DOI: https://doi.org/10.38027/iccaua2023en0386

Lighting design for public spaces using innovative luminescent technologies

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Abstract
For several years, urban lighting has been regarded as a functional tool that can only guarantee safety and orientation for citizens. In addition to safety and light pollution, a phenomenon that has been at the centre of numerous debates for several years now, there is everything to do with saving energy and reducing the costs of urban lighting. Reducing even some of the considerable consumption of energy resources would benefit both economically and ecologically. Research led to the identification of space in the Abruzzo region. After analysing the park's current state, the question was asked: how can the garden be redeveloped by paying attention to ecological aspects and new technologies? The project aims to intervene in specific areas of the park to redevelop the context under analysis through new technologies, stimulating a new awareness of the lighting culture of spaces.
Keywords: Design, Lighting Design, Photoluminescence, Energy saving, Sustainability

1. Introduction

The habit of living in an atmosphere of spectacle, an overdose of lights, now inevitably influences the demand for technological tools capable of creating an environment laden with visual suggestions. The relative weight attributed to visual information is enormous and far exceeds the importance we attach to data perceived by other sensory means. Electric light, born to see in the dark, has, over time, acquired an increasing function as an emotional signal in domestic space and the collective rituals of urban space. We already know how light, which is never neutral, can shape the context in which it is inserted, open an environment to visual penetration, expand a volume, animate a space, and enable a visual experience beyond mere vision. The symbolic value of light becomes perceptible according to the cultural orientation of perception. An example is photoluminescence, which is part of this perception. That is, it possesses the ability to culturally direct signals of change. And not only is there much change but also a great need for it in the culture of light. Among the latest application experiments for photoluminescence is its contribution to energy saving. The light emitted by photoluminescence is not comparable to the light sources we are accustomed to; the type of 'glow' it produces is, however, well perceptible and effective enough to make spaces and volumes stand out in the dark. Whenever light can be modulated or only 'presence' light, photoluminescence can render excellent service, primarily since it works without consumption.
In understanding one's relationship to space, one needs to make sense of one's surroundings. Through mental processes related to individual experience, we recognise light's ability to familiarise us with our surroundings. Feeling comfortable in a place depends significantly on our relationship with light (Kelly & Neumann, 2010). It is our perception of the visible that enables us to understand and interact comfortably with what surrounds us, assuming, even unconsciously, well-being through the pleasure of being part of that place and appreciating its characteristics without effort: the "pleasantness" of liking and being liked (Alfarano & Spennato, 2018; Aziz Amen, 2017; Aziz Amen & Nia, 2018; Amen & Kuzovic, 2018; Amen & Nia, 2021). Today, the new relationship with designed light reappropriates the need to restore emotionality to environments by producing new attitudes and imaginary projections (Giannini et al., 2011) through the new sensitivities induced, above all by the new technical-executive possibilities, light returns to being, within the project, a construction material capable of modulating spaces, of creating fluid atmospheres, changeable relationships where materials regain depth, variable vibration, representation of the story of everyday sensorial living. A new culture of light is thus emerging in close relation to the evolution of the culture of penumbra. A culture in which the fullness of light dissolves and leaves room for the nuanced secularity of chiaroscuro values (Arielli, 2003).

2. Methodology

The research, studies and interests in the field of the sustainability of energy resources conducted in the Smart Lighting Design Laboratory of the University of Florence have developed applicative research on the new morphology to be given to lighting fixtures not only as alternative solutions but made it possible to reconsider the concept of "diversity" about the new technological-productive potential, above all cognitive (Thorndike, 2013) due to the application of the contaminating cultural references in circulation. The research undertaken in the academic sphere, the experimentation of new materials and new applications to obtain low-consumption light have highlighted the significant potential that can be obtained from the phenomenon of luminescence of new-generation performance materials. *Photoluminescence* is a specificity that has made it possible to explore and make feasible new stand-alone lamps with zero consumption.

3. The Concept of Photoluminescence

Before discussing photoluminescence, the concept of luminescence must be introduced; this is defined as the process by which a substance absorbs energy and then naturally emits radiation in the visible range. Light or thermal energy excites the electrons of a luminescent material, causing them to move from the valence band to the conduction band, where they remain confined. The input energy source can be either electrons or photons. The electrons excited during luminescence fall to the lowest energy levels. In some cases, the excited electrons can recombine with gaps. Suppose the emission occurs within 10s of the excitations. In that case, the luminescence is called fluorescence (fast decay), whereas if it occurs after 10s, it is called phosphorescence (decline that continues even after the sample has ceased to irradiate). Luminescence is produced by phosphors that can absorb radiation of high energy and low wavelengths and spontaneously emit radiation of lower energy and longer wavelengths. Adding impurities called activators industrially controls the emission spectrum of luminescent materials. Activators provide discrete energy levels in the energy range between the conduction band and the valence band of their host material. One of the mechanisms postulated for the phosphorescence process is that excited electrons are trapped in different ways at high energy levels and must escape from the 'traps' before they can fall to lower energy levels and emit light with a characteristic spectrum. The trapping process explains the delay in light emission by excited phosphors. Luminescence classifies several phenomena depending on the substance and the processes that produce the effect. The best-known are:

- Bioluminescence, in which biological processes involving enzymes are involved;
- Chemiluminescence, in which chemical reactions take part;
- Photoluminescence, in which electromagnetic radiation intervenes.

Photoluminescence, in turn, is differentiated based on energy emission. It can thus be classified as:

- Fluorescence if the excited electrons re-emit light that falls within the visible spectrum and ceases when the excitation source ceases;
- Phosphorescence if the phenomenon continues for a certain period even when the source of excitation ceases;
- Thermoluminescence is the phenomenon of light emission in the visible range due to the heating of the material.

Special attention must be paid to the distinction between Photoluminescence and Phosphorescence. The substantial difference lies in the reaction of the elements producing the luminous effect:

- Photoluminescence is attributed to the property of certain inorganic aluminates to retain a light, whether of natural origin (UV radiation) or artificial origin and to release it for a particular duration of time.
- Phosphorescence is attributed to a chemical reaction that lasts only a few minutes, and the phosphor that produces it is toxic and radioactive.

In this discussion, we will be interested in photoluminescence for its innovative aspect introduced by the most recent innovations in industrial production that have focused research on the ability of light to last. The latest generation of photoluminescent pigments, thanks to the use of two substances, Europium and Dysprosium, which increase the duration, can remain lit for eight to ten hours.

Using the new generation of pigments saves energy if you ask for presence light, not glare light. There are many cases where adequate direct lighting is not needed, but a position light, a light that we can define as 'presence' that gives the environment both inside and outside luminous evidence that defines the space with a dim but sufficient light to see in the dark. Photoluminescence, obtained from non-toxic natural minerals, absorbs daylight and returns it at night with the science of energy consumption thanks to the properties of the minerals in the pigments. This natural phenomenon helps to save energy and educate people to have a new relationship with the amount of illumination needed for adaptive vision in the dark. To overcome darkness, it is not always necessary to 'daylight' a driveway or garden. Consumption-free lighting, such as that easily achieved with photoluminescence, provides sufficient soft perception to offer a degree of brightness that makes spaces and places visible in the dark. It should be noted that any emission of light with energy is more potent than that emitted by photoluminescence, but this does not prevent it from being sufficiently visible in a place subject to darkness. The effect can be achieved for about eight hours: the light emitted is visible for the first 15-20 minutes, then gradually fades. After the first hour of maximum illumination, it loses brightness and stabilises for the rest of the seven hours of visibility. The ecological impact of this technology is evident from several vital elements. The effect is direct, i.e. dependent on the system itself, and indirect due to the resulting impact triggered. Significant energy savings are achieved by the structures (luminaires) and places of use. In private and public outdoor spaces, such as gardens, terraces, squares or pavements, swimming pools, fountains or shop windows, savings of up to 90 per cent of traditional electricity consumption are possible. Indirectly, however, photoluminescence impacts CO2 reduction because it requires no energy for its operation and contributes to energy savings by acting as an alternative to other shading systems. The eco-friendliness of the pigments, the unlimited lifespan and the absence of electricity for operation put photoluminescence at the disposal of a new light culture against overconsumption and light pollution and contribute to making the culture of eco-sustainability practically feasible (Alfarano & Spennato, 2022, p. 64).

Figure 1. Example of photoluminescence on the cycle path.

4. Applied Photoluminescence

Research on photoluminescence has sought answers on the amount of light emitted, intensity and duration, considering this a new resource for application. At the same time, the effort to research the advantages of photoluminescence has been focused on demonstrating how pigments could align more with international safety standards. The latest generation of photoluminescence, after the most advanced discoveries of materials that are no longer radioactive, although it has faced various applications with various techniques and in various materials for some years now, has only recently seen its applicability extended thanks to continuous research and experimentation (Alfarano & Spennato, 2018).

The Smart Lighting Design Lab has now achieved remarkable results by putting photoluminescent artefacts into production and acquiring solid know-how and has moved on from application techniques and design experiments.

Among the various fields in which the new generation of photoluminescence has experimented, the results obtained in terms of ecology for energy savings and terms of safety for the considerable contribution that can be made by photoluminescence without energy use are worth highlighting. The applications explored so far range from signage to children's toys, street lights to naval safety, garden spotlights, and wellness effect enhancers in places dedicated to body care. One of the significant processing limitations of photoluminescent pigments is temperature. If the temperature exceeds 1000°C, the pigments 'vulcanise' become opaque and lose their light-emitting properties. Therefore, in all cases tested, the temperature never exceeds 700-800°C. The latest research has significantly reduced the drawbacks of the old generation of pigments. Until recently, the risks associated with incorporating pigments, especially in plastic products, made the result poor and unreliable. Experiments using pigments using molecular protection of the material structure made it possible to overcome many early drawbacks by allowing the new material to be subjected to the mechanical stresses required for extrusion processes.

Further advantages were achieved by reinforcing the particle size distribution. This reduced mechanical stress during production and led to better integration of the pigment with the material used. The latest generation of photoluminescent pigments has led to use designed concerning the technical qualities of the material used to such an extent that even the most potent acids are resistant to corrosion. The brightness has also been increased with an improved luminescent effect with a prolonged life cycle both in the duration of the effect and in the product's lifespan, which can now exceed several decades (Alfarano & Spennato, 2022).

5. The culture of light

The tools that the design culture of light has already honed primarily converge towards acquiring the founding principle that light can be declined as an emotional value. Light goes from being a necessary condition for seeing to being a perceptive element that arouses states of mind. Lightly used as an expressive language is translated into a symbolic value. The cultural orientation of perception greatly directs its representative capacity for communication. The 'hotter' the light functions more as an attractor. It becomes a 'fire' around which to gather. Emotionally, it generates a symbolic perception, an imagery that provides security and comfort. The consideration tells us that light

is a symbolic emotion and that the same path in attributing symbolic value cannot be found for both 'warm' and 'cold' light.
Suppose warm light associates emotional imagery that welcomes and warms with cold light. In that case, we are at a stage of cultural evolution where it becomes commonplace to associate low temperatures with colours that move towards blue. Today, the symbolic value of this gradualness of light is associated with new technologies. It is combined with the most advanced performance of innovative materials. Photoluminescence is part of this new perceptive perspective. The signs of change can indeed be appreciated, with various perceptive oscillations, precisely in the ability of the new generations of photoluminescent pigments to be a vector of cultural orientation.
To appreciate the remarkable shift in the cognitive parameter we are undergoing, we must first reiterate a fundamental theoretical concept that has accelerated this ongoing process: 'There is no such thing as light, but there is light in all its forms'. This sounds like an axiomatic, purely conceptual postulate. However, it has been the most significant stimulus that has given awareness to light as an emotional component in recent decades.
Richard Kelly, a pioneer of qualitative lighting design, distinguished three fundamental functions of light as early as the 1950s:

- light that provides general ambient lighting - Ambient Luminescence
- the accent light that draws attention separates and highlights - Focal Glow
- light that captures, attracts and distracts, that becomes information for itself - Play of Brilliants

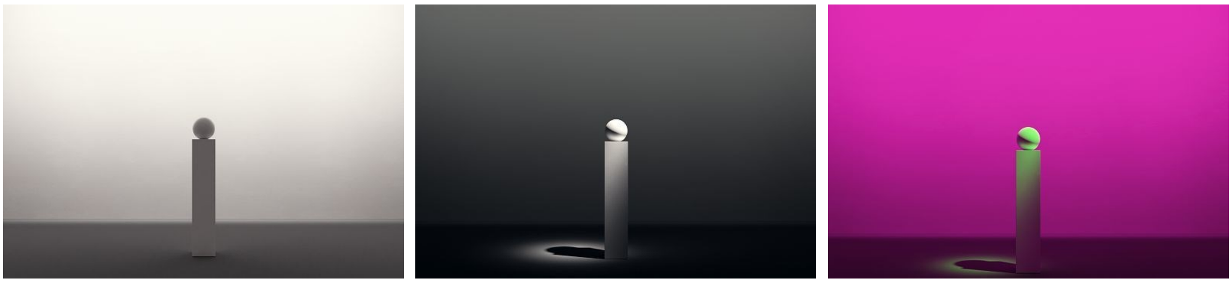

Figure 2. Ambient luminescence, Focal Glow, Play of Brilliants (Richard Kelly).

Lighting design is now more than ever a combination of these three functions. These criteria for evaluating light and its functions, applied in the various technical solutions available today, allow light to design the desired impact, effects and quality with extreme sensitivity. The lighting atmosphere that can be designed today has much technology at its disposal to go beyond the simple service of 'making light' by being more sensitive to the emotional perception of the lighting effect. Hence, in organising the position of the lights and considering the proper lighting, the study of the position of the lighting points becomes the spatial-geometric placement of the elements that unify the space. General lighting produces a shadowless light that minimises shapes and volumes; it reduces the importance of subjects and objects; it suggests an idea of infinity, freedom, and spatiality: the emotion of an experience of immersion in light. All this creates a reassuring feeling of a welcoming and serene environment. Diffuse and uniform light does not mean undifferentiated lighting for all spaces and contexts; on the contrary, it implies the search for adequate solutions to the different needs that each specific environment requires according to the activities that must be carried out in it. Diffused light radiation, appropriately manipulated, offers itself as an actual construction material when it is used to configure spaces and volumes by dynamically varying the colour and refraction effects of surfaces (Alfarano & Spennato, 2018).
The availability that photoluminescence gives us today is to educate us to an emotional perception of the whispering of light. Making with little much of the imagination we need. Photoluminescence reinterprets the dichotomy of light/shade, on/off, overcoming it by proposing that soft light, but valuable for illuminating small spaces. Faced with it, the eye purifies itself of the overload to which artificial light has accustomed it and, as in a night of moonless stars, slowly rediscovers the complexity of the world and new magical dimensions. Luminescence thus becomes a friendly, comfortable form useful for regenerating psychological and environmental energies.

6. The immaterial light

We are nowadays largely accustomed to seeing environments that only change colour with the temporary effect of artificial light. Therefore, we have culturally predisposed ourselves to accept and perceive, as a value, immaterial light effects that can change the visual perception of a place. As early as the 1960s, pop art led to the acceptance of illuminated advertising signs as the most advanced expression of lighting technology that the contemporary world could offer. Las Vegas and Times Square spread the culture of diffuse light. The 1960s were the years of fluorescent neon, ushering in the 'era of the bare bulb', the visible light fixture. The leap was made by no longer trying to hide the light source. Everything is left to view. The lamp no longer becomes not just a source but a legitimate medium that characterises the colour of spaces. The result is the diffusion of a fluid, magical, undulating perception devoid of weight.

In 'Testament' (1963), Frank Llyod Wright writes: 'Glass tubes superimposed like the bricks of a wall constitute the luminous surfaces' - we are in the era of 'diaphanous' light: light that envelops, light as much as you can.

With the advent of the digital control of artificial light, a new immaterial dimension is defined. The emotional dimension produced by the varied applications of lighting technologies adds to the conventional dimensions. The punctiform control of each lighting effect can be managed reactively with the environment, in direct correspondence with the moment's needs and varying according to the acute conditions of the users.

Light goes from being an immaterial dimension undergone to being an immaterial dimension participated in: it produces sensations and urges immersive perception. A new dimension that needs more awareness in the organised scanning of the use of space. The immaterial interconnectivity of objects, which is increasingly expanding, has the concreteness to exist if it finds the dimension in which to express the usefulness of its capabilities in the lighting apparatus. In this new advanced performance scenario, lighting design overcomes, with ever more sophisticated implementation tools, the commitment of making a correct contribution in lumens to environments to move quickly into a new methodological application phase. Moving lighting design towards a strongly cultural trajectory: educating to well-being by educating to the perception of light.

To save energy and experiment with new scenarios on the adaptability of the lighting coefficient to indoor and outdoor night-time spaces, photoluminescence can make an as-yet unexplored contribution. The close synergy that can be triggered between photoluminescence and new lighting systems already projects highly effective innovations, and the spin-offs that can be generated from this union point to a flourishing development of new exclusive products that are in functional harmony with the increasingly unbreakable ecological sensibilities.

7. Applied light research: the case study

Among the many varied results obtained in applying photoluminescence, experimentation on prototypes has made it possible to verify the feasibility of planned assumptions in indoor and urban lighting conditions. Unusual morphologies have been designed with the exclusivity of the proper use of photoluminescence and the inclusiveness of the most advanced technological apparatuses, obtaining the variable management of light in autonomous energy management and reactivity to environmental conditions.

In the applied research initiated by the Smart Lighting Design Lab research team, together with Martina Vallescura and Sara Scarponcini Fornaro, an experimental study was carried out in the Atri Municipal Park, called 'Villa de' Cappuccini' by the citizens. Today's Villa Comunale was originally the garden of the convent of the Capuchin Friars Minor, who settled in Atri in the 16th century and remained there until 1888 due to the suppression of the convent. Subsequently, the garden was transformed into a public park open to citizens. It is an extensive Italian-style garden park that was reorganised on an architectural basis with geometric layouts.

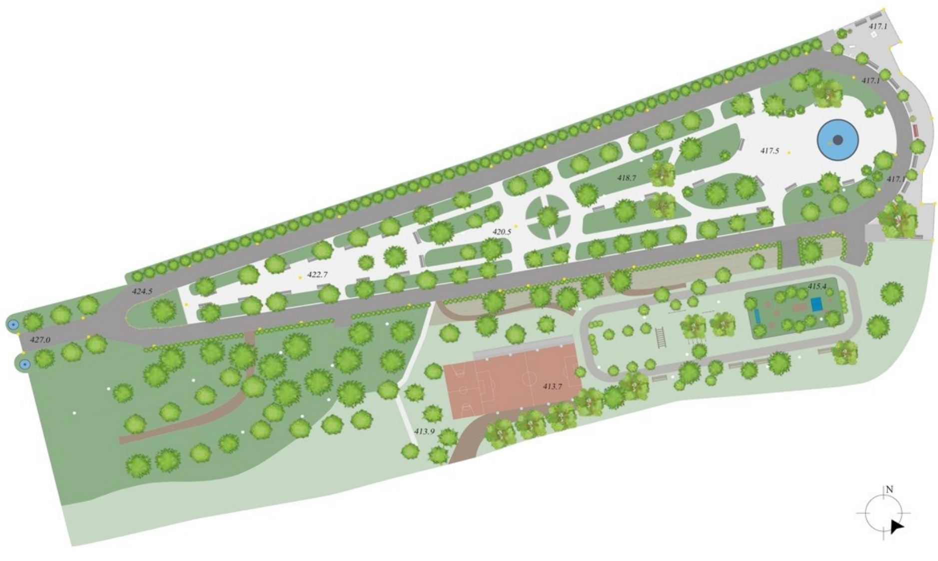

Figure 3. Status of the Park (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

The park extends over two flat, terraced areas of approximately three hectares in an ideal, airy, sunny position. On the upper level, a long, paved, circular avenue, closed to traffic, characterises the park's structure. Inside is a large green area with benches everywhere and characterised by high woodland, culminating in a sizeable, gravelled

clearing, where a large circular pool with water features stands. A crucial and privileged park area is the 'Belvedere', from whose long, mixtilinear balustrade one looks out over the Adriatic Sea.
The landscape, rich in distant perspectives, fascinates the visitor, who thoroughly enjoys this exaltation of nature.
Stone inventions, such as remnants of original sculptures and more recent works, together with a children's play area, enrich the elevated area of the Villa Comunale.
In the eastern section, the lower level features a large sports area with a football pitch, basketball court and sports equipment. In addition, adjacent to this area, there is a recently constructed recreational play area.
The starting point of the research was the study of the site analysed in its current conformation, dividing the park into its different zones. Specifically, the activities usually practised in each space mentioned above were observed. The element of interest in the survey was the observation of the behaviour of those who frequent the Villa Comunale during the day and night hours, thus noting the routes most frequently practised, the areas where they stop, and analysing the sun's rays at certain times of the year and at specific times of the day.
To be able to study the effects of lighting and the pattern of shadows in the Villa Comunale at different times of day, software was used that shows the movement of the sun and the phases of sunlight during a specific day and at a particular location.

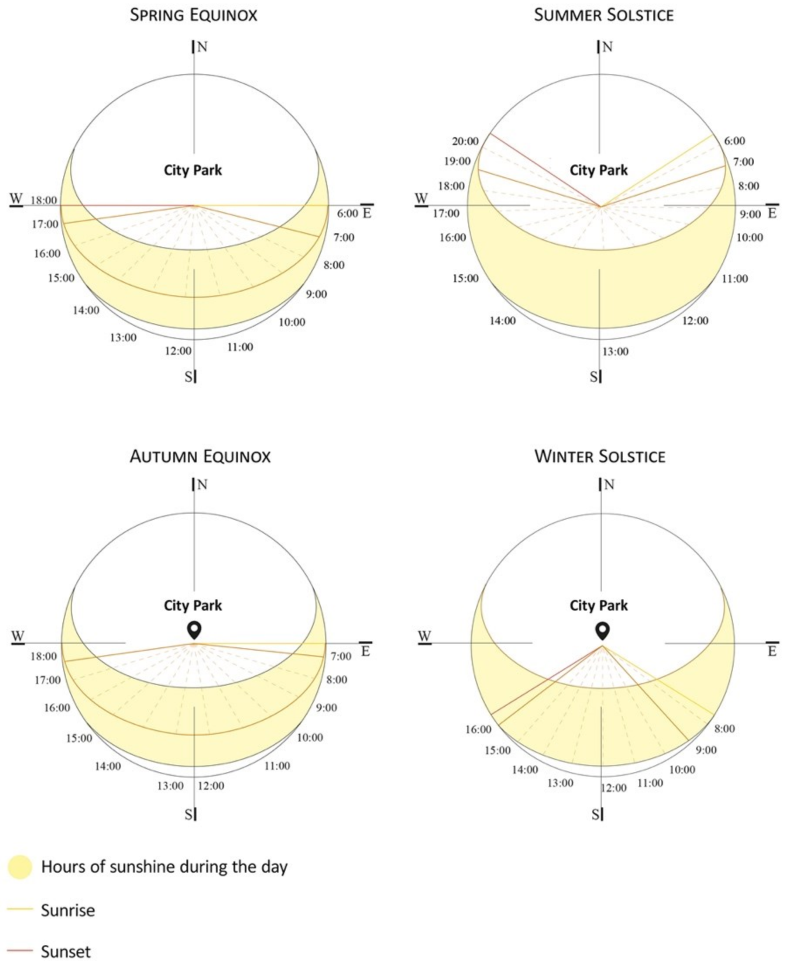

Figure 4. Development of sunlight (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

By entering the longitude, latitude, date and time, it was possible to carry out this study. Once the areas of interest had been identified, a three-dimensional model was created to which the data mentioned above was applied, which made it possible to visualise the course of the shadows generated by the plants. Subsequently, the shadows produced were brought back onto the context plan under examination and superimposed on three different layers with three shades of grey.

Figure 5. Shadow study (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

8. Results

The project's objective was to enhance the context from a lighting and safety point of view and offer a valid alternative to the current conditions, guaranteeing high energy savings and ensuring a reduced environmental impact.

The pilot study carried out on Atri's Villa dei Cappuccini led to identifying two enhancement areas: the 'Belvedere' on the upper level of the park, and the sports area, on the lower level.

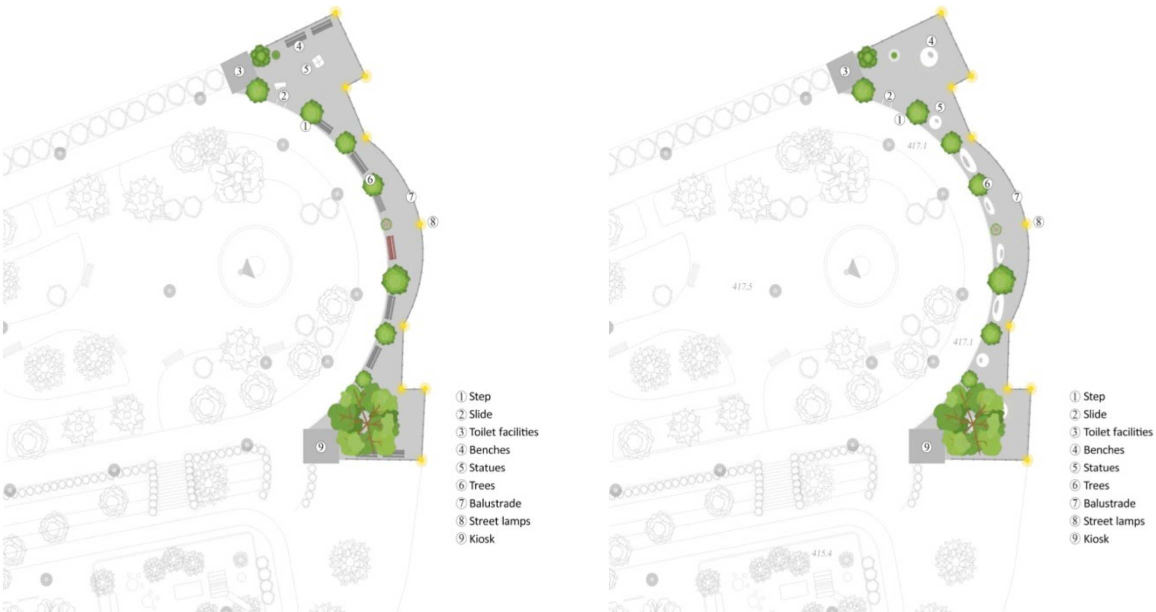

Figure 6. On the left the current state, and on the right the modified state of Belvedere (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

Figure 7. On the left the current state, and on the right the modified state of the sports area (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

Urban lighting has enormous disadvantages in terms of cost, maintenance and, above all, electricity consumption. New technologies and innovative sources make it possible to realise lighting that allows a high degree of control and reduced energy consumption.

The public lighting sector is facing a turning point, as it is possible to act despite not-too-invasive interventions that still allow significant gains in energy consumption.

The project in the 'Belvedere' area consists of elaborating a new formal language to be given to the area of interest through a system capable of connecting what is currently offered by the park to the new technologies identified. Precisely, it consists of vertical installations inserted into the ground and of varying heights, consisting of metal support frames and transparent LSC (Luminescent Solar Concentrators) sheets of coloured plastic material that has the characteristic of capturing sunlight and concentrating it at the edges, where it is intercepted by thin photovoltaic cells and converted into electricity. In addition to creating superimpositions of the various colours on the ground with its shadows, this design solution captures and conveys the solar energy necessary for operating the street lamps on the Belvedere.

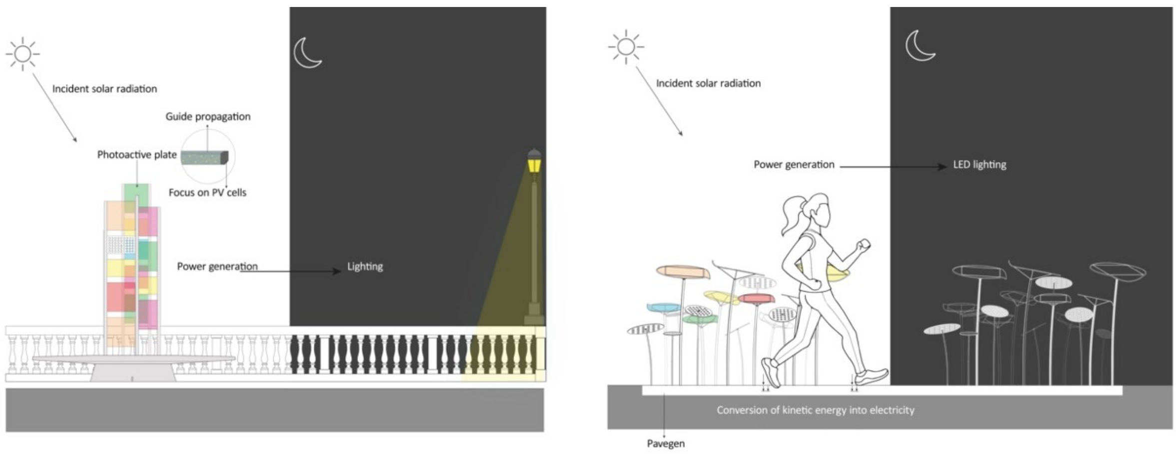

Figure 8. Scheme of operation (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

Subsequently, the project includes four new types of seating of different sizes and circular and oval shapes. Of these, the largest will see the integration of LSC panels.

The last action concerns the creation of ground elements arranged around the trees and seats with circular grids with two different diameters, enhancing the natural elements in the Belvedere area. Furthermore, through the presence of photoluminescent elements on the ground and the panels, the system is characterised by different visual effects between day and night.

Figure 9. Environmental renderings of the elaborated design (Developed by Martina Vallescura and Sara Scarponcini Fornaro).

About the sports area, on the other hand, the new proposal, unlike the current one, is designed to make users understand how with their steps and physical activity, they can contribute to making the place more sustainable. A path has been created interspersed with bright tiles that allow citizens to produce the energy needed to light up the area actively.

The electricity produced during the day is stored in batteries connected to a twilight sensor that activates the release of energy as the sun goes down. The latter is used to illuminate installations designed to be placed at the sides of the path.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare no conflict of interest.

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