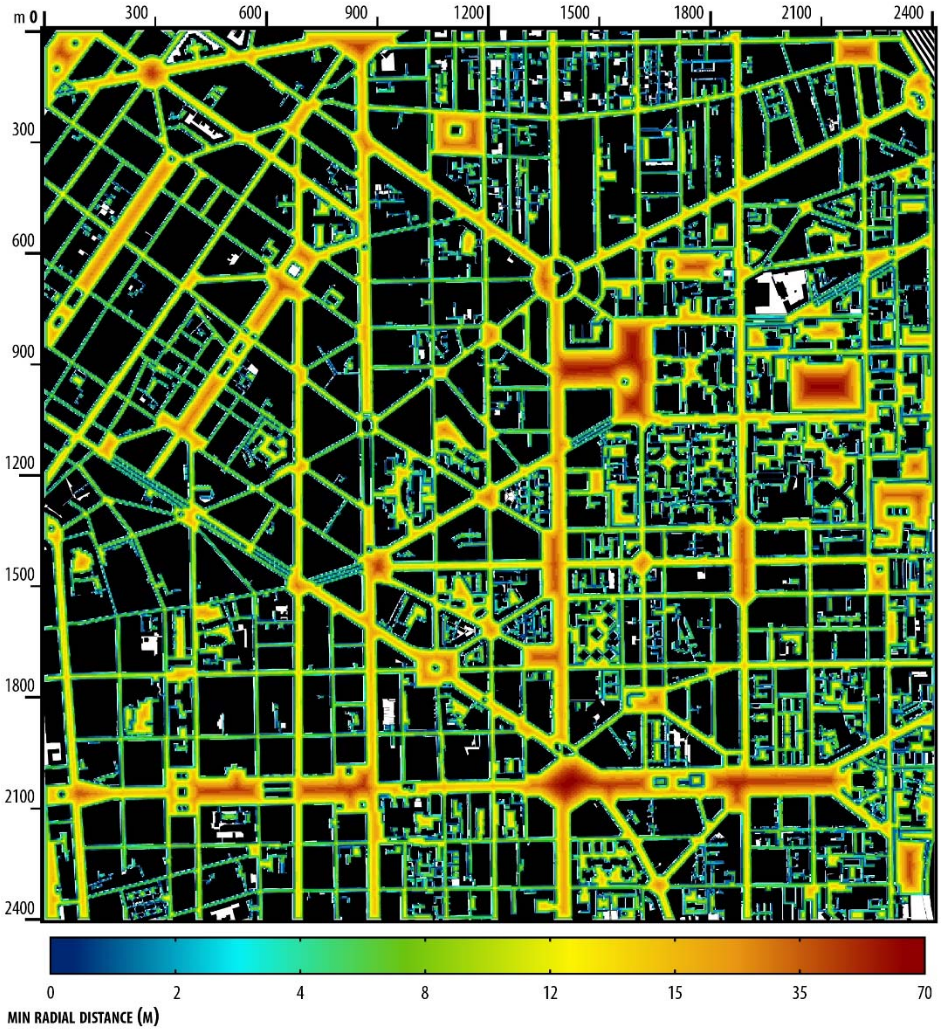


Figure 6.6 – Isovist Minimum Radial Distance

6.1.7. Isovist Occlusivity Or Occluding Perimeter

Figure 6.7 – Isovist Occlusivity Or Occluding Perimeter

ISOVIST OCCLUSIVITY OR OCCLUDING PERIMETER

Q_x Part of the perimeter of the isovist occluded, not coincident to the real surfaces.

"The length of the non-visible radial components of the total isovist boundary. (These are the radial components separating the visible space one cannot see from point x. (Benedikt, 1979)

POSSIBLE INSIGHTS

The Occlusivity value, by its self, have meanings that in terms of public lighting do not have remarkable impact.

6.2. VISUAL GRAPH ANALYSIS INDICATORS

6.2.1. VGA – The Clustering Coefficient

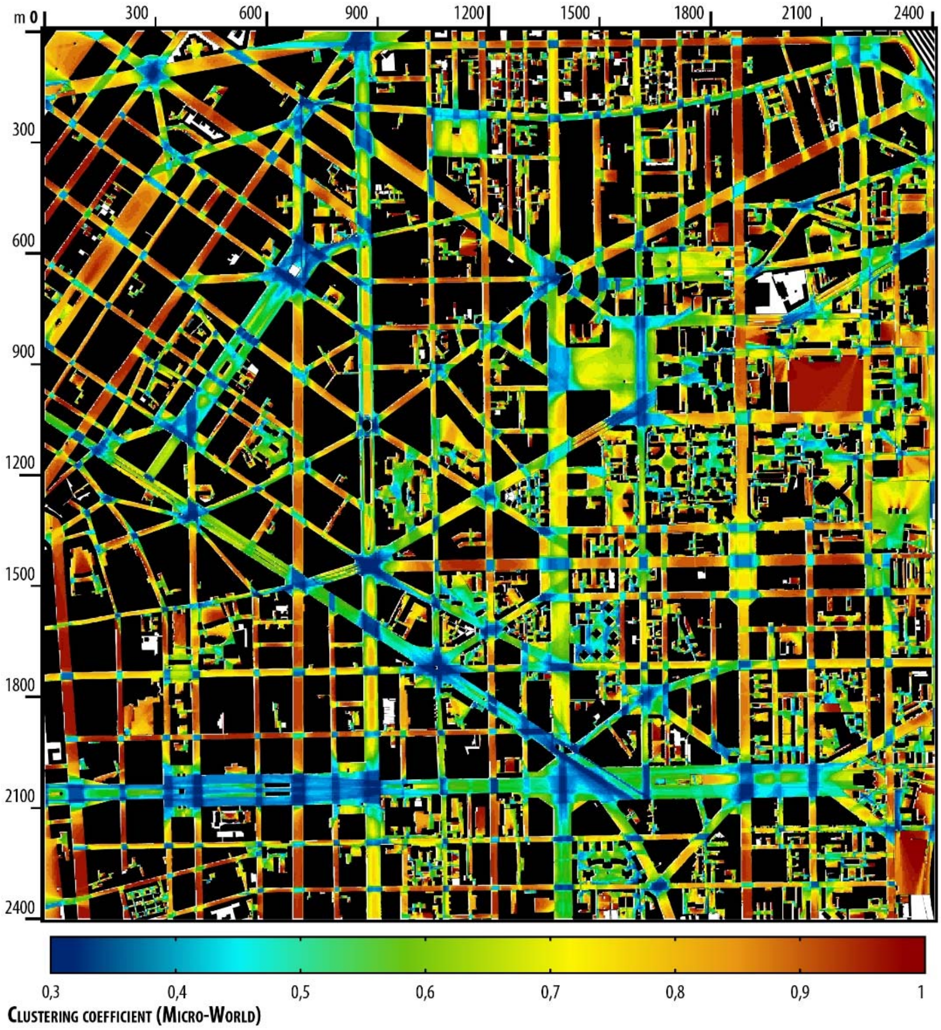


Figure 6.8 – Visual Graph Analysis – The Clustering Co-efficient

VISUAL CLUSTERING COEFFICENT

The clustering coefficient of a vertex is defined as the ratio between the number of visual connections inside his own isovist area, and the number of connection theoretically possible inasmuch constituted by segments that connect couple of points inside them. Referring to the territorial characteristics that identify this property, the clustering coefficient identify the grade of convexity of a given isovist.

Clustering coefficient is a measure to help assess whether or not a graph is a `small world' or not. (Watts, Strogatz, 1998)

The clustering coefficient can represent the grade of intervisibility of a space corresponding to an isovist of a given vertex, represent the grade in which an isovist is shared by other points inside, and therefore it is an indicator of homogeneity in the shift from a point to another one inside an isovist. The clustering coefficient appears to give an idea of the `junctionness' of locations, and how the visual information is changing within systems, dictating, perhaps, the way a journey is perceived and where the decision points come within it (Turner, 2001).

POSSIBLE INSIGHTS

The clustering coefficient, identifying areas with homogeneous visual characteristics, can be decisive, not in the management of the amount of luminous flux necessary, but to identify those areas where this flow should be kept evenly. In this sense, the "cluster" precisely identified, they will become, by borrowing from the lighting engineering vocabulary, “Isolux” areas, or those areas that need to have better values homogeneous illumination. On how much illuminate, however, please refers to other possible indicators that suggest the most appropriate value.

6.2.2. VGA – Visual Control and Controllability Coefficient

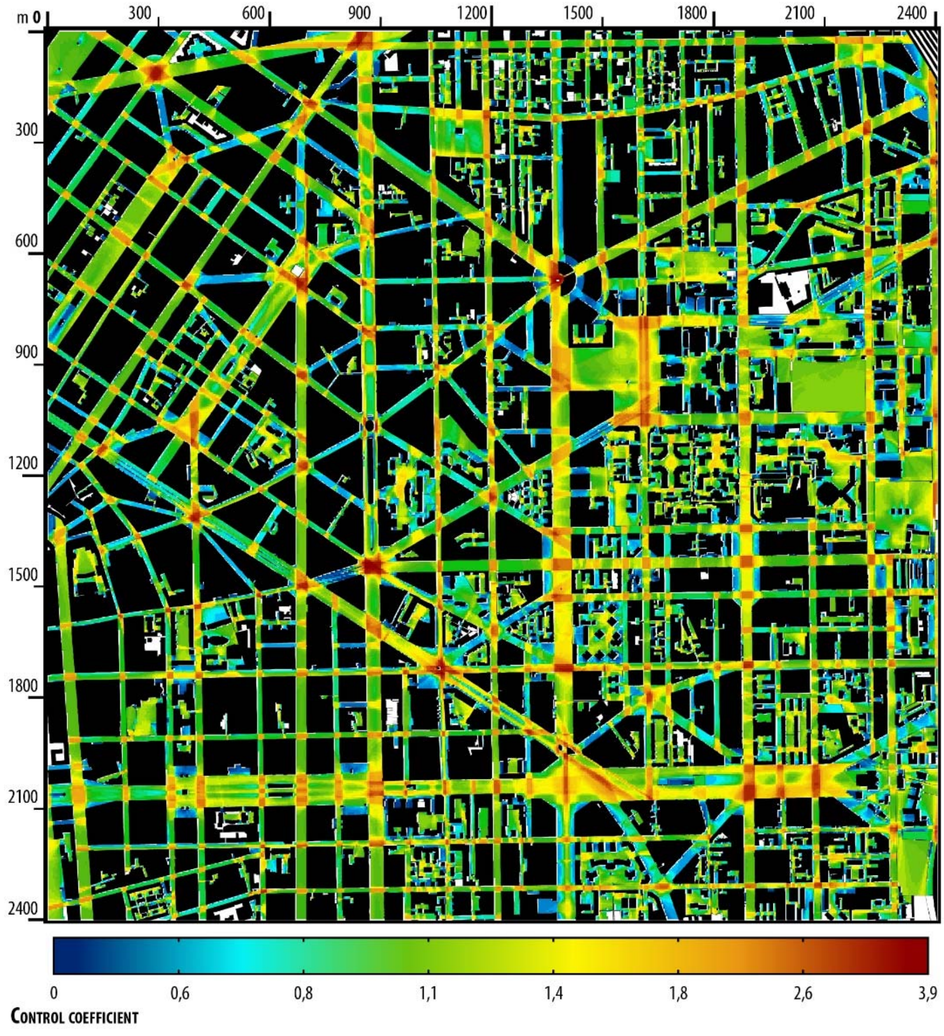


Figure 6.9 – Visual Graph Analysis – Visual Control

VISUAL CONTROL AND CONTROLLABILITY

As the names suggest, control picks out visually dominant areas, whereas controllability picks out areas that may be easily visually dominated. For control, each location is first assigned an index of how much it can see the reciprocal of its connectivity. Then, for each point, these indices are summed for all the locations it can see. As should be obvious, if a location has a large visual field will pick up many points to sum, so initially it might seem controlling. However, if the locations it can see also have large visual fields, they will contribute very little to the value of control. Therefore, in order to be controlling, a point must see a large number of spaces, but these spaces should each see relatively little.

The control value represent the grade of control that a given vertex plays on the connection, connected to it. In other words, the control is the indicator that quantify the grade of power that a vertex has on the other vertex. (Hillier, Hansen, 1984)

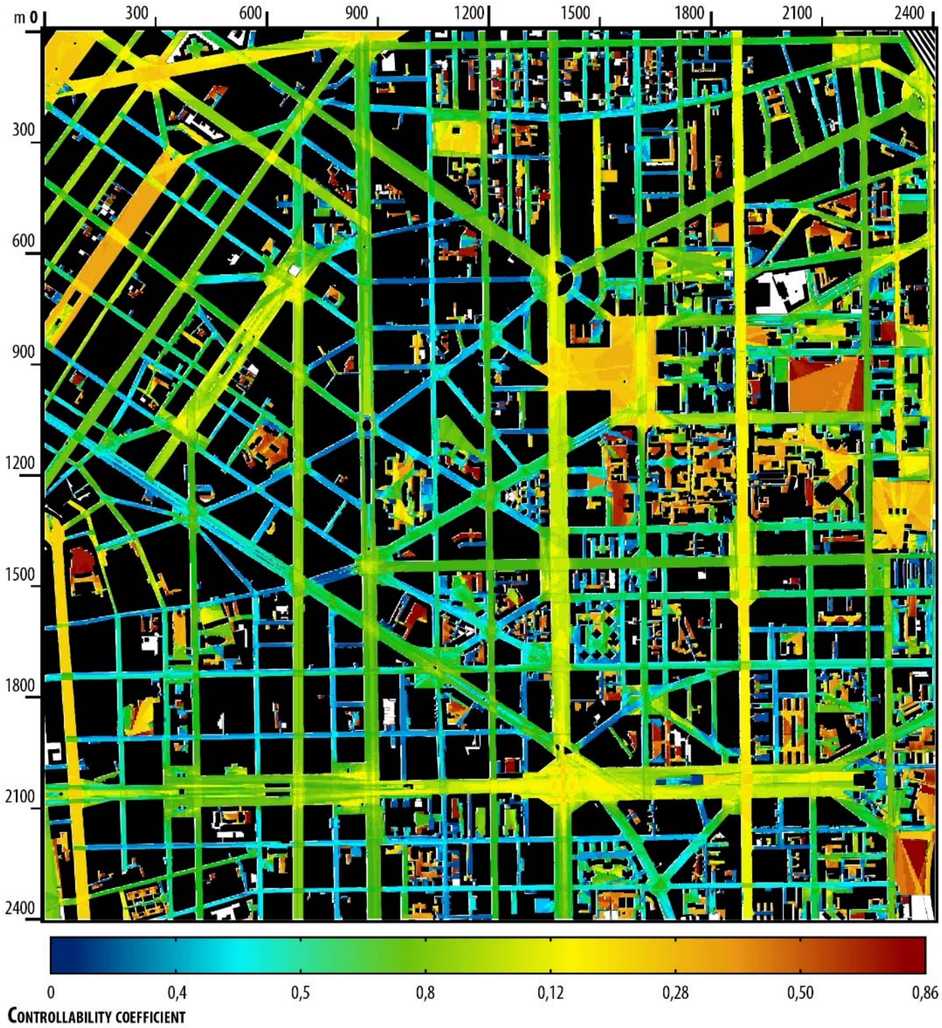


Figure 6.10 – Visual Graph Analysis
Visual Controllability

The value of controllability, defined by Turner, is the grade in which a vertex can be controlled by other vertex in the connection with other vertex. The maximum value admitted is 1.(Turner, 2001)

POSSIBLE INSIGHTS

The coefficient of control highlights, Within the map, the areas which are capable of controlling more points on the map, or even better, in terms of absolute accessibility, assuming an infinite matrix origins and destinations in the map are the points crossed over. By itself, these points, constitute focal points and stations, where the user, pedestrian or car driver, cross with a higher probability than others. In these terms, being that the points with high value of control are more likely to accommodate vehicular and pedestrian flows, the map of the coefficient of control seems to be most suitable to carry out an assessment of the amount of luminous flux.

6.2.3. VGA – VISUAL ENTROPY AND RELATIVIZED ENTROPY

Figure 6.11 – Visual Entropy And Relativized Entropy

VISUAL ENTROPY AND RELATIVIZED ENTROPY

There are two global measures calculated by Depthmap, called `entropy' and `relativized entropy' described by Turner (Turner, 2001).

The reason for their introduction was that Depthmap seems to priorities open spaces or wide streets in terms of integration, whereas people seem to cognize space on a much more one-dimensional level. A measure of entropy is a measure of the distribution of locations in terms of their visual depth from a node rather than the depth itself. Therefore, if many locations are visually close to a node, the visual depth from that node is asymmetric, and the entropy is low. If the visual depth is more evenly distributed, the entropy is higher. Relativized entropy takes account of the expected distribution from the node. That is, in most cases, you would expect the number of nodes encountered as you move through the graph to increase up to the mean depth and then decline afterwards. Within the text here, it is worth mentioning that there is a spatial interpretation problem for both entropy and relativized entropy, and that is that entropy is low for uneven distributions, whether these are close or far away from the current node.

6.2.4. VGA – Integration Value Teklenburg

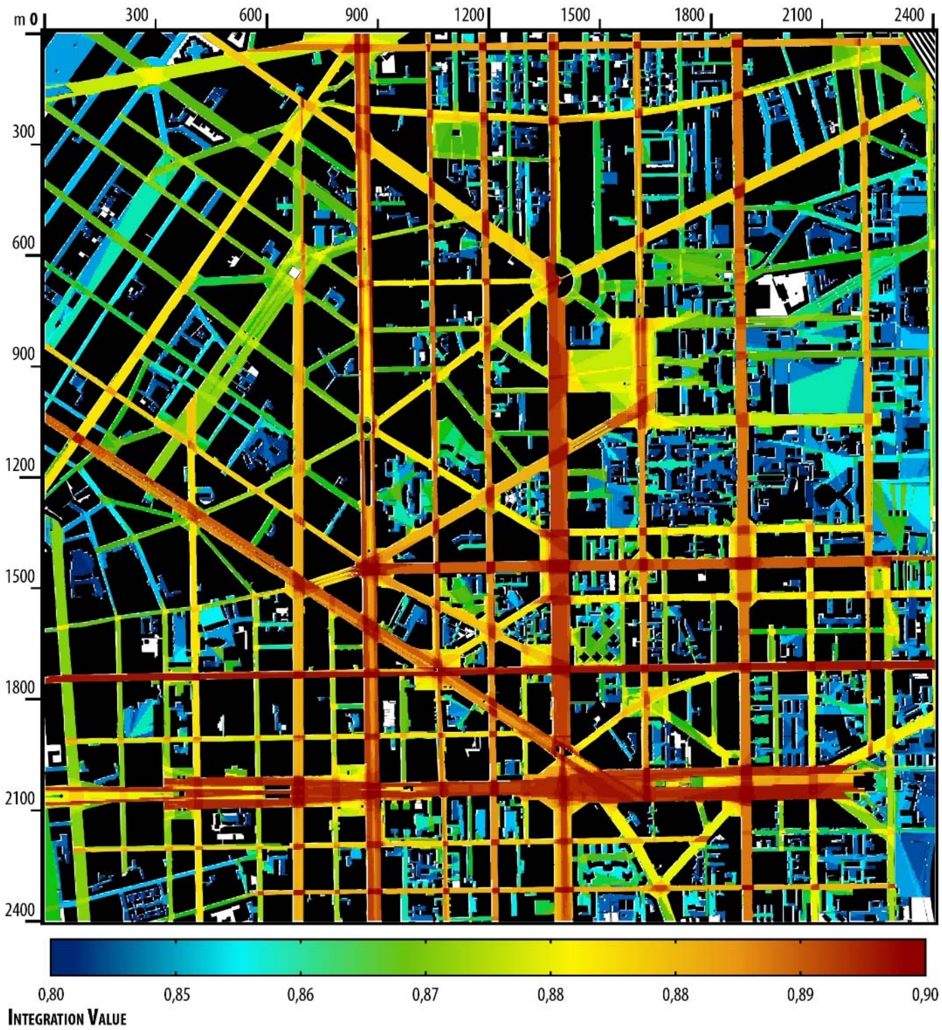


Figure 6.12 – Visual Graph Analysis – Integration Value Teklenburg

VISUAL INTEGRATION

The measure is essentially a normalized version of the mean depth, and it is important because it has been found to correlate well with pedestrian movement `gate' counts. (Hillier et al., 1993)

The integration value is the most important, and the most used parameters of the space syntax analysis. The index of integration identify the grade of integration of a vertex inside a given matrix, and therefore, the grade of pure accessibility raise according to the integration value. The value of integration differ from the size of territory analyzed, over the years have been developed several methods of normalization, the method used in this thesis is the Teklenburg because his comparability with different size of map. (Teklenburg et al., 1993)

Of how the luminous flux should be provided at large scale. The Integration factor, highlighting the most important or integrated road axes, seems likely that these values could suggest a general quantification

POSSIBLE INSIGHTS

While the Control Coefficient affect the possible management of the luminous flux, form an absolute point of view, or better, the value can be managed for a specific area therefore at small scale, the visual integration value gives a relative idea of the illumination value that should be provided. Another interpretation of the integration and control factor, could be that while for the first one can suggest a distribution of the illuminances for satisfy the pedestrian requirements, the second one, suggest the requirements of the vehicular flow, and therefore both are complementary.

6.2.5. VGA – Mean Depth Value

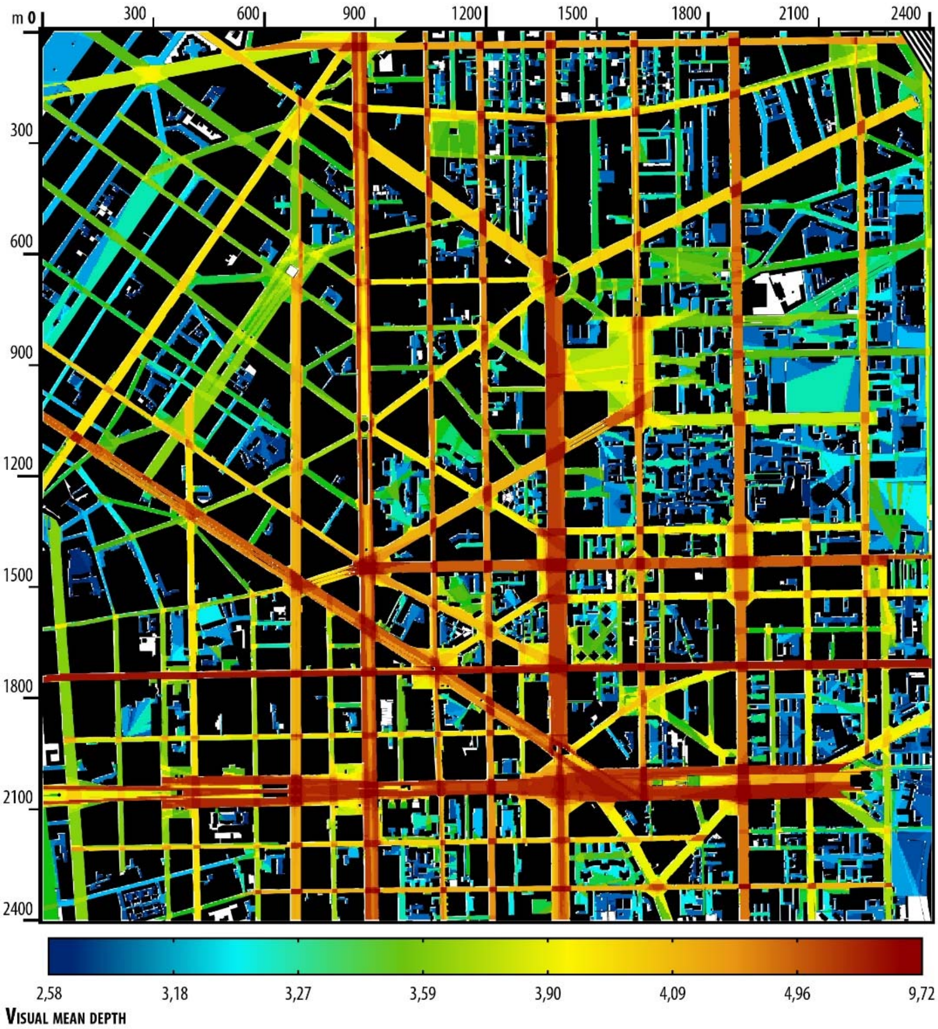


Figure 6.13 – Visual Graph Analysis – Mean Depth Value

MEANINGS

The mean depth of an isovist measured in meters.

6.2.6. VGA – Max To Min Ratio

Figure 6.14 – Max To Min Ratios

MAX TO MIN RATIOS

Square root of the ratio between the maximum and the minimum radial distance.

"Intermediate spaces, where is possible to identify a private space without losing the contact with the public space" (Morello, Ratti, 2009).

Wide and opening visual area with a low exposure, are often strategic spaces where you can be well covered and at the same time have a good view of the surrounding area.

POSSIBLE INSIGHTS

This last indicator shows the zones of the territory analyzed which the city user feels comfortable, in this case, an insight could be that, in case of high values of indicator providing an adequate illuminance value for satisfy the needs of the user that choose these zones just for staying.

6.3. KEY POINTS AND INSIGHTS

In order to sum up the main findings of this part of the thesis is presented in the Figure 6.15 a diagram where are linked the most useful indicators to their meanings in term of public lighting.

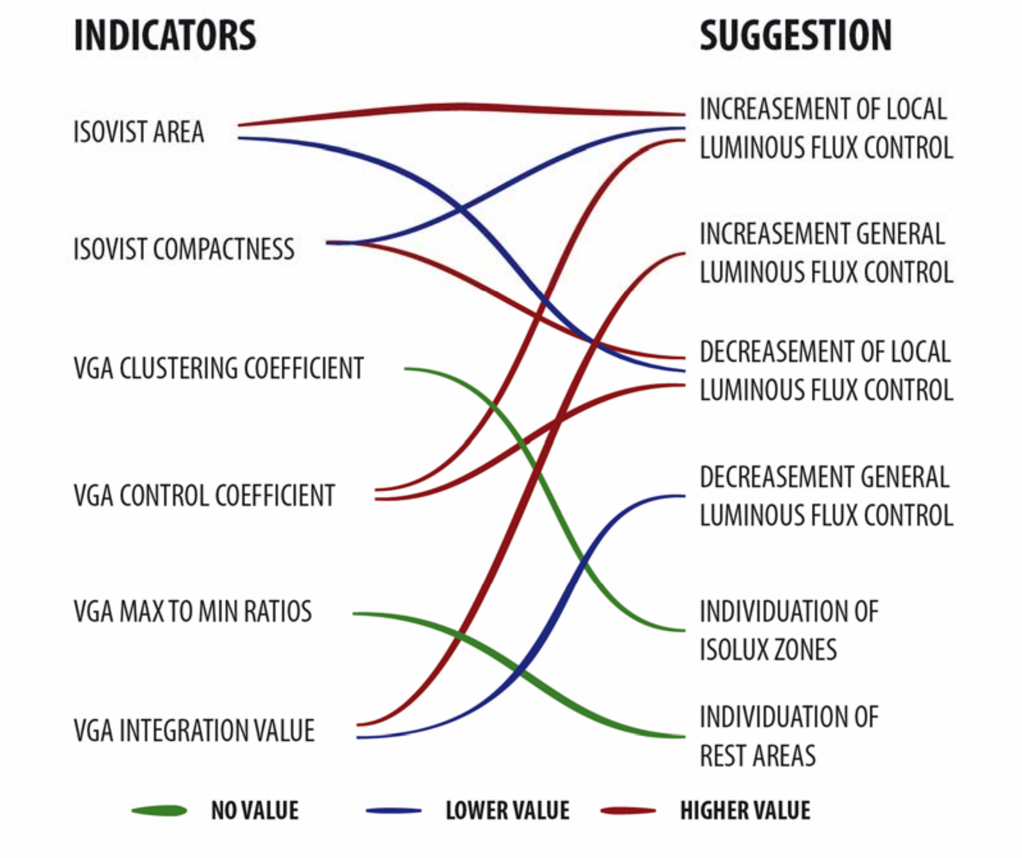


Figure 6.15 – Interpretation of the results in lighting terms

The main control actions identified regards the control of the general luminous flux that concerns wider zones than the local luminous flux. In fact while the general one may relate to a neighborhood or an entire road, the local one regard a given zone such as a crossing or a plaza. The indicators that affect the general control are the integration value, because, as stated in the previous chapters, the integration that at higher value can identify the major roads with high density of flow. The local control of the luminous flow can be affected by the Isovist area, or by the compactness or even better by the control coefficient that at higher value identify the most crossed areas.

Moreover there are also indicators that can identify areas of study, such as the clustering coefficient is able to identify the areas that have the same behavior in terms of spatial perception of the observer, and consequently, such areas should be have a precise illuminating value throughout its extent.

The last interesting indicator is the max to min ratios that can identify the rest area where the observer can stay for a while for resting or enjoy the city.

PART IV
SMART STREETS AND THE MANAGEMENT OF A RESPONSIVE PUBLIC LIGHTING SYSTEM

1. ABSTRACT OF THE THIRD PART

ITALIANO

I consumi energetici determinati dall'uso della pubblica illuminazione corrispondono al 17% della spesa totale per l'illuminazione in Italia. Ma da un punto di vista economico e gestionale la spesa per la fornitura dell'energia necessaria ad illuminare costituisce solo una parte delle spese di gestione totale ti tutto il sistema di illuminazione. Ricerche recenti dimostrano come in Italia le spese di gestione dell'illuminazione pubblica superino di gran lunga le spese per i consumi energetici, portando ad una spesa per punto luce in alcune città insostenibile. Questa parte della tesi si propone di indagare nelle diverse componenti della gestione della pubblica illuminazione quali sono le tecnologie ed i metodi ad oggi a disposizione che ci permettono di portare dei grandi risparmi. Queste componenti sono: la fornitura dell'energia elettrica necessaria ad alimentare l'impianto, e la gestione e manutenzione dell'impianto. Oltre ad aver indagato su diverse ricerche che ad oggi sono a disposizione, questa parte di tesi si conclude proponendo un architettura di gestione innovativa introducendo il concetto di Responsive Smart Lighting System. Il modello si basa sull'utilizzo di nuove tecnologie atte a raccogliere informazioni utili per gestire in modo ottimale le risorse ed andare a produrre dei risparmi consistenti nelle diverse componenti. Il modello proposto ha un potenziale in termini di risparmio energetico che però comporta uno sforzo in termini di investimento e programmazione delle azioni. Come dimostrano casi studio che già stanno portando a compimento prototipi di questo genere, le possibilità di realizzazione di un sistema innovativo di questa portata sono tutt'altro che poche.

ENGLISH

The energy consumption resulting from the use of public lighting correspond to 17% of the Italian energy total expenditure for lighting. Form an economical and management point of view such expenditure is only a part of the total management expenditure of the whole system.
Recent research shows that in Italy the cost of public lighting management far outweigh the cost for the energy consumption, leading to a cost per light point in some cities unsustainable.
This part of the thesis aims to investigate the various components of the public lighting management in terms of technologies and methods available today that allow us to lead to huge savings.
These components are: the supply of electricity needed to power the system, and the management and maintenance of the system. In addition, after investigating several studies which today are available, this part of the thesis concludes by proposing an architecture for innovative management by introducing the concept of Responsive Smart Lighting System. The model is based on the use of new technologies to gather information to optimally manage the resources and go to produce significant savings in the different components. The model proposed has potential in terms of energy savings but requires an effort in terms of investment and planning of operations.
As demonstrated by the case studies that are already bringing to completion prototypes of this kind, the possibility of realization of an innovative system of this magnitude are anything but few.

2. INTRODUCTION

In the introduction of the first section, was stated that the public lighting is responsible for the 17% of the total energy consumption in Italy for lighting. Still in the first section, how from the morphology and the functionality of the roads and open spaces affect the light requirements, and consequently the relative energy consumption for satisfy this needs was analyzed.

If we would put in a balance the cost for the energy supply, comparing them with the cost for the management of the public lighting system, we would find that the second category of cost override even up to the double the cost for the first category. This means that, in terms of cost, the priority is the model of management of the public lighting system.

In this section of the thesis, a model of architecture for manage the smart lighting system will be proposed. This architecture will be develop using most of the technologies today available in order to grasp useful data that are able to support the decision making of the system.

General Target

- **CITY SENSITIVENESS** Being more aware about how the city behave
- **SYSTEM RESPONSIVENESS** Knowledge based adaptation in the deployment of service
- **SUSTAINABILITY** Decrease the cost of the management

Specific target

- **BEING AWARE** Create awareness in the decision makers about the phenomenon that may affect the light requirements, through the use of technology able to grasp data, and react accordingly
- **BEING SUSTAINABLE** Being more effective in the management of the lighting system decreasing the management costs
- **BEING RESPONSIVE** Develop an "on demand" based supply of the luminous flows
- Develop a maintenance system that should be design and programmed in advance in order to decrease the cost
- Develop a maintenance system that is able to react to failures detected on remote.

Questa sezione della tesi

Questa sezione serve per fare diversi affondi e proposte di ricerca, sottolineare diversi campi e ambiti di ricerca che si potrebbero sviluppare.

An efficient public lighting system should focus on the technology available, for light up the street, but there are other aspect that an intelligent public lighting system should take into account. These aspects are all contained in what is called: management of the public lighting system. A system of management is composed by a system of programmed maintenance, because as explained before, a good scheduled and targeted maintenance can lead to substantial savings on maintenance.

Another relevant aspect is the real-time lighting control according to the need of light in a given moment of the day. As demonstrated before, there are many research that presents good practices and technics for manage and control the public lighting, bringing significant energy savings due to wastage.

2.1. RESEARCH QUESTION

The lighting system, as it stands, is conceived as a system that supply light with criteria defined a priori causing often some concern relating to the effective satisfaction of the requirements in given moments of the night. The purpose of this part of the thesis is to explore practices, technologies and solution in order to assess the possibility to conceive a new way to supply the public lighting service. Is there any possibility to re-develop the public lighting as an integrated, interoperable, implementable, and especially adaptable system? Which are the technology and the tools that can make sure that such system can became a Smart Service? Which are the benefits that can be achieved with such service?

2.2. SYNTESIS OF THE CHAPTER

CHAPTER 3 – STATE OF THE ART

In this chapter a framework about the smart public lighting will be delineated, and subsequently, some case studies about smart lighting around the world and in Italy will be introduced. Then will be proposed a summary of the main references used to construct the architecture of the smart public lighting

CHAPTER 4 – SMART CITY AND THE IMPORTANCE OF A SMART LIGHTING SYSTEM

As a part of the Smart City, the smart lighting have some repercussions among the six characteristics of the Smart Cities individuated by the Polytechnic of Wien. In this chapter the relation between the Smart Lighting and the Smart City will be defined going in deep in the six characteristics.

CHAPTER 5 – SMART STREETS AND THE CONCEPT OF SMART LIGHTING

In this chapter will be defined the difference between the concept of Smart Streets and Smart Lighting

CHAPTER 6 – THE ARCHITECTURE OF THE SMART PUBLIC LIGHTING

In this chapter will be proposed the architecture for the responsive public lighting. In a first moment a set of assumption will be proposed, after which, a set of target will be delineated on which the entire development of the model is based.

CHAPTER 7 AN 8 – THE DATA PLATFORM AND THE REMOTE CONTROL MANAGEMENT

In those 2 chapters will be defined the main parts of the architecture with some proposal. While in the 7^{th} chapter, I have talked about the data and the information relatives to the environmental brightness and the traffic flows. In particular we have underlined how they can be collected, and how they can be stored. Moreover, we have talk about how this information must be modelled in order to build-up indicators. The purpose of the 8^{th} chapter is to understand how such information can be used in order to take some decision, and in a Smart Lighting Service, this function is dislocated in the Remote Control Management, that is the core where all is decided.

CHAPTER 9 SMART SERVICES, INTERNET OF THING AND BIG DATA

In this chapter will be introduced a general overview of the use of the technology mounted on the lamp-posts according to the architecture developed in the previous chapters

3. STATE OF THE ART

In this chapter a framework about the smart public lighting will be delineated, and subsequently, some case studies about smart lighting around the world and in Italy will be introduced. Then will be proposed a summary of the main references used to construct the architecture of the smart public lighting

3.1. THE WORLD INNOVATORS IN PUBLIC LIGHTING, CHICAGO'S "ARRAY OF THINGS"

The open release of city data has given residents exciting new ways of interacting with and benefiting from the information collected by city agencies.

Nevertheless, what if there was a way to collect even broader, higher-resolution data on the daily life of the city, providing a massive stream of open data for research and the development of new applications to improve urban life? The Array of Things is a project of the CI's Urban Center for Computation and Data (UrbanCCD)[14] to deploy interactive, modular sensor boxes around Chicago to collect real-time data on the city's environment, infrastructure, and motion for research and public use.

The purpose is to use the street lamppost in order to install sensors able to grasp data about the sound, the air temperature/humidity; the pedestrian and vehicular flows and other purposes. The pilot area identified is the Michigan Avenue in Chicago; anyway, the first nodes will not be installed until the end of August '14.

While the benefits of collecting and analyzing giant sets of data from cities are somewhat speculative, there is a growing desire from academic and industrial researchers to have access to the data, said Gary King, director of the Institute for Quantitative Social Sciences at Harvard University. *"You really don't know until you look,"* King said. *"We don't collect things that can identify people. There are no cameras or recording devices,"* he said. Sensors will be collecting *"sound levels but not recording actual sound. The only imaging will be infrared,"* rather than video, he said.

3.2. THE EFFICIENCY IMPROVEMENT IN THE NATIONAL AND LOCAL CONTEXT

Improving the efficiency of public lighting systems is one of the interventions, in addition to responding to the needs of environmental, it can also help in the medium term to contain current expenditure of local authorities. On this measure, Regione Lombardia had issued in the year 2000 a specific law on light pollution (Lr March 27, 2000 n. 17). With the new energy planning, continue, on the one hand, with the restructuring of lighting systems, on the other hand by promoting the installation of multifunctional light poles

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[14] The Urban Center for Computation and Data (UrbanCCD) was created in 2012 within the Computation Institute, a joint initiative of the University of Chicago and Argonne National Laboratory.

prepared for the provision of telecommunication services to combine the energy goal with the diffusion of ICT services.

Starting from end of 2014, the Municipality of Milan will be managing authority for about €40 million of structural funds in the framework of a National Operational Program (PON) for Cohesion Policy. The main pillars of the Program are Smart Cities and Social Innovation. Funded actions (under negotiation) consider residential buildings refurbishment, smart public lighting, electrical mobility, ICT. The Municipality plans to address part of these resources in ACTIVE's integrated and coherent manner for the development of the Porta Romana[15] – Vettabia area. In each pilot area within the three cities, new public lighting systems will be equipped with sensing and remote management infrastructure. This will enable control of lighting levels on the basis of real-time pedestrian traffic data and other urban mobility indicators, with the aim of providing significant cost reductions and energy savings. In some cases, additional systems such as air pollution detection and Wi-Fi will be incorporated, in order to provide wider integration with the intermodal transport systems, and to increase opportunities for citizen engagement with these systems.

3.3. THE RESEARCH FRAMEWORKS ABOUT SMART CITIES AND SMART LIGHTING

Research on the Smart City topic that focus on the "Smart Lighting" issue are several with good insights that have inspired this section. From the general point of view of the Smart City, a reference was a scientific paper from the Vienna University of Technology who gave the general approach of how they should be interpreted and evaluated the Smart Cities (Giffinger et al., 2007). They were subsequently published other research, because after almost seven years, it is not yet clearly defined what a smart city is, was, therefore, useful to follow the approaches of two other studies that interpret and explain how it can be defined the Smart City (Kitchin, 2014) and how a Manager of Smart City should approach towards the city to optimize the results (Cohen, 2014). From a specific point of view of the Smart Lighting, a major contribution was made by the research carried out by ENEA (Annunziato et al., 2011; Gugliermetti et al., 2011). These references, after analyze and demonstrated how the management of the lighting system has highest cost compared to the cost derived for the energy supply, identifies a number of practices and management models of a smart lighting system.

[15] *The project regards 296 street lighting posts in the pilot area of Porta Romana*

4. SMART CITY AND THE IMPORTANCE OF A SMART LIGHTING SYSTEM

As a part of the Smart City, the smart lighting have some repercussions among the six characteristics of the Smart Cities individuated by the Polytechnic of Wien. In this chapter the relation between the Smart Lighting and the Smart City will be defined going in deep in the six characteristics.

The big city, the one with more than half million of inhabitants are the focus of many research in these years for many reasons. Firstly because more than half of all humans will soon be living in cities according to a recent forecast by the United Nations. Europe (including Russia) is even more urbanised as 72 percent of its inhabitants live in cities (Giffinger et al., 2007). For this reason, we should thinking about innovative solution for enhance the sustainability in these city. A city is a complex system of infrastructures, services and human capital, and for manage such complexity there is a need to use innovative solution with the technologies available today. The city that can design, supply and manage a complex of services together with the use of the ICT can be defined Smart. The use of the Information and Communication Technologies is relevant because can make a service intelligent.

'Smart cities' is a term that has gained traction in academia, business and government to describe cities that, on the one hand, are increasingly composed of and monitored by pervasive and ubiquitous computing and, on the other, whose economy and governance is being driven by innovation, creativity and entrepreneurship, enacted by smart people. (Kitchin, 2014)

The Smart Cities have an integrated approach to improving the efficiency of city operations, the quality of life for its citizens, and growing the local economy and this is about not only technology but also approach. Recently I have read an article (Cohen, 2014) that identifies three key drivers to achieving the goal.

STEP 1: CREATE A VISION WITH CITIZEN ENGAGEMENT

The city used "social media and digital technologies to spark citizen-led public-engagement activities like online discussion forums and workshops at community centres,

STEP 2: DEVELOP BASELINES, SET TARGETS, AND CHOOSE INDICATORS

Before creating numerical targets for achieving a smart city vision, it is helpful to actually benchmark where you are. Let us take Smart Mobility as an example. The Smart Cities Wheel has three key drivers for Smart Mobility: mixed-modal access; prioritized clean and non-motorized options, and integrated ICT.

STEP 3: GO LEAN

It makes sense for a city to start with a pilot project as a way to get feedback on their hypothesis.

Smart cities are not one size fits all. Yet, the smart-cities movement could benefit from frameworks like the Smart Cities Wheel that allow a common language to develop amongst citizens, city staff, mayors, and the private sector.

The term Smart City is also used regarding the education of its inhabitants. A Smart City has therefore smart inhabitants in terms of their educational grade. In other literature the term Smart City is referred to the relation between the city government resp. administration and its citizen. Good governance as an aspect of a smart administration often also referred to the usage of new channels of communication for the citizens, e.g. “e-governance” or “e-democracy”. Smart City is furthermore used to discuss the use of modern technology in everyday urban life. This includes not only ICT but also, and especially, modern transport technologies. Logistics as well as new transport systems as “smart” systems which improve the urban traffic and the inhabitants’ mobility. Moreover various other aspects referring to life in a city are mentioned in connection to the term Smart City like security/safe, green, efficient & sustainable, energy etc.

A Smart City is a city well performing in a forward-looking way in the next six characteristics, built on the ‘smart’ combination of endowments and activities of self-decisive, independent and aware citizens. In the next paragraphs will be pointed out how a smart lighting system can emphasize each of these characteristic.

4.1. SMART ECONOMY

The concept of the smart economy is rooted in innovation and a city on its ability to transform between creating conditions attractive to talented and virtuous companies. A system of public lighting Smart does not enter directly into play under Smart Economy, unless the companies mentioned, to work together to develop an innovative public lighting project. The realization of a project of this scale in fact constitutes a potential in terms of attractiveness is not indifferent.

4.2. SMART PEOPLE

The Smart People dimension regards the personal motivation of each citizen, assess their level of qualification and attitude to continuously learn ad acquire knowledge. The economy of a prosperous city is knowledge based, the more you know, the more you can innovate. The Smart Street Lighting does not enter in this characteristics, anyway a comfortable lighting system may lead to a higher participation I public life by the city users, affording a large number of knowledge exchange moment even during the night.

A newfound awareness and participation in public life, high levels of qualification of citizens, peaceful co-existence of different stakeholders and communities are some of the smart features that can be found in a "smart city".

4.3. SMART GOVERNANCE

The Smart Governance characteristic, assess the foresight of the public administration. Transparency and participation in the decision making process, plus the deployment of high quality of public and social service make a city very prosperous from a governance point of view. The development of a Smart Lighting Service demonstrate the foresight of the public administration because of the attention paid to the public safety and more over to the energy saving.

A smart government has a strategic vision of their own development and knows how to define the basis of this choices and courses of action, it is able to engage citizens in issues of public importance, to promote awareness-raising and use technologies to digitize and shorten procedures administrative.

4.4. SMART MOBILITY

The "Smart Mobility" dimension trace its roots on the local and international accessibility of the city taken into account, important is the use of the ICT for enabling smartness throughout the infrastructure. In this terms the Smart Lighting System is not relevant by itself, but because of the possibility to accommodate innovative technologies that can support the mobility system as will be shown in the next chapters when I will talk about the use of the sensors in order to allow innovative uses of the infrastructure.

4.5. SMART ENVIRONMENT

A smart city promotes sustainable development aiming at reducing the amount of waste and recycling, the reduction of greenhouse gas emissions by limiting the optimization of traffic and industrial emissions. These objectives can be added to the rationalization of the building and the consequent reduction of the impact of heating and air conditioning, the rationalization of public lighting, promotion, protection and management of urban green spaces and remediation of brownfield sites.

The "Smart Environment" dimension is the parameters that assess the quality of the city in the use of sustainable resources. The smartness from an environmental point of view is assessed by the quantity of pollution measured, regarding both the air and the sound, recently also the lighting pollution anyway was subjected to the study of many researchers because of the unhealthy condition that may cause. The Smart Lighting System may enter in this dimension in many ways, for instance, as stated before, the control of the lighting pollution is the first step for a lighting system to become smart. Then the control of the luminous flux for light-up the public spaces only when necessary, can save a lot of energy wasted and therefore a decrease of the CO_2 emissions. The use of sustainable material and technology moreover, is crucial because all devices have their life cycle, and if at the end their lead to an environmental pollution because of their tough disposal, even the technology that allows higher energy savings nullify such effects.

4.6. SMART LIVING

The last dimension of a smart city is the “Smart Living” characteristic that assess the quality of life of a city. This dimension is more related with the assessment of the quality of the primary service of a city like the health care system, the educational system, but also the assessment of proper quality such as the cultural activities, or rather the touristic attraction. Then important for this dimension is the individual safety of the people, and in this dimension, the Public Lighting System may enter affecting in a positive way the individual safety. In the Part III, we have seen how important an appropriate illumination in order to create perceived safety condition.

A smart city founds its growth on respect for its history and its identity; promotes its tourist image with an intelligent presence on the web; virtualizes their cultural heritage and traditions, and the returns on the network as the "common good" for its citizens and its visitors; uses advanced techniques to create paths and "mapping" issues of the city and to make them easily accessible.

5. SMART STREETS AND THE CONCEPT OF SMART LIGHTING

The branch of the smart city concept that regards the road system, go under the system of "Smart Street". The smart street is a system that lie on the public lighting network for "borrowing" his intelligent and multifunctional structure equipped with a various set of sensors that through advanced communication systems interact with an intelligent system that can track the activity profile of a network, collecting data that can support the decision making. The continuous collection of data, allow having an intelligent system on which activate an automatically adaptive regulation of the luminous flow.

A Public Lighting System is regulated for supply a higher lighting flow than the standard requirement recognized to a given area. Most of the street light produce a quantity of light higher by about the 30-35% (Annunziato et al., 2011) justified by the wear coefficient that decrease the functionality, and since , even at the end of life term, by law, a street light must guarantee a given standard, the lighting calculation are overestimated by the 35% more.

The street lighting as it stands today is a rigid and not adaptable system with the exception of those system that are remotely tele-managed point by point, this represent the first step for the realization of an integrated system.

The Public Lighting System of today the management system is never connected to detection system of environmental condition , and this means that the control strategy is defined in advance regardless whether the real supply of the service exceed or lack. On the first part of this thesis, I have presented how predetermine the lighting requirements of a given road starting from functional and morphological characteristics, but all that was as it is it was a static system at risk of obsolescence if not improved with something dynamic and adaptive.

The above-mentioned limits, has stimulated a set of research and initiatives for increase the efficiency of the public lighting system from an energy saving point of view. The possible improvements are various: on one hand we have the possibility to retrofit of the system – for instance through the use of LED technologies – on the other there are a new field that focuses on the management system that succeed in a rational, autonomous and adaptive way the lighting requirements of a given environment.

6. THE ARCHITECTURE OF THE SMART PUBLIC LIGHTING

In this chapter will be proposed the architecture for the responsive public lighting. In a first moment a set of assumption will be proposed, after which, a set of target will be delineated on which the entire development of the model is based.

6.1. ASSUMPTION

RE-THINKING THE LIGHTING SYSTEM IN A SMART KEY ADOPTING NEW TECHNOLOGIES

The lighting system as is conceived today, is static, the model presented in this thesis starts from the premises that, using new technologies, a lighting service can became smart

BLACK BOX AND REAL TIME ADAPTATION

The lighting project of a given territorial reality as explained in the part one, is connected to the functional and technical classes of the roads. Once established the classes the luminous flow of the streetlight is almost the same. The model developed in this parts starts from the idea that the management of a lighting system could became more dynamic, and in some way responsive in order to satisfy the demand in the different hours of the night.

THE ENVIRONMENTAL LIGHT CAN VARY ACCORDING TO SOME NATURAL CONDITIONS

The lighting system often can be perceived excessive or weak when given natural conditions occur. In-fact as will be afterwards explained, the presence of rain storms or snow, can vary respectively the twilight time and the lighting reflection due to the albedo effect

PASSIVE LIGHTING

The presence of commercial area that facing the roads can decrease the need of light due to the already existing of illumination of the commercial activities in front of the street.

LIGHTING SYSTEM AS AN INTEGRATED, SCALABLE AND IMPLEMENTABLE MODEL

The management of the lighting system nowadays, is a static model, the purpose of this thesis is that of developing an integrated model in order to taking into account different variables and being responsive in respect of the demand. A scalable system, in order to being able to accommodate not only the lighting system of a given zone of the city but also others, especially those outside the administrative boundaries. And finally an implementable model because the technology are changing continuously, and therefore the system should be adaptable to the new technologies.

6.2. TARGET

6.2.1. OPTIMIZING THE LIGHTING SUPPLY REACHING THE ENERGY SAVING

The main target of the construction of a Smart Lighting System is the achievement of savings in terms of energy consumption by the supplying of the light. The luminous flow during the night is almost the same, with some exception of reduction of the lighting flow turning off in an alternate way the streetlights. The matter of this pattern of supply is due to the fact that the decision of how much light-up and when is decided "a priori", according also to the technology that a lighting system have implemented. More or less advanced the nowadays system is not able to being responsive to a dynamic demand of light by the city users. The purpose of this thesis is to set up an architecture of lighting system that is able to supply and manage the luminous flow of the lighting system in a dynamic way, manage the luminous flow "on demand". Consequently, the power used for the lighting system is not the same during the night, and huge saving will be applied due to the decreasing demand of light during the dark hours. Anyway, the technology available nowadays are useful in order to build-up an integrated system that can support the management system in the decision of how much power apply to a given street light, or perhaps also manage an entire set of streetlights that take part of an entire neighbourhood that have a precise function[16].

6.2.2. OPTIMIZING THE MAINTENANCE SYSTEM

If the decrease of the supply of light due to the responsive system can lead to remarkable savings in the cost of the energy supply, there is another field of the public lighting that have high cost: the maintenance system. A good management in the maintenance system of the public lighting can lead to a twice save: firstly the decrease of the cost due to the ordinary maintenance, and, secondly, a scheduled maintenance contributes to the optimization of the efficiency of the streetlights. But this kind of maintenance can be already implemented in a standard lighting system, the purpose of this "architecture of smart public lighting" is to construct a model of Responsive Maintenance System. The difference is firstly in the diagnostics of the issues and fault detected; in fact, the faults can be detected and anticipated by the sensors installed on the lamp and this can bring to different effects. Firstly, the immediate detection make sure that the faults will be fixed as soon as possible, and secondly the detection of the faults can be implemented with other information about his localization – for minimize the time spent to find out the fault – and more information about the origins of the problem. This second information open to the possibility to fix the faults by remote. The possibility to check values like the stability of the electric voltage, the consumption of the single light sources, can suggest to the maintenance staff that something is going wrong, and anticipate the faults.

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[16] For instance, a predominance of the residential or industrial function, during the dark hours ask for less luminosity. For the road inside part of the city with a prevalent commercial function, instead, the pattern of the demand can vary and being more dynamic according to the needs of the users.

6.3. FROM THE BLACK BOX TO THE DESIGN

While the first part deal with the way in which the lighting project can be driven by a recognition of the lighting requirements, in a way that in this part could be called “a priori”. The importance of a lighting project is crucial in order to define the way in which a road should be lit-up to ensure condition of security to the users. However, at a given stage, the decision taken in the project should overcome or even worst lack the requirements during the discharge of the luminous flux due to some situation better explained in the next paragraphs in which the illumination value should be higher or lower.

For this reason, starting from the outcome of the first part, is reasonable hypothesize a system able to adapt the lighting supply to the small or big changing that affect the requirements of luminous flow. The twice target are firstly an on demand based supply of the luminous flow, and so an adaptive lighting system, and secondly the decrease of the energy waste because of the not required light.

6.4. THE ARCHITECTURE OF A RESPONSIVE PUBLIC LIGHTING MODEL

The construction of responsive lighting systems starts from the technology and in particular those devices that can lead to the collection of information on which taking the right decisions about the control of the luminous flows and about the management of the maintenance of the system. Each part of the architecture developed is better explained in the next chapters, in this chapter, instead, I would better explain the general idea of the whole model.

The architecture developed reflect the naïve approach kept in the whole thesis with the consequents strength and weakness. In fact, while this kind of approach can lead to some unexpected results due to the different perspective from which a problem could be saw, the contents can be very weak because such inexperienced can override some specific limits and problems. In my opinion, often is useful to detach itself from a perspective accustomed to dealing with certain issues, and observe them in a more ingenuous way.

The technology nowadays allow us to override certain problems that few years ago would be insurmountable, for this reason I have tried to built-up a model where through the use of sensors and ICT, we are able to manage the public lighting in all its components.

The architecture, displayed in the Figure 6.1, starts from the individuation of a set of equipment that can be mounted on the street poles showing the main purposes. The information grasped are then elaborated in a data platform that constitute the basis on which the remote control management can take decisions.

Then I have decide to split the competences of the Remote Control Management in two parts, the first one related to the lighting supply and therefore the control of the luminous flow based on the real time requirements recognized using the information coming from the sensors. The second related to the maintenance system, structuring it in two parts, the scheduled maintenance and the targeted one. The part related with the more "smart" purpose of the model is the second one because is related with the use of technologies able to detect the faults on time and programming the quickly restore.

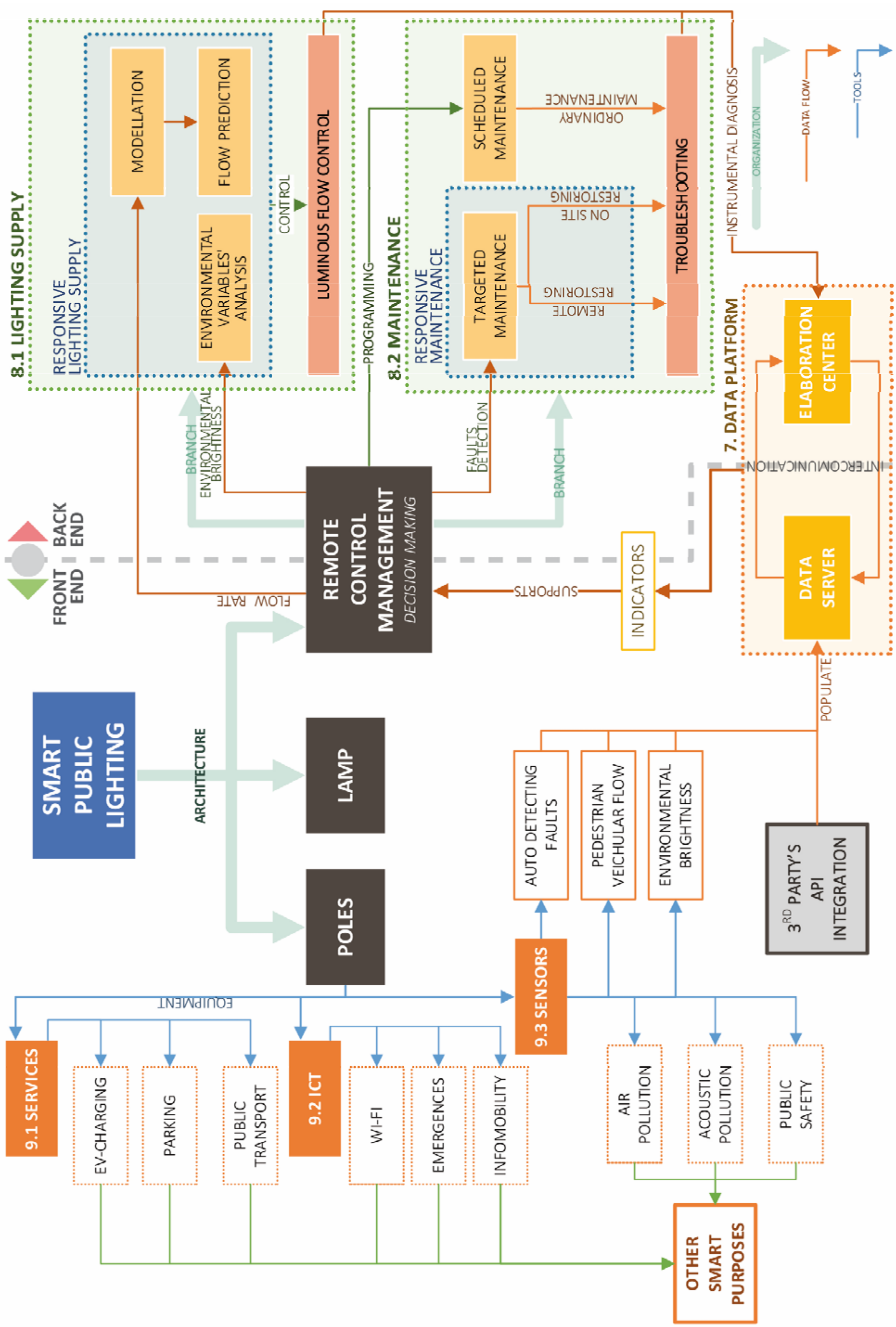

Figure 6.1 – Smart Lighting Architecture (Own elaboration)

7. THE DATA PLATFORM AND THE MANAGEMENT OF THE INFORMATION

7.1. GENERAL ISSUES

The lighting project starts from the classification of the roads according to their functional and technical class, and other information such as the capacity, the walkability, for make a lighting classification. This classification assigns to the roads the minimum requirements about the brightness to guarantee during the dark hours following the luminance and illuminance criteria. These values are then converted to luminous flow that the streetlight should have. Thus, the requirements that each road should satisfy is defined a priori regardless of whether the actual luminous flux is more or less close to the estimated requirements or if the supply of required lighting is actually guaranteed (undersized or oversized).

During the year round, or of the months, or even so more evident during the whole night, occurs events and phenomena that are relevant and affect the requirements of light increasing or decreasing the estimated value, causing a greater demand of light, or sometimes perceive the environment as over lighted. Consequently, this leads to two situation: on one hands, the lack of an adequate illumination can leads to perceive the urban environments as unsafety, on the other, the over lighting leads to an increment of the lighting pollution.

These phenomena, small or big that may be, constitutes a set of concerns that should be considered in order to achieve good results in term of energy saving and reduction of the light pollution and information about these could support the management of the luminous flows.

But the information required that should be stored and elaborated in the data platform in order to support the Management System, are those relative the fault and the incoherence that occur to the power supply. The detection of this kind of problems can lead to a real time response to the faults. In the next chapter will be presented the problems that can occur and how could be detected in order to reach savings also in this branch of the public lighting system.

7.2. SENSORS THE TECHNOLOGY AVAILABLE THAT ENABLE THE DETECTION OF ISSUES

The lighting poles are a stable unit that spread out in the city, actually, their function is only to elevate the height of the light to better light the street. If we re-think about their function, we could discover that there is something more than being a fixed structure. Different devices and services that can make the simple pole a smart pole could fulfil the iron-base structure. These devices can be simple sensors able to catch different information, or I.C.T. able to connect it to a large number of services. The possibility are several, from the management of the parking, information about the traffic, to the ability to communicate an emergency in a given position.

The devices that are able to grasp all the information briefly introduced before, are more or less complex hardware that ca be installed on the lighting poles. These devices thanks to their ability to catch information are called sensors. In the Smart city era, is common to talk about ICT devices that allow collecting a various kind of data, and sensors are part of those devices. Their function works with a linear communication with a platform that is able to grasp, store and elaborate the data coming from there. Clearly, the infrastructure designed should be capable to implement such technology, and for this reason I am arguing to a lighting system that has some requirements such as the integration, the scalability, and finally should allow a good implementation to other future technologies

7.3. THE NATURAL BRIGHTNESS DETECTION AND THE RESPONSIVE POWER SUPPLY

7.3.1. THE SITUATION IN WHICH THE BRIGHTNESS DETECTION CAN MAKE THE DIFFERENCE

The urban environment have different condition of natural brightness during the year, but the main changes happen during the night, in this paragraph are presented which are the main factors that affect the natural brightness , that one of which the streetlights are not responsible.

PASSIVE ILLUMINATION

The first one is what is called passive illumination, there some situation in which the building that face on the street have their own light turned on. This, sometimes makes even unnecessary the presence of a streetlight, but sometimes is not enough. So, which is the way for detecting the right situation? Do I lit-up or not? In addition, how do I lit up, or better, which is the right brightness?

THE NATURAL ILLUMINATION BY THE WHEATHER

The weather condition often affect the required luminosity according to the specific meteorological condition. First of all the presence of a particular climatic condition of a rainy day, can shift of minutes hours the precise time in which the light should be turned on. Assuming a given day where, in optimal condition, the turn on hours is fixed at half past six, the presence of a meteorological condition, as the rain is, that decrease the brightness during twilight, can anticipate this time by 30 to 45 minutes. The same for the sunrise, where the turn-off time can be postponed.

Another meteorological condition that can affect the brightness is the snow. Once fallen the snow, create a white coating that causes a light refraction called “albedo effect”. In the first part has been dealt with the problem of shifting from the illuminance value to the luminance with the use of a refraction coefficient that for the asphalt is fixed to 0,07, that means that only the 7% of the light is reflected due by the dark colour. The snow has a reflection factor between 0,9 in case of fresh snow, and 0,4 for the dirty snow. Anyway, this means that the reflection in case of snow can increase from five to twelve time during the snowy day, and these value increase definitely if the weather are cloudy and it creates a situation of counter reflection that causes a situation of daylight during the night. It is clear that during these hours the artificial brightness could be decrease up to the required environmental brightness value.

THE LUNAR CYCLES AND THE NATURAL BRIGHTNESS GIVEN BY THE MOONSHINE

The brightness due to the moonshine is irrelevant, without cloud and during the full moon phase, the environment illuminance is quantified in half LUX. Anyway should be underlined that some research in this direction should be carried-out, in my opinion a saving could be applied during those days, although in small quantities.

7.3.2. Environmental Brightness's Sensors

The last question is answered in the first part, each situation is modeled in a set of requirements defined in LUX, and for the other question, and there is clearly the need to know the situation that spread out in the city. For this purpose, we can use sensors that detect the environmental brightness. The values grasped should be compared with the values required in order to balance the lack or the plenty of brightness.

7.4. THE FLOWS DETECTION – HOW THE CITY IS MOVING

7.4.1. The information about the vehicular flows

The lighting system for the motorized roads is designed according to the capacity that has in term of vehicle per hour, this means that there is a close correlation between the traffic flow measured according to the maximum capacity, and the brightness that should be guaranteed. The difference between the lighting classes of relevance and the operating one is exactly what just stated. A lighting class can vary during the night according to the traffic flow. Anyway, now the traffic flow, as it stand, is not studied as should be. There is the need to go more in deep with the information elaborated. If we were able to collect the data about the traffic flow during the year, matching them whit the events that occur around the city, we would be able to model this information in pattern of flow tracking different profile for a given category of roads. In this way, we would be able to know during a precise moment of the year, a given road, in which kind profile we are in. Thus the roads can have also temporal information about the

7.4.2. The information about the pedestrian flows

Often, as we saw in the Part II, the sidewalks requires their own lighting system besides the lighting system of the streets. Because of that we can find streets that has sidewalks with their streetlights, those streets are the most crowded by the pedestrian that moves, for instance from the transportation system and their working places and vice versa. The flows are not homogeneous during the night, and because of that, we could control the luminous flow according to the actual pedestrian flow, in order to be responsive to a dynamic demand by the pedestrian. This could lead to high savings because in these parts of the city we could think even to turn-off the light and let the streetlight lit up the sidewalks. Moreover, the information about the pedestrian flows, could be matched with the environmental brightness in those streets that have a commercial vocation in order to adapt the luminous flows both according to the natural brightness and the pedestrian flow.

7.4.3. Sensors and detection of pedestrian and vehicular flow

Research about the vehicular flow founds that, during the nighttime only 3-4 hours are interested by an intense traffic, especially between the 5:30 PM to the 9 PM, while the other hours are characterized by a mobility that gradually decrease. During these hours with less traffic condition that there is the need to decrease also the luminous flux and optimize the lighting system for reaching huge saving. (Annunziato et al., 2011). Concerning the pedestrian flow, the modelling of the crowded hours is more difficult. The pedestrian movement is strictly related with the function inside a city. A presence of point of interest, such as a commercial street or a touristic zone connected with a good transportation system can increase a lot the movement also during the dark hours. In the next chapters will be proposed different kind of methods for catching the pedestrian flow with external information, anyway the movement inside a street can be measured with sensors that count the crowding rate. This could be connected with the video surveillance system that use cameras. The use of particular software able to count the people that are moving inside a road can contributes to the estimation of the pedestrian flow and creating the condition to modelling different pattern of flows and consequently adapting the luminous flux as much as necessary to increase the perception of safety. This is also true to the less crowded streets that low level of luminosity flux can make a space uncomfortable during the night.

7.5. THE FAULTS DETECTION – HOW CAN SUPPORT THE MAINTENANCE SYSTEM

The immediate fault detection can lead to several advantages that regards mainly the maintenance system, but also the energy saving because a fault detection system is able to detect also the energy loss due to the malfunction of some components of the system.

7.6. THE ELABORATION OF THE INFORMATION

The data platform inside the architecture of a Smart Lighting Model, is the beating heart that support the entire decision process. The information grasped from the Sensors are collected, stored and modelled, generating information able to support the decision-making. Basically, the data platform as it is conceived, is composed by a data base, where the different information are located in an integrated way, with clear relationship with the other data. The sensors through a complex system of telecommunication, direct the data collected in real time to the database. At the first step the information are pure, and as they stands are not useful to support the decision making. For this reason, there is the need inside the Data Platform to build up a system of indicator that will constitute the base of a decision process.

7.7. THIRD PARTY'S SERVICE INTEGRATION

The information that can support the decision-making about the management of the luminous flows can be collected, besides the integration of sensors, through the integration of services supplied by different third parties' such as social network companies or companies that deal with vehicular mobility . In computer programming, the integration of third parties application occurs through the API or application programming interface that specifies how some software components should interact with each other.

Nowadays the service that detect the flows both of pedestrian and vehicular are used by the majority of the people and the potential of information collected by these services are underestimated.

Nevertheless, how could be part of a lighting system these kind of services?

The Data Server introduced in the architecture, collect information that flows from the sensors, anyway this structure can be implemented with other kind of information, and the difference is the use of them. Taking the example of the city of Milan, the city user that constantly communicate through the social network are almost the majority of them. The data collected by the social network, are not only personal status and daily mood, but also localization and places most visited with the relative temporal information.

The information about the events that occur inside a city are relevant in order to match the information about the flow and the real time requirements, to what happen inside a city in a given moment. This could be useful mainly for the flows' modelling. Given amount of flows happens because in the city something happens, and for this reason is important to have stored in the data server information that can explain and anticipate in the future such amount of flow.

For instance, take the example of the "Salone del Mobile" it would be interesting analyse the flow of people during this events, especially because most of the micro-events happens after the sunsets.

These lasts information could take part to the set of data useful to support the decision-making, thanks to the real time information about the flow and the position of the city users.

The social networks often provide these information through the use of the APIs, and lately were published a lot of articles where, through the use of these service, were build-up a set of flow map that identifies the movements of the people inside a given city, and the place most used in given hours.

In the next table, I will resume the potential use of common services that use internet in order to put together the information. Is it possible to manage the luminous flow according to the information coming from such sources? It could be, but an experiment should be carried-out in order to better explore the potential of such service.

8. REMOTE CONTROL MANAGEMENT – THE SUPPORT OF THE DECISION MAKING

In the past chapter, we have talked about the data and the information relatives to the environmental brightness and the traffic flows. In particular we have underlined how they can be collected, and how they can be stored. Moreover, we have talk about how this information must be modelled in order to build-up indicators.

The further step is to understand how such information can be used in order to take some decision, and in a Smart Lighting Service, this function is dislocated in the Remote Control Management, that is the core where all is decided.

This important part of the Smart Lighting Architecture is a place wired with the entire system, able to check and control each part of them. Innovative hardware, ad hoc software and a working group able to interpret and use the information to take decision in terms of lighting compose this structure that is completely similar to a G.I.S. Structure[17].

In the model are individuated two big function of the lighting system, on one hand we have the control of the lighting system, and on the other one the management of the maintenance. In the first part of this thesis was underlined how a given road should be lit up according to different functional and physical characteristics of the roads, while in the first section of this part, has been pointed out how the maintenance, if not planned, can became very expensive for a public administration. Hence, given these premises, the Public Lighting Service, for becoming Smart, should supply light with an on-demand adaptation to the requirements, or for using a more appropriate term here and after named Responsive Lighting Supply. Furthermore, this service must pay attention also in his maintenance, therefore a scheduled maintenance is preferable for minimize their costs, and moreover, with the implementation of the sensors, the system should be able to anticipate the faults and warn out the Remote Control in order to fix the fault in a short time, or even better, if possible, fix the problem on remote.

8.1. THE RESPONSIVE LIGHTING SUPPLY AND THE LUMINOUS FLOW CONTROL

The luminous flow provided nowadays is predetermined by a project that according to given conditions, establish a given lighting category that has an illumination value to guarantee. This category during the night can change according to the fact that the road is not used in a homogeneous way. However, this is not enough, because the city is dynamic, and therefore we need a system that can easily meet the needs in given moment of the night. As said in the past chapters, there are some conditions in which the roads results over or under lighted, and therefore, we need to use the information about the environmental

[17] A G.I.S. is not just a software, but is a complex of, software, hardware and skilled stuff who manage geo-referenced data.

brightness and the actual flows rate, in order to meet the needs of the users in the different moments of the night.

Currently some researcher are developing innovative technology that overcome the limits of the actual technology, and that will lead to a responsive lighting system that sees on the "smart poles" – able to integrate smart services and ICT- the key elements.

The responsive lighting system, based on the "on-demand" concept, need a system of control and monitoring of the flows both pedestrian and vehicular, and sensors able to detect the environmental brightness at given time in order to better adapting the supply with a diversified demand.

The control system could be implemented with system of real time elaboration of the demand, and using an optimization system. If we would being able to acquire the capacity to modelling and predict the short-term evolution of requirements, it would be very possible to develop an adaptive system that evolves in time of application and generating information on the application of the same energy. In the Figure 8.1 is shown the process in which the luminous flow can be managed through the use of the previous information.

8.1.1. TECHNOLOGY AND TECHNICAL REQUIREMENTS

In order to achieve a good level of saving is useful to underline some general aspects regarding the technology adopted on the lighting system. The main parts of this system actually composed by streetlight, grouped and controlled by an ignition where the light are powered and controlled.

The technology available on the market for the management of the luminous flows, operates mainly on the turn-on and turn-off of the system, then operates also on the stabilization and the regulation of the luminous flows. In this section we will focus on the devices that can stabilize the luminous flow.

The light sources to work correctly maintaining their characteristics during the entire life cycle, must be powered by an operating voltage not higher than 5% of the nominal value. Often an increment of the operating voltage occurs especially when the consumers decrease their electric power consumption, and this happens during the night. The voltage fluctuations and over voltages especially, are extremely critical for all types of lamps, as they accelerate the aging by reducing both the duration, both the luminous flux emitted in time. A 10% overvoltage causes a drop in the average life of the lamps of up to 50% and an over consumption of 20%. For reaching life expectancy values, and luminous flows expected and declared by the manufacture, is necessary the voltage stabilization decreasing the ageing of the lamps and therefore the maintenance costs composed by the disposal and the substitution of the device. Hence, is possible to better planning the maintenance, reducing the intervention for the substitution and consequently decreasing the management costs.

The voltage stabilization fixes the tension to a given value on which is possible to vary the luminous flow emitted. More over the benefits of the stabilization is the saving on the energy consumption because of the cutting in the overloading of the system, and this saving is quantified up to 7%.

A luminous flux regulator starts following the ignition cycle of the lamps gradually reaching the nominal voltage value; the transition from the nominal regime and the reduced one, and vice versa, is always done gradually.

8.1.2. THE FLOW MEASUREMENT

The objective of this action is to exploit the low cost sensors installed on the smart poles, for extract the information useful on the environment. The first phase sees the acquisition of the data coming from the sensors located over a given area (a street or a plaza) and transmit such information on server dislocated in the data platform. The servers elaborates the information and supply value of the indicators that measures the entity of the flow. Such values are useful for the construction of a responsive model of the lighting system. The subsequent step is the modelling, or reconstruct with the data grasped a set of pattern of flows that occur during given time of the night in relation also with occasional events, if any correlation can be found, that affect the traffic flow. In this way the model, know in advance, in given moment of the day and of the year what will be the traffic in the next hours. This model, which in some way could be named as self-learning model, should be always compared with the data that continuously flow in to the data server, for applying correction and reducing the probability of error.

The model generates the prediction of the lighting requirements in the near future and generate these information to a control system on which will channel also the information coming from the environmental variables and from the instrumental diagnosis. The diagnosis identify any abnormal situation exploiting the information on the actual flow rate and those predicted by the model.

In order to determinates the power to supply to the streetlight is necessary known, besides the potential traffic flows, also the environmental condition, regarding both the brightness and the weather, an finally the lamp condition[18]

8.1.3. THE ENVIRONMENTAL ADAPTATION

The objective of this action is to grasp the information about the environmental brightness in order to adapt the luminous flow to the real requirements in a given moment. The information grasped by sensors scattered in the roads detect the brightness in a given moment and transforms this information in data stored in the data server. Afterwards these data are elaborated and compared with the data about the flow that have inside the ideal requirements in terms of luminous flow according to the rate of the flow. If the

[18] *A worn lamp ask for more power for having the same brightness of the other new lamp*

actual environmental brightness is less than this requirements the interested light receive a command to increase their luminous flow as much as necessary, on the contrary, if the actual brightness is more than the requirements, the luminous flow will be decreased.

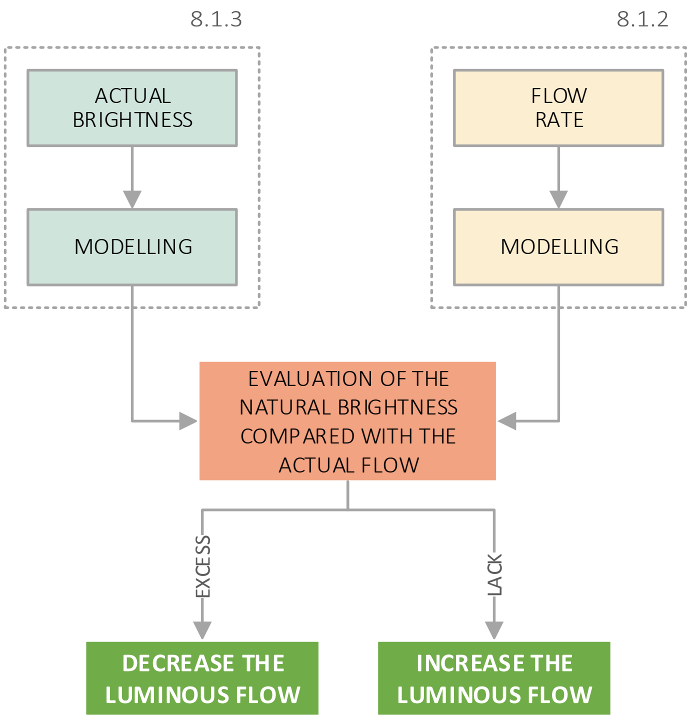

Figure 8.1 – Adaptation of the lighting flow evaluating the environmental brightness and the flow rate (Own elaboration)

8.2. THE RESPONSIVE LIGHTING MAINTENANCE AND THE FAST-PROBLEM-SOLVING

The maintenance costs are difficult to quantify, especially if there is no maintenance program. In this case, the maintenance is often left to the single ad-hoc intervention and this clearly raise up the costs.

A responsive lighting system, would not only lead to advantages of a remote controlled lighting system, but would allow the customized management of the public lighting service, allowing remarkable savings both on the energy consumption and on the maintenance service, thanks to the waste elimination on the central hours of the night and the reduction in the intervention on site of the technical staff.

In the meanwhile a responsive lighting system, would supply useful information for the management, measuring the actual yield of the components mounted and monitoring the maintenance evaluating the efficacy of the intervention. Would guarantee, moreover, a higher security, anticipating dangerous situation, in short a high level of quality service, with the reduction of the complaint and of the response time, and higher environmental protection, decreasing the wasting of the faulting lamps, decreasing in the lighting pollution and consequently a lower gas emission.

8.2.1. Scheduled maintenance

"Cielobuio", in one of his researches, in attempt to comparing the maintenance cost of the actual lighting sources with the maintenance of lighting sources with LED technology, have quantified the mean costs of the maintenance, identifying three scenarios. The first one is the maintenance cost with the scheduled maintenance, the second one is the maintenance ad-hoc- the maintenance that is done only when needed buying the light in stock[19]- and a third scenario with the hypothesis of an ad-hoc maintenance applying the cost of light using the price list of a big Italian vendor.

For the first scenario the costs are quantified in ten €/year, while in the second scenario, the costs raises to 15-20€/year while for the last scenario the costs raises even to 65€ per year[20].

Moreover, the efficiency not depends only by the light source, but also by the efficiency of the lamp that should be maintained efficient on time, otherwise the illuminance and luminance values of project will not be guaranteed. The UNI 11248, oblige the presence of a maintenance program for preserve the project values, and because of that, at least each 4-5 years it's necessary clean the glass of the lamp, both for the traditional and for the LED lamp. Economically speaking this means at least five €/years. (Cielobuio, 2008)

In a Smart Public Lighting services the maintenance is programmed with a precise schedule of intervention. But this is not enough, because in order to optimizes the costs, the information about the maintenance are useful to evaluate the performance of the maintenance system, and evaluate if in given zones the street light are more are subject to wear. The information grasped are all-useful in order to re-modulating the scheduling.

8.2.2. Targeted maintenance

The sensors mounted on the light, could be even capable to predict the expiring time of a given light. If we know that, a worn light ask for more power, the abnormal drop of the efficacy ratio (power used for each lumen emitted) could be a useful indicator for anticipate this kind of fault and anticipating the maintenance for a given light.

Nevertheless, this is not even enough, because the exit of the technical staff to fixing the fault detected have costs. Those costs could be reduced if the problem is individuated in advance. For instance, how many times the technical staff go out and spent the half of time just to understand where is the fault? Well, in a predictive maintenance service of a Smart Public Lighting, the fault could individuated and localized in

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[19] Is useful to remember there that in this scenario will not be applied economy of scale useful to achieve a good saving in the purchase of the light needed to the maintenance. The optimization of the purchase, can lead to huge saving that anyway for a short-sighted administrator the high initial costs are seen too big.

[20] All the costs are quantified for the substitution of one lamp

advance, and perhaps the problem could be solvable by remote where the fault is detected. Anyway could happened that the fault could not be recognized by the system, in this case can be implemented a service, for instance a mobile application, for reporting problems by the citizens, this application can be developed ad-hoc for the lighting system or even better could be part of a bigger service that includes other services regarding the public administration. The central core of the problem is the individuation of the problem, or even better the anticipation of that, could lead to further savings in the expenditure for the maintenance system.

8.3. CONSIDERATION ABOUT THE COST AND THE BENEFITS

The dark side of a smart service with such technologies, would certainly to an increment of the costs, but not so much as we could think inasmuch the useful sensors have a low cost and the Intelligence have really inconsiderable costs in the replication and scalability of the process. Nevertheless, such costs are relatively low if we consider the increment of the savings. This increment can swinging from a further 10% to a further 40% according to the technology compared with. (Annunziato et al., 2011)

Developing a responsive public lighting system would lay the basis for having a platform that enable advanced services and optimizing the existing services for the territory and the citizens. Moreover the new service would lead to a concept of wired territory that use the public lighting system as infrastructural element, without new cable and new excavation works that one by one affect the functionality of the roads and oh the same underservices with the added value of a diffuse net with the node easily localizable.

9. SMART SERVICES, INTERNET OF THING AND BIG DATA

The lampposts are an excellent support for sensors that collecting data and useful information. In the previous chapters, we saw how certain sensors might be able to collect information about vehicle and pedestrian flows. We have also seen that it is possible to collect information on faults in order to intervene as soon as possible.

In this section instead, we will deal with of technological solutions that make it possible to gather further information or even better provide other types of smart services. On the one hand, the lampposts can host new services such as electric vehicle charging, or be predisposed to pay the ticket of the parking or public transport. On the other hand, may be included other information and communication technologies such as introducing access point for the diffusion of municipal open Wi-Fi. Besides the street poles may be able to host additional sensors, besides those already mentioned that they become part of the management system of public lighting.

In the previous part, we saw how those data can indeed influence in a certain way the management of public lighting, but thinking about the system to a more large-scale, and adding sensors for detecting air quality and acoustics (to prevent the peaks of pollution) you may begin to think about a system able to collect so-called "Big Data".

The motivations for wanting to collect a range of information lies in the fact that the city, the bigger ones, nowadays constitute quite complex organisms, besides gather information on those who live them is one of the best ways to understand them. This obviously opens up discussion on the levels of privacy interpreting the territory as a big eye that monitors every single movement of citizens.

9.1. SMART SERVICES

9.1.1. EV-CHARGING

Large-scale deployment of electric vehicles (EVs) is anticipated in the near future. Heavy intermittent charging load of EVs will create bottlenecks in supplying capacity and expose power system to severe security risks. (Cao et al., 2012) One of the potential in terms of smart services is the implementation of the charging column for the electric vehicle. In order to implement these devices, standardized devices that take the energy from the same power supply of the streetlight compose the technology needed. Inside this device, that with the adequate filters supply the charging for the E-vehicle, should be implemented the possibility to pay with NFC technology, or just with the credit card. The distribution of these devices should be studied in order to have an adequate distribution and accessibility in the whole territory.

9.1.2. Parking payment

The streetlights localized in proximity of parking lots could accommodate devices that are able to pay the ticket for the parking payment without using other structure that ask for new connection.

9.1.3. E-ticketing system

Another interesting service that could be implemented is the possibility to buy the ticket for the transportation system. The localization of such services should be close to the railway station, to the bus stops and so on.

9.1.4. Emergences

An interesting service that could be implemented is the possibility to call a set of various emergency numbers in order to have a quick emergency response

9.1.5. Infomobility

With the term infomobility, we refer to the broad range of Intelligent Transport Systems (ITS) information services. The information about the vehicular traffic can guide the different drivers of the city to take different routes in order to avoid traffic jam. Moreover, the Infomobility service can inform the citizens about the public transport condition. A systemic approach is needed to foster the growth of novel solutions for the delivery of integrated real-time and always-on infomobility services, to be seamlessly provided across different transport operators, modes and geographical areas. (Giuli et al., 2011)

9.2. IMPLEMENTATION OF INFORMATION AND COMMUNICATION TECHNOLOGY

9.2.1. Open Wi-Fi

The urban Wi-Fi provides access to the Internet faster and more active in this area highly frequented crossroads because of passengers passing through the intermodal hub (train, tram, and bus) and characterized by the presence of a large school complex.

The implementation of the system of urban Wi-Fi allows you to access the services provided by the platform, allowing you to route a connection to the world intranet / internet also via the mobile devices tablets and smartphones.

The poles can accommodate also access point that are able to spread the internet connection through the Wi-Fi. The entire system of connection should be centralized and controlled by the municipality.

9.3. INTERNET OF THINGS, SENSORS AND BIG DATA

Internet of Things (here and after IoT) will comprise billions of devices that can sense, communicate, compute and potentially actuate. Data streams coming from these devices will challenge the traditional approaches to data management and contribute to the emerging paradigm of big data. Big data is not new concept or idea. However, earlier notions of big data was limited to few organizations such as Google, Yahoo, Microsoft, and European Organization for Nuclear Research (CERN). However, with recent developments in technologies such as sensors, computer hardware and the Cloud, the storage and processing power increase and the cost comes down rapidly. As a result, many sources (sensors, humans, applications) start generating data and organizations tend to store them for long time due to inexpensive storage and processing capabilities. Once that big data is stored, a number of challenges arise such as processing and analysing. Thus, big data has become a buzzword in industry.

Big data is important for us in many perspectives. The significant amount of data generated allows us to make decisions in timely manner where money can be saved and operations can be more optimized in both public and private. For example, in retail business, consumer behaviour and preferences can be understand by analysing the big data which includes, customer movement in the store or online webs site, transactions, product searches. Big data allows Data-Driven Decision Making (Zaslavsky et al., 2012).

Cities are moving with many complex dynamics that we should be able to catch in order to understand these process. The sensors in this terms can be useful to collect information useful to the decision making, and, at the urban level, the high amount of data that can be acquired by the spreading sensors all around the city should be managed through the elaboration of raw data and creation of reports able to explain the events, exactly as happens in the big firms.

In this section we will focus on few kind of sensors that can lead to acquire some useful information about the city.

9.3.1. AIR POLLUTION

The atmosphere is a complex natural gaseous system that is essential to support life on planet Earth. Stratospheric ozone depletion due to air pollution has long been recognized as a threat to human health as well as to the Earth's ecosystems. Air pollution risk is a function of the hazard of the pollutant and the exposure to that pollutant. Air pollution exposure can be expressed for an individual, for certain groups (e.g. neighbourhoods or children living in a county), or for entire populations. The health effects of air pollution have been subject to intense study in recent years. Exposure to pollutants such as airborne particulate matter and ozone has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular disease. These effects have been found in short-term studies, which relate day-to-day variations in air pollution and health, and long-term studies, which have followed cohorts of exposed individuals over time. (Brunekreef, Holgate, 2002) .Air pollution is a significant risk factor for a number of health conditions including respiratory infections, heart disease, COPD[21], stroke and lung cancer. The health effects caused by air pollution may include difficulty in breathing, wheezing, coughing, asthma and worsening of existing respiratory and cardiac conditions. The recognition of the pollutant that can affect the public health is crucial in the biggest city because of the number of citizens involved, and in order to take the right compensation measures for lowering the quantity of the pollutant.

9.3.2. Noise pollution

Noise pollution is the disturbing or excessive noise that may harm the activity or balance of human or animal life. Machines and transportation systems, motor vehicles, aircraft, and trains mainly cause the emission of most outdoor noise worldwide. Outdoor noise is summarized by the word environmental noise. Noise is a prominent feature of the environment including noise from transport, industry and neighbours. Exposure to transport noise disturbs sleep. Noise interferes in complex task performance, modifies social behaviour and causes annoyance. Studies of occupational and environmental noise exposure suggest an association with hypertension, whereas community studies show only weak relationships between noise and cardiovascular disease. Aircraft and road traffic noise exposure are associated with psychological symptoms but not with clinically defined psychiatric disorder. In children, chronic aircraft noise exposure impairs reading comprehension and long-term memory and may be associated with raised blood pressure. (Stansfeld, Matheson, 2003). The importance of a survey that assess the noise pollution is fundamental in a city that want to care about the health of its citizenship. The microphones scattered in the city, can be located over the light poles, and the data stored and elaborated with a GIS software able to put the data on the map and highlight the vulnerable areas.

9.3.3. Public safety and the tele surveillance

There is a potential use for images collected through the increasingly ubiquitous use of CCTV cameras in urban areas as a means of increasing understanding of the causes of road traffic accidents. Information on causation and contributory factors is essential as a means of understanding why accidents occurred and how the occurrence of similar events may be prevented in the future. CCTV records of accidents could provide an independent perspective on an accident and have the potential to increase both the quality and quantity of information available to the safety researcher.(Conche, Tight, 2006). The existing theoretical literature has tended to explain the resort to CCTV in the context of disciplinary subjection. Whereas one set of studies explains CCTV surveillance using the metaphor of panopticon, more recent argumentation has identified CCTV as a social ordering strategy.(Hier, 2004)

[21] Chronic obstructive pulmonary disease (COPD), also known as chronic obstructive lung disease (COLD), and chronic obstructive airway disease (COAD) is a type of obstructive lung disease characterized by chronically poor airflow.

PART V
CONCLUSIONS

1. SUMMARY

The general purpose of this thesis was to investigating on the Urban Public lighting as a part of a bigger and ambitious research effort about the investigation of the urban consumption taken place at the "Laboratorio di Simulazione Urbana Fausto Curti" at Politecnico di Milano. The intention was to integrate a thesis carried out by another student that has assessed the consumption of the built environment (Bignardi, 2013), and in order to achieve this objective, there was the need to evaluate other forms of consumption such as that of the public lighting. Given the first experience in the field of the public lighting and in particular in the field of the illuminating engineering the entire construction of the thesis has kept a naïve approach.

The specific object of this thesis focuses on some assessment regarding the public lighting and the role of the urban planner. Only recently, the topic of public lighting has raised the attention of the public administration becoming a priority after the large number of researches that underlines the potential saving in terms of energy consumption, which a forward-looking design and management of this infrastructure can lead. On one hand, there was the need to explore the regulatory framework and acquire notions connected to the lighting engineering in order to build a model that was able to assess firstly the light requirements of the public spaces, and then to evaluate the resulting energy consumptions. The results achieved afterwards were validated with real data coming from survey highlighting the accuracy of the methodology in the calculation.

In the thesis, was also carried out some experimental explorations trying to link the perceptive dimension of urban space and the public lighting. The goal was to looking for clues that may suggest methods to enlighten the public space using tools that nowadays are available which allow analyzing the public space from the point of view of perception. Several studies conducted over the years have demonstrated a close correlation between the indicators and the resulting increase or decrease of pedestrian flows. The outcome of this part was a set of analysis of indicators with further possible research insight.

In the final part, instead, was proposed a model that would meet the concerns about the cost of maintenance and management of a lighting system. The outcome of this part was the development of an architecture for a Responsive lighting system. The model was built on order to reach two main target: on one hand the optimization of the lighting supply with the purpose of reaching energy savings, on the other the optimization of the maintenance system. The construction of responsive lighting systems starts from the technology and in particular those devices that can lead to the collection of information on which taking the right decisions about the control of the luminous flows and about the management of the maintenance of the system.

2. THE URBAN PLANNERS AND HIS ROLE IN THE PUBLIC LIGHTINGS

2.1. THE ROLE IN THE LIGHTING DESIGN AND THE CITY PLANNING

The lighting design, in the detail remains a very important task to be assigned in the hands of experts in lighting design. In fact, values such as horizontal luminance, illuminance and are easily managed, however, when the project concerns the vertical illuminance or even semi-cylindrical become unmanageable at large areas. The Urban Planner, however, can come in two phases: the first one, certainly within its competence, in the design phase of the city and functions established, the second, at the time of the lighting project, can enter the vision of giving city that others can overshadow.

Urban planning, has obligations well defined. The city is like a machine in which each of its components conduct their tasks in specific fields. These tasks contribute to the optimal functioning of the machine and determine especially consumption: a machine that does not work well will surely lead to higher expenditures. The use of this metaphor, which in itself may seem trivial, conceals a more complex discourse that regards the functions within the city are distributed usually dictated by economic principles of accessibility and thus differential rent.

The choice to allow specific functions that are actually incompatible with the territory determines often negative effects on several aspects. Within this thesis the negative effects taken into account concerning the design and management of public lighting. The presence of certain functions during the dark hours that attract pedestrian or vehicular flows, contribute to the need of light itself. These functions should be located in areas compatible, or at least in areas where the illuminations are already calibrated for similar functions. For instance, a purely residential area in the evening, will require light flows necessary to create conditions of safety for pedestrians as they move along the roads to suit the particular needs of their function, such as evening walks to lead to walking the dog, and so on.

If we suppose to partially change the function of these areas with activities that attract external population, the increase in flows will require higher lighting requirements. The mechanism itself is much more complex, of course, you will encounter situations of promiscuity where citizens have already entered the general metabolism of the neighborhood that hosts them. It is unthinkable that all at once in a rigid way classify the different parts of the city and adjust accordingly with the lighting, here comes the expert lighting that is able to study solutions appropriate to meet the diverse functions that divide the public space. My attention, however, is placed on the fact that when is designed the city, it is important to think about the functions established as changing urban space during the evening.

Nonetheless there are not only aspects of the energy savings to be affected from a rationalization of the functions established compatibly to the city's context, but there are also aspects related to the health of human beings who are worthy of note. For instance the compact city and transit oriented developments

(TODs) aim at creating more walkable cities: this requires designing attractive and vibrant urban spaces, whereby public lighting plays a crucial role in providing safer places. In other words, promoting walkability and sustainable mobility modes means to facilitate people to transit from one mode to the other within a safe and attractive space. Hence, according to these conclusions the planner is ask to decide where to design better and comfortable lighting deciding therefore which parts of the cities are candidates to become local TOD nodes or rather where locate more residential area.

Another relevant aspect regarding the public illumination that the planner must be able to ensure is that one connected to the public safety. If, on one hand, the energy saving is guaranteed also through the decrease of the luminous flow this may affect, on the other, the decrease of the safety perception by the citizens as well. As presented in the part III, there is a strong correlation between the safety perception and the brightness of the roads, therefore the planner should be able to manage situation where the safety is missing, deciding where and when improve the brightness of the roads. This rightly looks like a scale, where improving one aspect it worsens another, surely the decision to be taken must always be preponderant at the highest priority in this case is the safety of the citizens.

2.2. THE URBAN PLANNER IN THE MANAGEMENT PROCESS

The issue of public lighting design plays a secondary role in the question of energy savings, but to make a difference, however, is the management part of the system itself, in its main components: the supply and control of the luminous flows, and the maintenance of the system itself and therefore the management of faults and inconsistencies in consumption.

We have seen how the planning of urban lighting as it is conceived today is a model too static, however, be interesting possibility for future implementations, with equally interesting implications in terms of energy savings, comfort and livability of the area itself.

From the point of view of the management of the light flows, calibrated on the basis of the demand in real time, it is important to identify a figure that is able to assess the flows (pedestrian or vehicular they may be) on the basis of the flow which has a specific road. Adequate study of these flows and the resulting calibration of the light flow can lead to substantial savings in terms of energy because the luminous flux can be reduced by 30 to 50% during the hours less used.

The urban planner can manage all the aspects that are related with the function and the accessibility. In particular the management of the land use, and the studies upon the urban activities over time. Moreover in terms of accessibility the planner is able to assess the capacity of streets in terms of vehicular and pedestrian flows. Given the strictly relation with the task argued in this thesis, these are all aspects that can help in the organization of the deployment of a public lighting service throughout his components, thus from the design to the management. Of course, the entire portion of the data stream, and technical aspects should be the responsibility of skilled industry insiders, but from the point of view of intelligence that lies behind of the decision-making process, or what data to process and use such indicators to decision support, they may be charged at a city planner who is able to keep that general view of the city that is missing when you look at the detail of the light sources.

Interesting, however, are the savings provided by an excellent maintenance scheduling system itself. Several studies, but also assessments on the financial statements of public administrations, show how poor planning of the maintenance of public lighting, leads in one hand to an increased consumption due to wear and tear of the equipment. On the other hand, maintenance done occasionally and only if strictly necessary, leading to an increase in costs for almost triple. This brings immediate savings, but in the long term result in huge costs.

The programming, as already mentioned in the previous paragraphs absolutely must be scheduled in order to organize the maintenance team and especially to organize the stocks of replacement parts that if purchased in the stock lead to substantial savings. In addition, it was also introduced how the use of certain sensors lead to even get information in advance of the event of the failure, ordering the immediate resolution of the problem remotely or on-site if necessary.

However the determination of the fault takes place in a preventive manner in order to have the awareness of how and where the fault has occurred, saving search time which now takes the most part of the whole time of the intervention.

The town planner, has the skills to take charge of this sector also, which is part of the public lighting, because the capacity from a programmatic point of view, temporal and locational, giving appropriate priority should be part of his skills and abilities, becoming mostly a figure of managerial and programmatic becoming part of a large sector of urban maintenance and management especially in the context of consolidated cites.

The management of place and time is crucial nowadays within the administration of public services, it is no longer possible to leave everything to chance and intervene only when needed necessary. In this way, operations that today are seen as routine and of secondary importance because they lead to high costs; enter into an integrated management system-monitoring-supply, optimizing time and resources as is the case in large private companies.

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ANNEX

"Nuovo codice della strada", decreto legisl. 30 aprile 1992 n. 285 e successive modificazioni.

TITOLO I - DISPOSIZIONI GENERALI

Art. 2. Definizione e classificazione delle strade.

1. Ai fini dell'applicazione delle norme del presente codice si definisce "strada" l'area ad uso pubblico destinata alla circolazione dei pedoni, dei veicoli e degli animali.

2. Le strade sono classificate, riguardo alle loro caratteristiche costruttive, tecniche e funzionali, nei seguenti tipi:

A - Autostrade;

B - Strade extraurbane principali;

C - Strade extraurbane secondarie;

D - Strade urbane di scorrimento;

E - Strade urbane di quartiere;

F - Strade locali;

F-bis. Itinerari ciclopedonali.

3. Le strade di cui al comma 2 devono avere le seguenti caratteristiche minime:

A - Autostrada: strada extraurbana o urbana a carreggiate indipendenti o separate da spartitraffico invalicabile, ciascuna con almeno due corsie di marcia, eventuale banchina pavimentata a sinistra e corsia di emergenza o banchina pavimentata a destra, priva di intersezioni a raso e di accessi privati, dotata di recinzione e di sistemi di assistenza all'utente lungo l'intero tracciato, riservata alla circolazione di talune categorie di veicoli a motore e contraddistinta da appositi segnali di inizio e fine. Deve essere attrezzata con apposite aree di servizio ed aree di parcheggio, entrambe con accessi dotati di corsie di decelerazione e di accelerazione.
B - Strada extraurbana principale: strada a carreggiate indipendenti o separate da spartitraffico invalicabile, ciascuna con almeno due corsie di marcia e banchina pavimentata a destra, priva di intersezioni a raso, con accessi alle proprietà laterali coordinati, contraddistinta dagli appositi segnali di inizio e fine, riservata alla

circolazione di talune categorie di veicoli a motore; per eventuali altre categorie di utenti devono essere previsti opportuni spazi. Deve essere attrezzata con apposite aree di servizio, che comprendano spazi per la sosta, con accessi dotati di corsie di decelerazione e di accelerazione.

C - Strada extraurbana secondaria: strada ad unica carreggiata con almeno una corsia per senso di marcia e banchine.

D - Strada urbana di scorrimento: strada a carreggiate indipendenti o separate da spartitraffico, ciascuna con almeno due corsie di marcia, ed una eventuale corsia riservata ai mezzi pubblici, banchina pavimentata a destra e marciapiedi, con le eventuali intersezioni a raso semaforizzate; per la sosta sono previste apposite aree o fasce laterali esterne alla carreggiata, entrambe con immissioni ed uscite concentrate.
E - Strada urbana di quartiere: strada ad unica carreggiata con almeno due corsie, banchine pavimentate e marciapiedi; per la sosta sono previste aree attrezzate con apposita corsia di manovra, esterna alla carreggiata.

F - Strada locale: strada urbana od extraurbana opportunamente sistemata ai fini di cui al comma 1 non facente parte degli altri tipi di strade.

F-bis. Itinerario ciclopedonale: strada locale, urbana, extraurbana o vicinale, destinata prevalentemente alla percorrenza pedonale e ciclabile e caratterizzata da una sicurezza intrinseca a tutela dell'utenza debole della strada.

4. È denominata "strada di servizio" la strada affiancata ad una strada principale (autostrada, strada extraurbana principale, strada urbana di scorrimento) avente la funzione di consentire la sosta ed il raggruppamento degli accessi dalle proprietà laterali alla strada principale e viceversa, nonché il movimento e le manovre dei veicoli non ammessi sulla strada principale stessa.

5. Per le esigenze di carattere amministrativo e con riferimento all'uso e alle tipologie dei collegamenti svolti, le strade, come classificate ai sensi del comma 2, si distinguono in strade "statali", "regionali", "provinciali", "comunali", secondo le indicazioni che seguono. Enti proprietari delle dette strade sono rispettivamente lo Stato, la regione, la provincia, il comune. Per le strade destinate esclusivamente al traffico militare e denominate "strade militari", ente proprietario è considerato il comando della regione militare territoriale.

6. Le strade extraurbane di cui al comma 2, lettere B, C ed F si distinguono in:

A - Statali, quando:

a) costituiscono le grandi direttrici del traffico nazionale;

b) congiungono la rete viabile principale dello Stato con quelle degli Stati limitrofi;

c) congiungono tra loro i capoluoghi di regione ovvero i capoluoghi di provincia situati in regioni diverse, ovvero costituiscono diretti ed importanti collegamenti tra strade statali;

d) allacciano alla rete delle strade statali i porti marittimi, gli aeroporti, i centri di particolare importanza industriale, turistica e climatica;

e) servono traffici interregionali o presentano particolare interesse per l'economia di vaste zone del territorio nazionale.

B - Regionali, quando allacciano i capoluoghi di provincia della stessa regione tra loro o con il capoluogo di regione ovvero allacciano i capoluoghi di provincia o i comuni con la rete statale se ciò sia particolarmente rilevante per ragioni di carattere industriale, commerciale, agricolo, turistico e climatico.

C - Provinciali, quando allacciano al capoluogo di provincia capoluoghi dei singoli comuni della rispettiva provincia o più capoluoghi di comuni tra loro ovvero quando allacciano alla rete statale o regionale i capoluoghi di comune, se ciò sia particolarmente rilevante per ragioni di carattere industriale, commerciale, agricolo, turistico e climatico.

D - Comunali, quando congiungono il capoluogo del comune con le sue frazioni o le frazioni fra loro, ovvero congiungono il capoluogo con la stazione ferroviaria, tranviaria o automobilistica, con un aeroporto o porto marittimo, lacuale o fluviale, con interporti o nodi di scambio intermodale o con le località che sono sede di essenziali servizi interessanti la collettività comunale. Ai fini del presente codice, le strade "vicinali" sono assimilate alle strade comunali.

7. Le strade urbane di cui al comma 2, lettere D, E e F, sono sempre comunali quando siano situate nell'interno dei centri abitati, eccettuati i tratti interni di strade statali, regionali o provinciali che attraversano centri abitati con popolazione non superiore a diecimila abitanti.

8. Il Ministero delle infrastrutture e dei trasporti, nel termine indicato dall'art. 13, comma 5, procede alla classificazione delle strade statali ai sensi del comma 5, seguendo i criteri di cui ai commi 5, 6 e 7, sentiti il Consiglio superiore dei lavori pubblici, il consiglio di amministrazione dell'Azienda nazionale autonoma per le strade statali, le regioni interessate, nei casi e con le modalità indicate dal regolamento. Le regioni, nel termine e con gli stessi criteri indicati, procedono, sentiti gli enti locali, alle classificazioni delle rimanenti strade ai sensi del comma 5. Le strade così classificate sono iscritte nell'archivio nazionale delle strade previsto dall'art. 226.

9. Quando le strade non corrispondono più all'uso e alle tipologie di collegamento previste sono declassificate dal Ministero delle infrastrutture e dei trasporti e dalle regioni, secondo le rispettive competenze, acquisiti i pareri indicati nel comma 8. I casi e la procedura per tale declassificazione sono indicati dal regolamento.

10. Le disposizioni di cui alla presente disciplina non modificano gli effetti del decreto del Presidente del Consiglio dei Ministri 10 agosto 1988, n. 377, emanato in attuazione della legge 8 luglio 1986, n. 349, in ordine all'individuazione delle opere sottoposte alla procedura di valutazione d'impatto ambientale.

TITOLO II - DELLA COSTRUZIONE E TUTELA DELLE STRADE

Capo I - COSTRUZIONE E TUTELA DELLE STRADE ED AREE PUBBLICHE

Art. 13. Norme per la costruzione e la gestione delle strade.

1. Il Ministro delle infrastrutture e dei trasporti, sentiti il Consiglio superiore dei lavori pubblici ed il Consiglio nazionale delle ricerche, emana entro un anno dalla entrata in vigore del presente codice, sulla base della classificazione di cui all'art. 2, le norme funzionali e geometriche per la costruzione, il controllo e il collaudo delle strade, dei relativi impianti e servizi ad eccezione di quelle di esclusivo uso militare. Le norme devono essere improntate alla sicurezza della circolazione di tutti gli utenti della strada, alla riduzione dell'inquinamento acustico ed atmosferico per la salvaguardia degli occupanti gli edifici adiacenti le strade ed al rispetto dell'ambiente e di immobili di notevole pregio architettonico o storico. Le norme che riguardano la riduzione dell'inquinamento acustico ed atmosferico sono emanate nel rispetto delle direttive e degli atti di indirizzo del Ministero dell'ambiente e della tutela del territorio, che viene richiesto di specifico concerto nei casi previsti dalla legge.

2. La deroga alle norme di cui al comma 1 è consentita solo per specifiche situazioni allorquando particolari condizioni locali, ambientali, paesaggistiche, archeologiche ed economiche non ne consentono il rispetto, sempre che sia assicurata la sicurezza stradale e siano comunque evitati inquinamenti. [1]

3. Le norme di cui al comma 1 sono aggiornate ogni tre anni.

4. Il Ministro delle infrastrutture e dei trasporti, entro due anni dalla entrata in vigore del presente codice, emana, con i criteri e le modalità di cui al comma 1, le norme per la classificazione delle strade esistenti in base alle caratteristiche costruttive, tecniche e funzionali di cui all'articolo 2, comma 2.

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[1] *Comma modificato dal decreto-legge n. 151/2003, conv. con legge n. 214 del 1° agosto 2003.*

4-bis. Le strade di nuova costruzione classificate ai sensi delle lettere C, D, E ed F del comma 2 dell'articolo 2 devono avere, per l'intero sviluppo, una pista ciclabile adiacente purché realizzata in conformità ai programmi pluriennali degli enti locali, salvo comprovati problemi di sicurezza. [2](2)

5. Gli enti proprietari delle strade devono classificare la loro rete entro un anno dalla emanazione delle norme di cui al comma 4. Gli stessi enti proprietari provvedono alla declassificazione delle strade di loro competenza, quando le stesse non possiedono più le caratteristiche costruttive, tecniche e funzionali di cui all'articolo 2, comma 2. Enti proprietari delle strade sono obbligati ad istituire e tenere aggiornati la cartografia, il catasto delle strade e le loro pertinenze secondo le modalità stabilite con apposito decreto che il Ministro delle infrastrutture e dei trasporti emana sentiti il Consiglio superiore dei lavori pubblici e il Consiglio nazionale delle ricerche. Nel catasto dovranno essere compresi anche gli impianti e i servizi permanenti connessi alle esigenze della circolazione stradale.

7. Gli enti proprietari delle strade sono tenuti ad effettuare rilevazioni del traffico per l'acquisizione di dati che abbiano validità temporale riferita all'anno nonché per adempiere agli obblighi assunti dall'Italia in sede internazionale.

8. Ai fini dell'attuazione delle incombenze di cui al presente articolo, l'Ispettorato generale per la circolazione e la sicurezza stradale, di cui all'art. 35, comma 3, ha il compito di acquisire i dati dell'intero territorio nazionale, elaborarli e pubblicizzarli annualmente, nonché comunicarli agli organismi internazionali. Detta struttura cura altresì che i vari enti ottemperino alle direttive, norme e tempi fissati nel presente articolo e nei relativi decreti.

[2] *Comma inserito dall'art. 10 legge 19 ottobre 1998 n. 366.*