Smart lighting in a historic context: a case study

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Received 17 June 2015
Revised 13 October 2015
21 December 2015
Accepted 2 February 2016

Abstract

Purpose – The purpose of this paper is to address a project for lighting an old town in Italy. Its originality lies in the holistic approach that aims to fulfil several objectives. One is to reduce energy consumption by using efficient lamps and advanced control systems; the second one is to make the network viable and useful for many purposes by integrating ICT devices; the third one is to provide a new identity to the older part of the city by using new technologies and design concepts; while the last one is to ensure street and pedestrian safety according to codes and standards.
Design/methodology/approach – The plan of the city of Bagheria and the stock of luminaires of the city are analysed. A multidisciplinary approach has been adopted in order to: analyse the existing lighting infrastructure highlighting critical areas; design a new displacement and select typologies of luminaires able to provide proper light quality and distribution; propose an aesthetic solution and technical design for relevant historical building; and to include in the design process the concept of a new multifunctional pole. Together with an analysis of social benefits, an assessment of economic costs and benefits are discussed.
Findings – The project allows good energy savings, meets the standard requirements and gives a relevant and strategic improvement in social and environmental management of the city.
Originality/value – The work provides an example of integrated design of street lighting infrastructures for urban renovation in old cities in degraded environments.

Keywords Smart cities, Historic context, Lighting design, Smart lighting, Street lighting, Urban lighting
Paper type Research paper

Nomenclature

CRI	colour rendering index
E_{avg}	average illuminance (lx)
L_{avg}	average luminance (cd/m^2)
TI	disability glare (%)

1. Introduction

This paper presents a research project aimed at investigating the role of a new multifunctional lighting system in Bagheria, a small historic city in the south of Italy.

Urban degradation (lack of infrastructure, maintenance, services, etc.) is linked to poor quality of life issues, such as traffic, pollution, noise, lack of information, long time to access focus points and lack of safety. Simultaneously, the enormous potential related to the magnificent historic heritage (world-unique ancient villas and gardens) is consequently underexploited. Tourist flows and paths are nearly random and difficult to navigate and are not supported by proper information. A new urban lighting system can help to overcome these obstacles. Moreover, such a project aims to provide a new identity and new light to ancient buildings to enhance tourism. In fact, through nightscape lighting projects, it will become possible to perform night tourism activities, such as night sightseeing, entertaining and enjoying night scenery (Qin *et al.*, 2011).

To achieve energy savings, more detailed research in the scientific literature has shown several intelligent lighting systems for domestic and non-domestic buildings (Miki *et al.*, 2006)

Management of Environmental Quality: An International Journal
Vol. 28 No. 2, 2017
pp. 282-298
© Emerald Publishing Limited
1477-7835
DOI 10.1108/MEQ-06-2015-0109

by adding lighting fixtures and sensors. It is possible to employ this system for the urban area case (Chunyu *et al.*, 2010).

The use of multifunctional lighting infrastructure is often associated with the concept of smart city. "Smart cities" has become a popular catchphrase to describe a city that wants to increase the quality of life of citizens, safety and energy savings with intelligent management, active citizen participation and ICT integration. Following this idea, it is necessary to study and research the technological solutions linked to a new type of intelligent technology integration based on an aggregation of modern and traditional functions and new concepts of living and use for the city. Additional features of new lighting infrastructures should be aimed to improve the quality of the urban environment and to support the rehabilitation of large parts of our cities. Many projects and initiatives were developed in cities and in particular initiatives about street lighting systems. In Paredes (P) (Paredes Smart City project wins World's Economic Forum Award – Portugal, 2011), by the end of 2015, according to the project "PlanIT Valley", thousands of sensors will be installed in the city to monitor urban lighting systems and garbage disposal with a "central electronic brain" and in the houses to monitor and manage heating systems and energy use. Turin (I) aims to reduce 40 per cent of the CO_2 emissions by 2020 thanks to an efficiency plan for buildings. Public administration wants to realise a wideband focus and digital services for people and business and to transform light poles into a "spread intelligence hub". There are many experiences around the world regarding smart city projects where lighting systems embedding additional functions are installed or planned, e.g. a Minos system (by Umpi elettronica) was installed in Barletta (I), Lisbon (P) and in Dubai (United Arab Emirates) (Adamson *et al.*, 2002). The system includes various functions and features: it provides traffic and weather information, has a charging point for electric vehicles, controls the lighting according to the traffic to reduce the light pollution and increase the lifetime of lamps and has also a Wi-Fi point. The Dibawatt system, designed by Sorgenia Menowatt, is an innovative electronic control system that improves lamp efficiency. It was installed in Castelsilano (KR) and Orta Nova (FG). This lighting control dimming system reduces the power consumption during selected hours. V-Pole, a system of light emitting diode (LED) lamps fuelled by an underground subway network and designed by Douglas Coupland, consists of a stack of small coloured cylinders that have various functions: a wireless charging station for electric cars, Wi-Fi access point and pole for telecommunications. Other typical elements of street structures have been rethought to provide services and information in an intelligent framework. In 18 points at the city boundary of Stockholm (S), a set of sensors for monitoring traffic flows was installed to implement smart traffic management. Smart Riviera is a project that uses a set of totems located in the city of Cesenatico (FC). It provides general information about, for example, emergency services, along with the remote management of public lighting, energy monitoring and video surveillance. In Eindhoven, the new smart lighting design "wants to make Eindhoven as comfortable as possible for every resident" as said the city's lighting project manager Rik van Stiphout. The new LED lighting system can be controlled and can be switched on and off depending on how busy the street is (if nobody is there, they dim, but as soon as a car, bike or pedestrian approaches, they turn themselves on and accompany the vehicle or person on his way). Here a Tvilight system has been adopted. Tvilight, a startup based in the Dutch university city of Groningen, offers similar light systems with dimming lights. In Sulbiate (I), 27 CitySoul Mini LEDGINE (by Philips) have been installed. Action has been conducted by Società Edison, as energy partner, and Philips Professional Lighting Solutions, as technology partner. They wanted to test a public lighting system with LED sources and remote control in different urban areas. The combination of the use of LED and a lighting asset management app allowed to achieve energy savings (50 per cent with LED and 30 per cent with control system) (Philips). In early 2013, a pilot project started is under way in Amsterdam, Leiden and Zaltbommel, to gain experience with the flexible switch system by Alliander. The Amsterdam pilot (in Osdorp, Nieuw-West) forms part of the Amsterdam Smart City programme. The tests in Amsterdam and Leiden involved placing 50 "smart" light masts, to try out the flexible switch system. Furthermore the next step of this project is to implement the smart streetlights on the Arena Boulevard and the entire area around the Amsterdam ArenA. (Smart Light, 2015). The light can be adjusted for a range of situations (e.g. according to the weather, traffic conditions and at pedestrian crossovers) via remote operation or sensors, helping to improve security and save energy.

Schréder, in collaboration with the city of Vilvoorde (Brussels), Eandis (gas and electricity supply) and Living Tomorrow (an innovative company) have designed and supplied a smart lighting system (Schréder).

It consists of Teceo 2 fixtures and Owlet control system and has been installed lining a 1 km long street, with cycle route. Luminous flux is knocked down to 15 per cent when there is no traffic. In front of the Living Tomorrow centre Neos Zebra LED fixtures, with white and amber LED, have been installed. When there are no pedestrians, only white ones are turned on at 15 percent. The SMARt lighTing, 2015 project, co-funded with the European Regional Development Fund and by the Italian Government (Research and Competitiveness programme 2007-2013), also focussed on intelligent control of urban lighting (Progetto SMART (SMARt lighTing) 2014). Its purpose is to design a multifunctional pole prototype with sensors and camera, which supply information on pedestrians and vehicular traffic and environmental light levels.

Similar outcomes are expected by the iNext project, also funded by the same institution.

These interesting examples do not provide evidences of actual installations of multifunctional lighting infrastructures in urban environment having a strong need of rehabilitation, such as, for example, many old towns in South Europe.

The authors have been inspired from these examples, each for a specific aspect (operating by remote control, touchscreen integration, sensors integration, app, light colour change, etc.) to conceive a "smart lighting network for urban rehabilitation and environmental sustainability" and a multifunctional pole with integrated design.

The paper is structured according to the multidisciplinary approach of the study. First of all, the city of Bagheria is described, highlighting its history, current status and future potential. An analysis of the existing lighting system is then provided accounting lamps typology, number, power and consumption, and assessing and highlighting criticism in providing illuminance performances for comfort, safety and aesthetic value to the point of interest. A first design approach is then discussed regarding the choice of lamp typologies and introducing the concept of a new luminaries design. By the way a description of the detailed lighting design for some sample streets is presented. Economic performances are then assessed and discussed. Last but not least the project of lighting the Historic Villas is proposed and discussed. Some considerations about the potential of this project on the way to implement a more sustainable and smarter city are presented.

2. The case study: Bagheria

Bagheria is a town near Palermo. During the eighteenth century, it was a holiday location for the nobility of Palermo, who lived in magnificent villas. In Figure 1, the urban development from 1700 to 2000 is shown.

The first developments built in Bagheria were Villa Butera and the houses for the staff that worked in the villa. Later, other nobles built their villas in the area. During the eighteenth and the nineteenth century, approximately 16 villas with gardens of great historic value were built. At this time, it was necessary to draw new roads to connect villas, other buildings and other roads. As time passed, the northern part of Bagheria expanded (1911) (Scaduto, 2007). Several important individuals, e.g. Goethe, visited the city and wrote about it. Furthermore, during the twenty-first century, several intellectuals and artists chose Bagheria as the setting of their work (film directors such as Roberto Benigni, Giuseppe Tornatore, Francis Ford Coppola and Alberto Lattuada; the writer Dacia Maraini; the photographer Ferdinando Scianna; and the

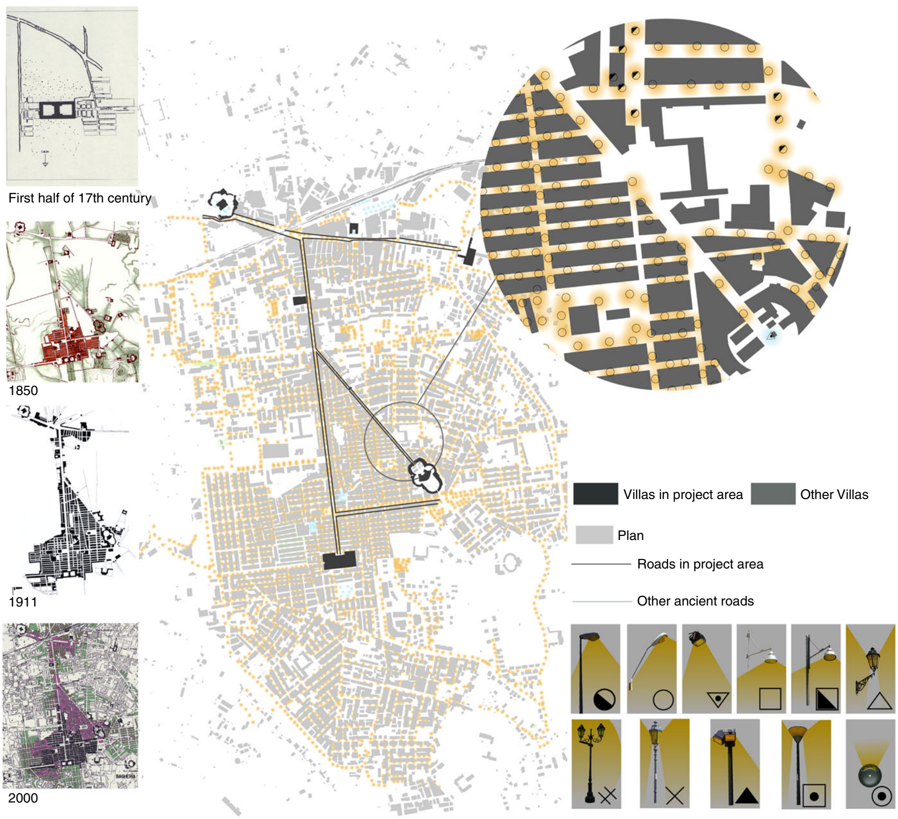

Figure 1.
Urban development of Bagheria from 1700 to 2000 and the plan with state-of-the-art lighting system of Bagheria (luminaires' typology and position) and the position of old roads, old villas and project area

painter Renato Guttuso). Today, Bagheria is a medium-large city with more than 70,000 inhabitants. New buildings, built during the last 40 years, obscured the structure of the original plan and are often of poor quality compared with the ancient buildings.

Moreover, today, the historic buildings are practically not illuminated. Visitors are not properly guided through a proper tourist path during the daytime or night-time. The development of a new public infrastructure, which will improve the quality of the urban environment, providing a recognisable guide to the city's key points and function as an organised set of active milestones, is the objective of this project. Although the main function of this infrastructure will be to improve public lighting (through the use of the best available technologies), it will provide additional functions to make the city smarter and sustainable.

This project is focussed on the valorisation of the main historic paths linking the system of villas.

The project is analysed from different points of view. First, all technical aspects related to the lighting and energy side will be approached. Subsequently, an analysis of the possible benefits related to smartness and sustainability improvements will be presented.

3. State-of-the-art of the lighting system of Bagheria

The urban area is analysed from multiple perspectives. For all considered streets, the survey is performed, considering the characteristics of the luminaries and lamps. The urban stock of the luminaires installed in Bagheria today consists of high-pressure sodium (96.5 per cent), metal halide (1.2 per cent), mercury-vapour (1.1 per cent) and fluorescent lamps (0.40 per cent). In the entire city, the lighting system comprises 6,526 luminaires, 54 switchboards and 45 luminous flux control systems. Narrowing the analysis to the project area, the number of luminaries is 312, and there are five switchboards equipped with luminous flux control systems.

Specifically, the types of the luminaires present in these areas are the following:

- older lampposts that do not offer good control of the luminous flux;
- installations on a pole with a projector system of a cut-off shield and a light fixture diffused for large urban and interurban lighting, which presents good control of the luminous flux through a cut-off control;
- floodlights with a flood optic installed on a pole or directly on the facade;
- recessed fitting lights recessed into the ground; the luminaires are provided with built-in electronic control gear screens that cover two-thirds of the floodlights to avoid glare;
- projector designed for metal halide with a street reflector compliant with the light pollution's strictest standards; and
- installations on a modern iron pole with similar problems of the old lantern.

Regarding the luminous flux control, during the early evening, the voltage is at its highest and is set at 220 V, and it decreases at 22:00 p.m. Overnight, the flux is lower and is set at 190 V. The voltage increases at 4:00 a.m.

In 2011, energy savings of 3 per cent was achieved thanks to the light control system application; it was applied in 45 switchboards (five in the project area). However, this type of luminous flux control is not sufficient to guarantee higher standards of energy savings.

In Figure 1, the lighting system distribution of the city of Bagheria is shown. This figure shows that many luminaries are not appropriate because the luminous flux is dissipated upward. Moreover, the lamps generally have a low colour rendering index (CRI) and weak luminous efficiency (Pulvirenti, 2001-2004).

Initially, a numerical analysis of the weakness of the existing lighting system was performed by consulting the lighting standard requirements. According to the national and European standards UNI 11248:2007 and UNI EN 13201-2, the roads are organised into categories based on speed limit and the use of these standards. The standards indicate the illuminance and luminance requirements for each type of road.

According to the standards, the installed lamps are not suitable for providing the appropriate luminance and illuminance values for many of the roads in the project area. This analysis was performed using the simulation software Dialux (Software DIALux, 2014). Simulations were performed for each combination of road class and lighting equipment along the main streets of the city.

Specifically, it has been highlighted that the luminaries (called "lanterns") that are very common in the old town are unfit because they disperse most of the luminous flux. Moreover, lanterns hold high-pressure sodium lamps and produce excessive luminance values on streets (Menga and Grattieri, 2009).

To assess the achievable energy savings related to street lighting, the authors have, for the first time, analysed the consumption data and electric performances of the existing equipment provided by the City of Bagheria's administration.

In the context corresponding to the main streets (project area), the analysis shows that the annual energy consumption is 133 284 kWh and that the installed power is 35.85 kW. Considering the energy consumption and installed power, the average yearly equivalent operating time in the central area is 3,720 hours with a peak of 4,660 hours ("Butera" switchboard) and a minimum of 2,730 hours ("Consolare" switchboard).

This survey highlighted the following issues: the unfit dimming systems, low efficiency lamps and fixtures, wrong distribution and orientation of lamps.

The current cost of the lighting service in the project areas was equal to €36,000 per year, including €16,000 per year in operation and maintenance (O&M) costs.

4. Designing a new lighting system for Bagheria

One of the aims of this project is to provide a new identity to the older part of the city by using new technologies and design concepts. The project for the new infrastructure adopts the most efficient lamps (e.g. LEDs) and control systems (dimmers) to reduce energy consumption and enhance the street and building lighting quality. Furthermore, by using a multifunctional street luminaire, it is also suitable for the integration of the ICT to make the network useful for many purposes.

The main drivers of the project refer to the needs to make the city "aestheticised", sustainable, recognisable, smart, safe and usable.

In a general way, light can be used as a building material, and it is a design object. The design of a light pole can be aesthetically pleasing both at night-time and in the daytime (e.g. the example *ante litteram* of the light pole/info panel/seat designed by Pere Faqués iUrpi Barcelona). Thanks to the multifunctional system, it is possible to not have too many objects in the pedestrian streets.

The city can be sustainable by the use of high-efficiency lamps and fixtures to protect the luminous flux, reflector, damper and efficient lamps.

In lighting monuments, it is necessary to use equipment with a luminous flux contained exclusively within the façades, e.g. through an asymmetric projector.

The city can be "smart" because a user can interact with the city and with the place where he lives. Thus, life in the city becomes better and easier, and users become "planners" of the city, in this case, through the control of Villas lighting (that can be set with different configurations).

The city can be safe by applying technical standards. Standard UNI13201-2 gives instructions regarding luminance and illuminance for different streets and road types.

Last but not least, the city can be "usable" because the city belongs to the citizen, and he lives in the city. A good light design in urban places, in squares and along streets promotes meeting and socialising, and enables the perception of the architectural context (Pulvirenti, 2001-2004).

5. StairLight: a concept of new multifunctional lighting fixture

These issues are considered at several levels during the design stage. The first stage in the process was to imagine a new fixture that provides additional functions versus typical lighting equipment.

A new multifunctional modular fixture (Figure 2), called the StairLight, is supposed to be utilised. Authors developed a design concept for a new fixture, including high-efficient LED sources and optics together with additional equipment. The idea is to make the StairLight able to embed ICT functionalities, including local data acquisition and transmission. Figure 2 shows the shape schema and a potential equipment installation and some possible StairLight configurations.

The sensors that could be installed with the system are designed, i.e. to gather several types of data: presence and activities of people, vehicular traffic, air quality, weather data and acoustic levels. These data can be utilised for many purposes: active control of traffic (traffic sign management, street closure, pollution monitoring and related traffic limitation policies), planning and real time management of public transport systems, street and sidewalk safety. It could also be equipped with smart screens to provide interactivity with users and tourists and with different sensors and monitoring devices.

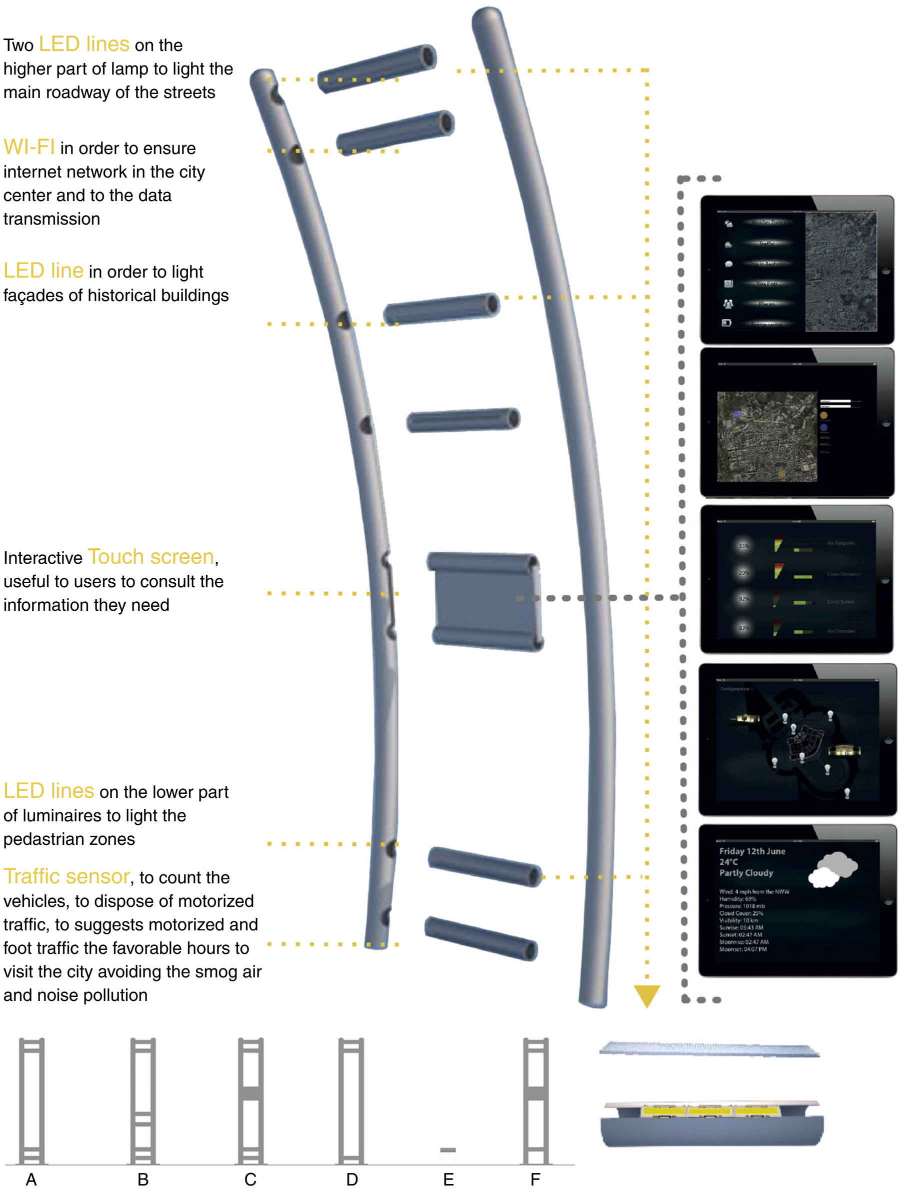

Figure 2.
StairLight, its additional features and its possible configurations

To do this, an app that could be installed, has been developed. In Figure 2, some screen shots of touchscreen are shown. The first one shows the home page with the main functions index:

- weather forecast;
- traffic information;
- stay in Bagheria;
- opinion poll;

- places; and
- energy savings.

Therefore, StairLight could provide information regarding weather conditions, cultural itineraries, historic notes, mobility networks (through installed traffic sensors that reveal traffic flux in several points of the city and send information to the pole using touchscreen), commercial information, emergency reports and alarms. The public administration, citizens and visitors can receive large benefits from the presence of this diffused "interface" with the city's area, i.e. using the function "opinion poll". Near the villas' entrance could be installed a StairLight with touchscreen in such a way that visitors can read historic and architectural villas information and choose one of the several lighting configurations (they are explained in more detail in Section 8).

In other words, StairLight represents a new light fixture concept to contribute not only to energy savings and light comfort issues, but also to safety, information and the satisfaction of the user. Thus, it represents a broader upgrade to the quality of the urban environment.

Apart from new flexibility, StairLight system is conceived in six different configurations, with three possible heights: 3, 6 and 9 m (Figure 2, Table I).

The lamp typology assumed to be mounted on StairLight is an LED, which was chosen for its good qualities, high achievable energy savings, lifetime of $>50{,}000$ hours, CRI of $\geqslant 96$, zero ultraviolet and infrared emissions, limited environmental impact, ability to be dimmed and instant-on switchability (Pacific Northwest National Laboratory, 2011).

Moreover, by selecting the red, green and blue sources in an LED configuration, it is possible to realise different light colours, which can also vary according to the environmental variables: e.g. the season (warmer during the winter season and colder during the summer season) and the actual use of the street (temporary pedestrian use).

Table I shows the possible characteristics of the light sources for each configuration of the fixture depending on the number of LEDs (Surface-Mount Technology, 780 lumen, 88 lm/W, 3,000 K, drive current 350 mA) installed on the horizontal bars.

The parts of StairLight that host the lamps are adjustable (tilt) to provide different possible lighting configurations and to direct the luminous flux and to limit light pollution.

Luminous performances of light fixture of StairLight have been assessed by using similar existing sources and optics as follows:

- light sources: n.3 Xicato XMS; and
- optics: Castaldi D49.

	A	B	C	D	E	F
Lighting and electrical data						
Number of LED sources	9	15	9	6	3	9
Total luminous flux (lumen)	7,020	11,700	7,020	4,680	2,340	7,020
Power consumption (W)	79.2	132	79.2	52.8	26.4	79.2
Possible colour temperature (K)	3,000					
Additional features						
LED lines (traffic)	✓	✓	✓	✓		✓
Wi-Fi		✓				
LED lines (facades)		✓				
Touchscreen			✓			✓
LED lines (pedestrian)	✓	✓	✓			
Traffic sensor	✓	✓	✓	✓		✓
LED lines (recessed fitting light)					✓	

Table I. Installed equipment in different StairLight configurations

For each street, the features of this fixture have been simulated at different heights and tilts in order to select the best configurations, which are shown in Figure 3.

6. The Design for street lighting

The design of the new lighting system is realised with a detailed analysis of the street scenarios using the DIALUX software to check for each street category and the fulfilment of the technical standard requirements either in the existing configuration or in the design scenario. Figure 3 shows some 3D false colour rendering and real colour rendering presentations with luminance and illuminance values related to the best obtained configurations and the sketches of ideas for the projects.

The project includes the replacement of 312 luminaires with 290 new StairLight (277 of A-type, 12 of C-type and 1 F-type) configurations along the main streets: "Corso Butera", "Corso Umberto", "via Consolare", "via Sant'Isidoro" and via "Palagonia".

Globally, the design installed power is equal to 32.00 kW.

As previously mentioned, the existing control system is based on a static voltage control during t night. From 0.00 to 5.00 a.m., the voltage is reduced to 67 per cent of the nominal value. The cumulative estimated energy savings (power reduction and existing voltage control) is 15 per cent, yielding an equivalent of approximately 3,800 operating hours per year.

If a reliable information network is built, an intelligent control system based on wireless or power line communication is possible. A lighting system can be operated according to the

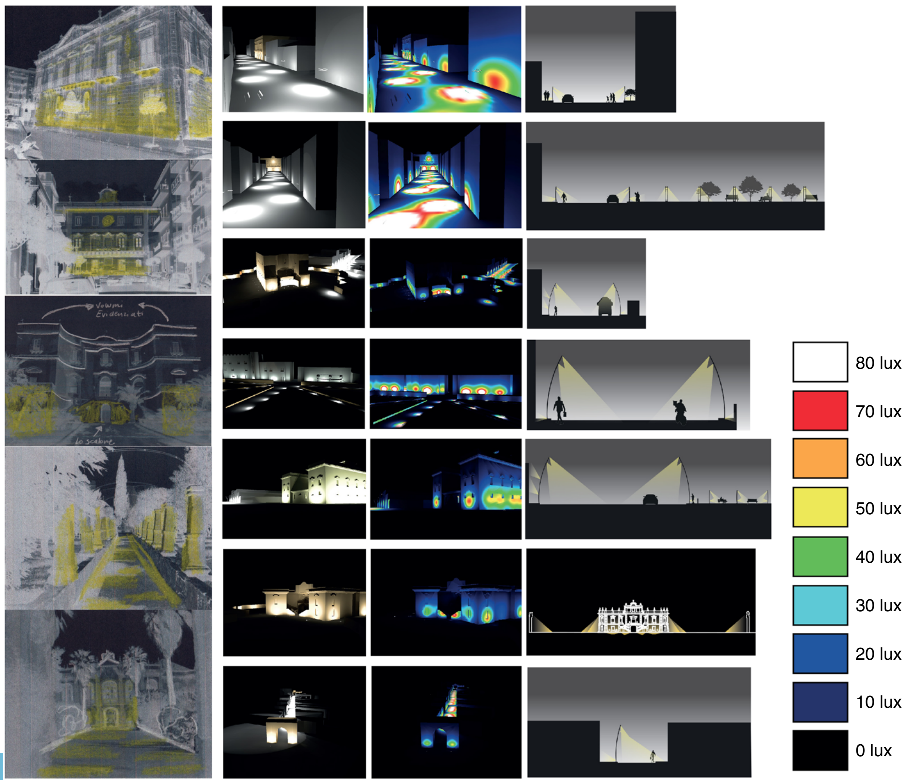

Figure 3.
Project 3D rendering for a false colour presentation and real colour rendering presentation with luminance and illuminance values and the sketches of ideas for the projects

lighting and environmental conditions. Each fixture can perceive several relevant characteristics, such as solar luminance or the presence or activities of vehicles and pedestrians (Elejoste *et al.*, 2012).

Obviously, a more efficient control system would allow additional energy and economic savings (Beccali *et al.*, 2015). For instance, a dynamic dimming system can reduce the equivalent operating hours by 3,000 hours (Miki *et al.*, 2006; Annunziato *et al.*, 2012). A "step-by-step" remote management system can decrease this parameter by 2,800 hours, while innovative smart strategies based on an adaptive method that processes traffic and pedestrian data can ensure a decrease of approximately 2,600 hours (Annunziato *et al.*, 2012). In these types of systems, the data collected by sensors (which can be mounted directly on StairLight) are processed by a remote system to develop a "customised" use profile for each luminaire (or group of luminaires). The aim is to improve the on–off cycle and flux control according to specific profiles, dramatically reducing the energy consumption (Mehmeldalp and Cengiz, 2006).

7. Energy and economic performances

An assessment of the yearly energy savings is performed by considering the energy consumption based on a reduction in installed power, the benefits of electronic dimmers on power control and the reduction of the equivalent hours of lighting.

It must be noted that although the installed power (and the energy consumption) of the new system is lower than that of the existing system, the two systems are not properly comparable. In fact, the new system is designed to guarantee the lighting standards on the road surfaces for which the existing system is not able to fit (Figure 4). For this reason, additional luminous flux and light distribution are provided by the system. Its cost is higher than the one that would have a new system having the same lighting performances as the existing system. Furthermore, it is necessary to note that the improved "aesthetic value" of the new luminaries and urban environment should be considered in a wider range of comparisons.

Despite these considerations, we performed an economic analysis of the project based on the calculation of the simple payback time (SPT), net present value (NPV) and actualised return time (ART).

According to these options, the yearly energy consumption of the design area can range from 120,000 MWh in the case of an LED installation with the existing "standard control" to 83,280 MWh in the case of a control system implementation based on a step-by-step adaptive model. The estimated energy savings is approximately 10 per cent in the first case and 38 per cent in the second case. Furthermore, it must be noted that this assessment includes the electric consumption of the additional equipment (displays, sensors, TVCC system, etc.).

The economic benefits of the project is derived from the reduction of the variable part of the energy costs, of the fixed cost related to the installed power and of the yearly O&M costs.

The first two items are assessed assuming a cost of €0.14 per kWh for the variable part and of €38 per kW per y for the fixed part. Additionally, yearly O&M costs were calculated as a function of the lamps' replacement rate, cost (including installation) and expected lifetime (variable for different operating hours). We have assumed that the average lifetime of the lamp in the existing system is about 8,000 hours which became equal to 60,000 hours in case of LED.

In the first stage, we fixed a target SPT of 5 years for the project. We calculated the correspondent target cost of the StairLight for the two lighting control scenarios. The investment cost includes the cost of the lamps, fixture (only for the lighting functionality) and dimming system and the installation costs.

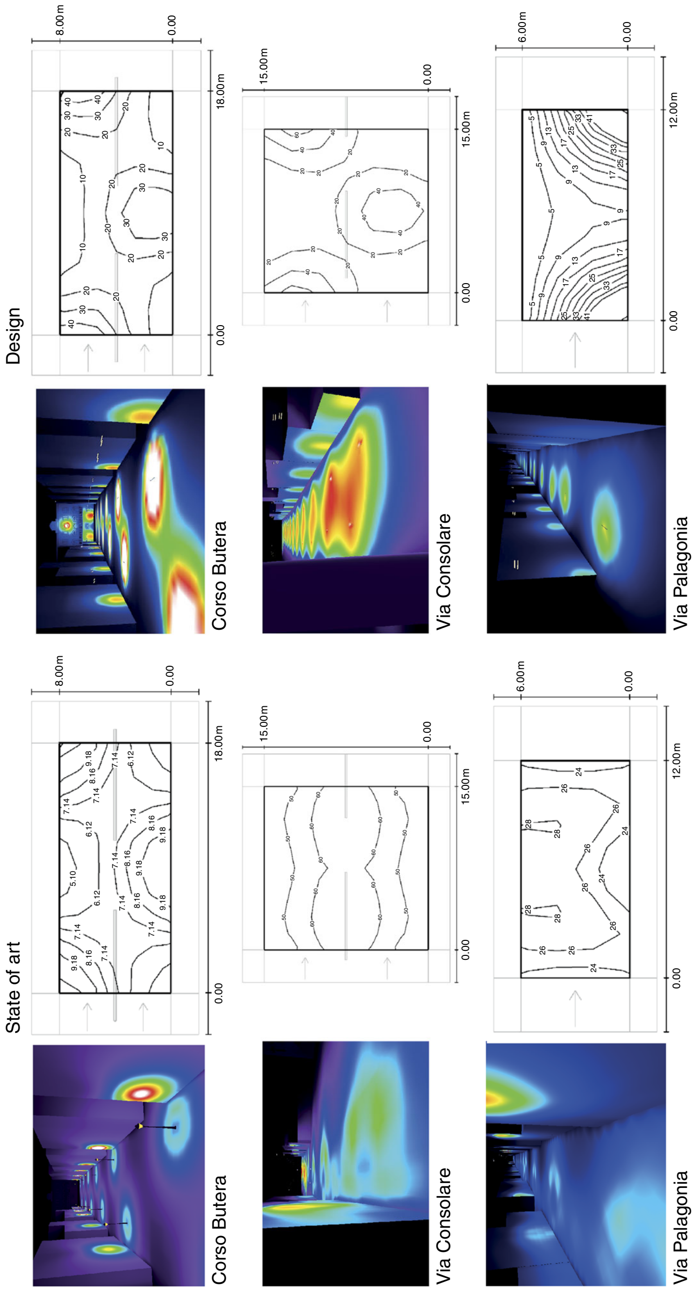

Figure 4.
Comparison between state-of-the-art and design light levels and distribution. 3D rendering in false colour rendering presentations and lux isolines on road surfaces

To achieve an SPT of 5 years, the cost of the StairLight (including the pro quota cost of the dimming system) must be equal to €400 in the case of the adaptive dimming system and €300 in the case of the standard system (due to the lower cost savings).

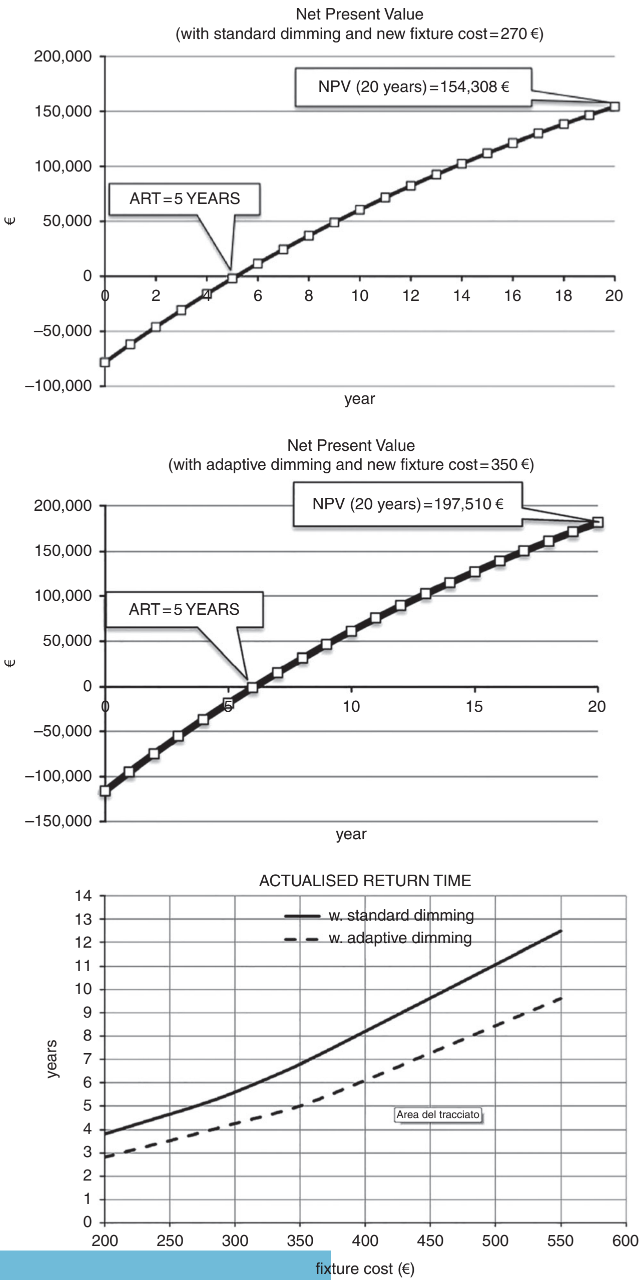

Figure 5.
Calculated cash flows, NPV and ART for two different system configurations together with the influence of fixture cost on ART

If we consider the actualised cash flow (ART) of the investment, assuming a net interest rate of 4 per cent, the unitary investment per StarLight, which makes the ART equal to 5 years, must be €350 in the case of the adaptive dimming system and €270 in the case of the standard system. Figure 5 shows NPV and ART calculations for the two configurations and how the ART is related to the StairLight cost in both the configurations and the influence of fixture cost on ART for the two different configurations.

Figures have been calculated for seeking a target price able to give an ART = 5 years.

The first assessment of the real cost of the StairLight was performed for a limited production (not considering any cost scale effect). It amounts to approximately €550, where 40 per cent is the cost of the structure and the rest is the cost of the lighting equipment. Thus, the cost is higher than the target figures. With these figures, the SPT and ART with the adaptive system will be 7.4 and 8.5 years and with the standard system will be 9.6 and 12.5 (see Figure 5).

A reduction of this cost could be possible in the low period for two main reasons: a large-scale production of the StairLight and an expected reduction in the cost of the LED.

8. The Villas' lighting design

The refurbishment lighting design also includes the villas of the city of Bagheria. Six villas were chosen as case studies. These systems are designed to improve the currently weak lighting of these buildings. The project represents a basic need to make the villas suitable for proper use by tourists and visitors. For these reasons, the energy consumption of these lighting systems is not compared with the energy consumption of the existing lamps.

8.1 Different configurations of the StairLight system were adopted

Specifically, six villas are chosen for project application. The villas are lighted with part of the StairLight, with the "rung" of the stair recessed into the ground and with an inclination that avoids flux dissipation. For all villas, an uplighting method is applied. This type of lighting can underline the architecture volume. Additionally, the user can see the villa from a different point of view and with a different look than at daytime with natural light.

Lamp dimming allows the lighting to be controlled based on the presence of citizens or visitors. Moreover, people can decide the configuration of light through the app installed. Thus, it is possible to choose different lighting configurations for each villa: exterior or interior lighting parts or more recent or older parts.

The concept of the design underlines the architecture of the building and the parts that compose it. In the case of Villa Cattolica, a greater luminous flux lights the lower part that is ahead. The secondary building surroundings (the chapel, the warehouses, etc.) are lighted, avoiding pointing the lights at the corners. The near Villa Cutò is characterised by an "introvert" architecture: the large stairs are inside and are not outside similar to those of other villas, and there is a courtyard. In this case, the main light is aimed inside the court, and the fixture is placed on the window sill to light the cornice as though the light is coming from the interior space. Villa San Cataldo was built over different centuries and periods. In fact, the building is composed of different body styles. This aspect is emphasised with the use of different temperatures of light. In fact, every body style is lighted by a different temperature of light: the body built in 1668 (the older) is lighted with a warmer light than the lights for the body built in 1933.

Different scenarios can alternate switching on or off for several sets of lamps. Therefore, visitors can distinguish between the different periods of construction.

Villa Inguaggiato and Villa Butera (the first villa built in Bagheria) are lighted by the uplighting (Mehmeldalp and Cengiz, 2006) mode only for the main façades because they are characterised by a simpler architecture than other villas. In the case of Villa Butera, the coat of arms and the clock on the façade are lighted with a spotlight. For the case of Palazzo Inguaggiato only, the yard is not lighted because the building is under private ownership.

For Villa Palagonia, the four towers placed on the corners are lighted with a higher luminous flux, similar to the convex main façade and the large stairs on the opposite façade, while the parts of the façades on the second level such as the two terraces or the parts between the towers are lighted with a shorter luminous flux. The buildings surrounding the chapel are lighted discontinuously only where there are surviving sculptures.

9. Further considerations about the potential benefits towards a sustainable and smart city development

Although the project refers to relevant energy saving objectives, it also provides through its "multifunctional" nature many potential contributions to improving urban quality and "smartness". A full implementation of such projects is not delimited by the boundaries of the energy theme. The project could encompass many aspects related to the progress of a city towards a sustainable and smart development scheme by increasing the quality of life and enhancing the exploitation of its potential in the tourism sector. Although energy saving targets are easily measured, other features are difficult to evaluate. Assessing the benefits of these additional features is not an easy task and is out of the scope of this paper.

Anyway, it is interesting to highlight in which way this kind of project can improve the quality of services and of the urban environment contributing to the so-called city smartness. This could be done through several indicators.

Nevertheless, an International and European agreement regarding smart city indicators has not been achieved because smartness is not always easily measured.

A lack of clarity has been detected in the way of describing what smart cities are, and some authors try to establish a methodology for urban policymakers to do so (Branchi *et al.*, 2015).

After a review of the state-of-the-art, Branchi *et al.* found that there are no existing systems for assessing smart city strategies regarding new, evolving technologies. They propose "a tool that evaluates new technologies according to a three-pronged scoring system that considers the impact on physical space, environmental issues and city residents".

Also Marsal-Llacuna *et al.* (2015) assert that reliable indicators and a summarising index for measuring "intelligent" cities do not yet exist, but interest in the initiative is growing, and it will not be long before the worlds of academia, business and government start to take notice (Marsal-Llacuna *et al.*, 2015).

Caragliu *et al.* (2009) also used the EU Urban Audit data set to analyse the factors that determine the performance of smart cities.

They found that among other factors, the attention to the urban environment, multimodal accessibility and use of ICTs for public administration are all positively correlated with urban smartness. A possible set of indicators were created using the Urban Audit Database, produced by the European Statistical Office (Eurostat) http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban) and organised into the following categories: Smart Economy, Smart Mobility, Smart Governance, Smart Living, Smart People and Smart Environment. A "smart city" is a city that performs well in all six categories. The IESE Cities in Motion Index (CIMI) (Berrone *et al.*, 2015; Barrionuevo *et al.*, 2012) seeks to evaluate cities as they relate to ten key dimensions: governance, urban planning, public management, technology, environment, international outreach, social cohesion, mobility and transport, human capital and economy.

A perspective that can be misleading in the selection of smart city indicators is to consider the smart city in a single way. The relationship between a smart city and human decisions is interconnected. It is now impossible to assert that there exists a difference between the objective and subjective indicators.

Another set of 18 smart city indicators have been proposed by Lazaroiu and Roscia (2012).

At any rate, it is clear that the impact of such the project in an urban environment for the City of Bagheria may not be easy to assess. Whether fully implemented, it could represent the first large-scale demonstration of a multifunctional infrastructure in south of Italy having by itself a relevant impact on the energy consumption for public lighting, quality of the lighting environment, traffic and pedestrian safety, support of citizen and visitor mobility, orientation and many other potential benefits that could stem from the use of in-field sensors, a communication network and central processing of information.

10. Conclusions

Giving new life to old town centres and achieving energy savings through good resource management and functional city planning are often presented as goals in the political and planning context. Additionally, the attention given to the "smart cities" concept has increased during the last several years. Many countries have already applied strategies to achieve the aim to be a "smart city". Suitable planning and control of an urban lighting system can have several advantages. In particular, this paper presents the design strategies for using a new lighting infrastructure for providing other services. The case study is Bagheria, a small town near Palermo (IT). The paper had four main objectives. The first one was to demonstrate that, through the use of efficient lamps and suitable fixtures and the exploitation of the ICT, it is possible to provide a new emphasis to the cultural and historic treasures of this city.

The results in terms of energy savings and economic performance are good, especially considering that the current lighting service is often weak and do not fulfil the technical luminance requirements. Further reduction of the investment cost is expected due to the LED cost trend and possible scale production of new fixtures. A reduction of approximately 38 per cent in energy consumption and variable cost is achievable. The economic performance is quite satisfactory.

Thus, the value of this type of project lies not only in these aspects but also in establishing a starting point towards the implementation of many other features typical of a "smart city". Concerning the goal of designing a future integration into a smart urban network, the study included the preliminary design of a new multifunctional light fixture.

Finally, the paper emphasised that a smarter lighting system can guarantee good standards of comfort and facilitate the use of the city, improve the quality of life for the citizens and avoid overillumination and light pollution. For these reasons, the project was developed for the most important touristic and social areas of the city today almost degraded and not properly exploited.

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