Chapter 7

New Perspectives Against Biodeterioration Through Public Lighting

Patricia Sanmartín

Abstract There is currently an increasing trend in urban centres towards the use of public outdoor lighting systems to illuminate historic and architecturally important buildings during evening hours, but for which there is no specific regulatory framework. Considering that the light is a key factor involved in regulating growth and physiological processes in photosynthetic organisms, it seems appropriate to address the effects that artificial light has on the organisms growing on the facades affected by public lighting. In this sense, despite scientific research in the fields of biological colonization of buildings surfaces and light technology has advanced greatly in recent years, the combination of both disciplines aimed at the correct handling of city public lighting remains uncharted territory with huge potential to provide innovative solutions for smart cities. Recent studies have examined how urban monuments are affected by night-time outdoor illumination in combination with natural sunlight and demonstrated that the use of suitable lighting can inhibit the development of biological colonization. In this frame, this chapter will look at ways of contribute to the long-term management of public illumination on monuments and other structures, while reducing negative impacts caused by night lighting.

Keywords Organism's control strategies · Cultural and natural heritage · Biodiversity · Light pollution · Public lighting · Smart cities · Stone · Biodeterioration · Urban fabric · GLOBAL change

1 Introduction

Light is a type of electromagnetic radiation that, via photochemical interactions, provides the main source of energy for the metabolism of photoautotrophic organisms (i.e. photosynthesis) and that is directly involved in fixing C, and in N and S

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metabolism (Willey 2016). Photosynthetic metabolism represents an adaptive advantage that enables photoautotrophic organisms to occupy various niches (Di Martino 2016). These organisms are therefore considered a key group in the formation of subaerial biofilms (SABs), which have been defined as “microbial communities that grow on solid surfaces exposed to the atmosphere” (Gorbushina 2007). These communities are mainly dominated by green algae and to a lesser extent by cyanobacteria in temperate climates characterized by warm summers and cool winters with high atmospheric humidity, as in many parts of Europe (Rifón Lastra 2000; Rifón Lastra and Noguerol Seoane 2001). The presence of photoautotrophic microorganisms (cyanobacteria and algae), i.e. primary colonizers, leads to the formation of more complex microbial associations, which in turn enables settlement of other species (heterotrophic microorganisms) and the concomitant growth of other colonizers, including lichens, heterotrophic bacteria, fungi, bryophytes, and vascular plants.

Because the occurrence of these pioneer algae and cyanobacteria (a phenomenon often referred to as “greening”: Smith et al. 2011; Sanmartín et al. 2012) is the first step in the sequential process of colonization, it requires priority research attention. Greening can be both detrimental and beneficial, depending on the substratum and microorganisms involved. Indeed, there is some controversy regarding the impact of greening on the physical and chemical integrity of stone. Although classic studies describe a role for greening in the weathering process (Ortega-Calvo et al. 1991a, b), it is increasingly considered to have a negligible (Sanmartín et al. 2020a) or even bioprotective role (Ramírez et al. 2010; Cutler et al. 2013). In the urban fabric of a city affected by high atmospheric humidity, biofilm formation and biological colonization are unavoidable because they occur as a result of interactions between the building material and the environment (Gorbushina 2007).

One of the main challenges facing cities is the management of biological colonization on building facades (Energy & Smart cities; Smartiago project). Cleaning is an important aspect of the maintenance and rehabilitation of stone buildings and structures, which are prone to being colonized by living organisms, removed frequently to prevent biodeterioration, including the simple aesthetic impact (Warscheid and Braams 2000; Scheerer et al. 2009). Removing these organisms from building facades requires a huge financial outlay by local governments and agencies. According to the Santiago de Compostela (NW Spain) city council, the cost of cleaning the main facade (Obradoiro) of the Pazo de Raxoi amounted in 2016 to €318,000.

In the current night-time environment of historic centres with a illumination that makes the buildings more visible and showcases different features (Fig. 7.1), and known the key role of light on greening-forming organisms; it is striking that few studies have addressed to study the influence of ornamental outdoor illumination from artificial night-time sources on the biological colonization on buildings and monuments.

In this chapter, lighting-based strategies currently used against biodeterioration are presented together with progress in the public outdoor lighting systems illuminating heritage buildings, and emphasis is placed on findings of the recent regional

Fig. 7.1 Night-time view of the Hércules Tower (A Coruña, Galicia, Spain) illuminated with purple, green, blue, and orange light in 2017. Source: Elena López

2-year Light4Heritage project (2016–2018), focused on developing lighting-based strategies to control biological colonization and to manage the chromatic integration of biofouling at laboratory scale. Finally, a critical analysis about in what form public lighting can be turned into a green method is also reported.

2 Lighting-Based Strategies Currently Used Against Biodeterioration

Lighting-based strategies that are currently used to control primary colonizers (algae and cyanobacteria) on the built heritage are described below (Borderie et al. 2012; Figueroa et al. 2017; Sanmartín et al. 2018a):

Restricting the Duration of Lighting The simplest way to restrict lampenflora, defined as “massive growth of cyanobacterial-based microbiota and of algae, mosses and other plants located near light sources in caves accessible to tourists” (Dobat 1998; Mulec and Kosi 2009; Mulec 2012), is to limit the time that caves are illuminated (during visiting hours) thus increasing the length of the dark period (Figueroa et al. 2017).

Changing the Amount of Light The use of low-intensity lamps reduces biological colonization. The use of low levels of illumination for short periods helps to prevent and control the growth of phototrophic biofilms (Albertano and Bruno 2003). The light must be strong enough to cause photoinhibition, considered a reduction in photosynthesis in response to increasing irradiance, although the term may refer more generally to inhibition of growth due to a change in lighting (Sanmartín et al. 2018a).

Using Different Wavelengths of Monochromatic LED Lights The use of LEDs with light qualities enriched in the wavelengths with low photosynthetic quantum efficiency for the target phototrophs has a biostatic effect (Sanmartín et al. 2018b). However, when LED lighting is used to control phototrophs, the ability of these organisms to photoacclimatize (MacIntyre et al. 2002) and adapt to light (Tandean

de Marsac 1977) must be taken into account, along with the presence of different pigments in photosynthetic organisms and other organisms in the same biofilm. Nonetheless, light quality is one of the most important and well-studied light parameters, and recent studies suggest that it is the main regulator of growth responses in algae and cyanobacteria (Kehoe 2010; Bussell and Kehoe 2013; Wiltbank and Kehoe 2016). Table 7.1 summarizes the most important contributions from previous studies regarding the responses of algae and cyanobacteria to LED light treatments.

Using UV (A, B, or C) Irradiation UV treatment is widely used to disinfect surfaces. Ultraviolet light has a short wavelength and high energy and becomes more energetic as the wavelength decreases, according to Planck's quantum theory, so that the energy increases in the order UV-A (315–400 nm) < UV-B (280–315 nm) < UV-C (190–280 nm). The sun emits radiation in all three UV ranges, but the UV radiation that reaches the Earth's surface comprises around 95% UV-A and 5% UV-B. As a physical and germicidal treatment, UV-C irradiation is a suitable alternative method of controlling or limiting biofouling, and its potential to damage phototrophic biofilms in caves has been demonstrated (Borderie et al. 2012, 2014, 2015). Although many studies have addressed the effects of UV rays not filtered by the ozone layer, i.e. UV-A and UV-B radiation, on algal and cyanobacterial cultures (Sinha et al. 1996; Wingard et al. 1997; Yakovleva and Titlyanov 2001; Mullineaux 2001; Bischof et al. 2006; Castenholz and Garcia-Pichel 2012; Moon et al. 2012; Shang et al. 2018), few studies have focused on longer-wave radiation applied to biological colonization in built heritage. Table 7.2 summarizes the most important contributions from previous studies regarding the responses of algae and cyanobacteria to UV light treatments.

All these aforementioned lighting studies are scarce in relation to poikilohydric organisms, such as lichens and bryophytes, and even more so in relation to vascular plants on cultural heritage. To the best of my knowledge, only the EU-funded ECOLIGHT (Ecological effects of light pollution) project has made major advances in discovering how terrestrial plants respond to artificial light at night. The project findings show that artificial light can prolong the retention of leaves in urban environments and initiate early onset of bud burst in the spring, thus increasing the risk of exposure to frost and pathogens.

3 Public Outdoor Lighting Systems Illuminating Heritage Buildings

Historic centres are tourist attractions of enormous importance to the economy of cities and regions, which today are faced with the important challenge of applying new technological and management strategies within the smart city concept. This model aspires to use technological solutions to improve the management and

Table 7.1 Behavioural responses of phototrophs to LED lights appraised by several authors on-site and laboratory-based experiments

Reference	Occurrence	Organism(s)	Light	Findings
Albertano et al. (2003)	Roman Catacombs of St. Callistus and Domitilla, Rome (Italy)	cyanobacterial and chemoorganotrophic bacterial biofilms	Blue	In 5 months, no photosynthetic activity was detected. In 10 years, the extent of phototrophic communities was reduced (Bruno et al. 2014). Bacteria increased in some treated areas, although Actinobacteria decreased by 40% over the 10 years (Urzi et al. 2014).
Roldán et al. (2006)	Bats' Cave, Zuheros (Spain)	<i>Gloeotheca membranacea</i> (cyanobacterium) and <i>Chlorella sorokiniana</i> (alga) biofilms	Green and white	Green light may prevent the growth of photosynthetic organisms, except for those capable of modifying accessory pigments.
Hsieh et al. (2013)	Roman Catacombs of St. Callistus and Domitilla, Rome (Italy)	7 cyanobacterial strains	Red	Decreased Quantum Yield of Photosystem II and photoinhibition.
			Blue	Increased photosynthetic activity and growth of biofilm.
Hsieh et al. (2014)	Roman Catacombs of St. Callistus and Domitilla, Rome (Italy)	5 cyanobacterial strains	Red and white	Decreased photosynthetic pigment content.
			Blue	Increased phycocyanin and phycoerythrin content.
Enomoto et al. (2015)	Not covered	<i>Thermosynechococcus vulcanus</i> and <i>T. elongatus</i> (cyanobacteria)	Blue	Damage to the manganese cluster of Photosystem II. Protection by cellular aggregation.
Han et al. (2015)	Not covered	<i>Nostoc flagelliforme</i> (cyanobacterium)	Green and blue	Change in the C/N ratio, indicating differences in cellular components.
			Red	Negative influence on primary metabolism. Photoinhibition.
			Yellow and violet	No inhibition of growth.

(continued)

Table 7.1 (continued)

Reference	Occurrence	Organism(s)	Light	Findings
de Mooij et al. (2016)	Not covered	<i>Chlamydomonas reinhardtii</i> CC-1690 (green alga)	Red	Low biomass. High specific growth rate.
			Blue	Low biomass. High specific growth rate. Increased Quantum Yield of Photosystem II.
			Yellow	High biomass. Improved physiological state of cells when combined with a small proportion of blue light.
Del Rosal Padial (2016)	Nerja Cave, Malaga (Spain)	Biofilms containing <i>Chroococcidiopsis</i> sp., other cyanobacteria taxa, red alga <i>Cyanidium</i> sp., and green algae	Green	Reduced growth of photosynthetic microorganisms.
Bruno and Valle (2017)	Roman Catacombs of Domitilla, Rome (Italy)	3 cyanobacterial strains and biofilms	Red, orange and blue	In 2 months, improved biofilm growth. High electron transport rate. High chlorophyll-a and carotenoids content.
			White and green	In 2 months, growth limited.

efficiency of the urban environment, with the ultimate aim of increasing urban sustainability (Energy & Smart cities).

There is currently an increasing trend for cities to install external lighting systems to illuminate buildings and monuments. Lighting components, as floodlights and spotlights, equipped with lamps are placed on the building itself, on its facade, lighting the architectural surroundings. This trend is favoured by technological improvements in lighting installations, specifically light emitting diode (LED)-based lighting. LED lighting has rapidly become sufficiently effective for use in exterior lighting systems and has several advantages over traditional lighting (less energy demanding, longer lifetime and mercury free). LED lamps not only increase the temperature and reduce humidity on building facades, but the artificial light also generates a specific physiological response in the colonizing organisms, interrupting their natural lighting cycle. This could favour the further development of biological colonization (Fig. 7.2), as previously observed in the subterranean cultural heritage (caves, catacombs, necropolis, etc.) by Albertano and Bruno (2003) and Albertano et al. (2003), and most recently by del Rosal and colleagues (del Rosal Padial et al. 2016; Jurado et al. 2020). Indeed, the term *lampenflora* defined above was coined to

Table 7.2 Behavioural responses of phototrophs to UV lights appraised by several authors on-site and laboratory-based experiments

Reference	Occurrence	Organism(s)	Light	Findings
Sinha et al. (1996)	rice paddy fields near Varanasi (India)	4 cyanobacterial cultures	UV-B and UV-A	30' to 5 Wm ⁻² caused the death of 50% population. Decrease in the uptake of ¹⁴ CO ₂ and protein content with increased exposure time.
Wingard et al. (1997)	Alkaline hot spring in the city of Rotorua (New Zealand)	4 cyanobacterial cultures	UV-B	Increased negative effect on ¹⁴ C incorporation rate relative to the control. Chlorophyll-a content decreased with increasing light intensity l.
Moon et al. (2012)	Not covered	<i>Synechocystis</i> sp. PCC 6803 (cyanobacterium)	UV-A	High-dose: negative phototactic response. Low-dose: photoregulation. Negative phototaxis affected.
Borderie et al. (2012)	3 caves of south west of France (Domme, Laugerie-Haute, Combarelles, Department of Dordogne, France) and 1 cave of northeastern of France, Moidons Cave (Department of Jura, France)	mixed algae cultures	UV-C	Chlorophyll-a, -b and carotenoids content was affected. Cell viability decreased greatly. Programmed cell death occurred in unicellular algae. Greater effectiveness in combination with high light.
Borderie et al. (2014)	Moidons Cave (Department of Jura, France)	5 biofilms (mainly algae)	UV-C	In 12 months, cleaning due to light was effective. In 16 months, biological colonization continued to increase. Treatment effectiveness depended on biofilm thickness.
Borderie et al. (2015)	Moidons Cave (Department of Jura, France)	Green algae	UV-C	Damage was greater in the planktonic than in the biofilm mode of growth.
Pfendler et al. (2017)	La Glacière Cave, Chaux-lès-Passavant (France)	<i>Chlorella</i> sp. (green alga)	UV-C	In situ, discoloration of biofilm. In 21 months, no photosynthetic

(continued)

Table 7.2 (continued)

Reference	Occurrence	Organism(s)	Light	Findings
				microorganisms were observed.
Shang et al. (2018)	dry desert steppes and bare land in Mongolia (China)	<i>Nostoc flagelliforme</i> strain CCNUN1 (cyanobacterium)	UV-B	In 1.5 h, decreased the Quantum Yield of Photosystem II. In 54 h, content of mycosporine-like amino acids doubled.

Fig. 7.2 Occurrence of phototrophic colonization around a streetlight. Source: Patricia Sanmartín

refer to the massive biological growth near light sources in caves accessible to tourists.

In outdoor environments, the lighting of buildings in white LED has given way to the use of coloured LEDs (red, green, yellow, blue, etc.) because the chromatic performance of the installation gives the building or monument of a higher symbolism. For instance, built structures illuminated in purple to mark the feminist movement and the fight for gender equality, especially the International Women’s Day on March 8, or illuminated in green to celebrate actions to combat climate change. The impact of the coloured illumination from artificial night-time sources on the

biological colonization on buildings and monuments largely depends on the composition and diversity of community, particularly its pigment content. Phototrophs (algae and cyanobacteria) need to live, to a greater or lesser extent, light from different parts of visible spectrum depending on the pigments that they contain. If they are rich in chlorophyll-a and -b, which absorb in the red and blue regions of spectrum, they should be more vulnerable to the effect of red and blue monochromatic lights. If their higher pigment content is in phycobiliproteins phycocyanin and allophycocyanin, which absorb in the red region, red light will have a greater effect. Finally, if total carotenoids and phycobiliprotein phycoerythrin (absorbing in the greenish-yellow and green regions respectively) are the main pigments, yellow and green lights will present the greater effect on organisms. However, this is an oversimplification. Microorganisms have several protective mechanisms that can be triggered by certain qualities of light. Account should also be taken of the light with long wavelengths (such as red and orange light) are more penetrating.

Artificial lighting on outdoor constructions cannot be considered without also considering the effects of daylight, as monuments and structures are always exposed to natural light. As indicated above, very few studies have been published regarding how urban monuments are affected by night-time outdoor illumination in combination with natural sunlight. The Light4Heritage project (2016–2018) has focused on developing lighting-based strategies to control biological colonization and to manage the chromatic integration of biofouling at laboratory scale. The first study carried out within the project involved the use of coloured cellophane films to generate different types of light (by cancelling out the spectral components in certain bands of the visible electromagnetic spectrum, thus emulating monochromatic LED lights) at different photon flux densities. The cellophane films were used to cover phototrophic cultures, derived from natural biofilm growing on a historic granitic building and mainly comprising green algae and cyanobacteria, in order to promote specific physiological responses. The blue cellophane inhibited growth of the test culture, while the yellow cellophane did not significantly decrease the biomass, pigment or EPS content, relative to uncovered, control cultures. The different coloured cellophane covers also generated colour changes in the cultures; e.g. the red cellophane produced notable greening, whereas the green cellophane enhanced the redness of the cultures (Sanmartín et al. 2017). Further experiments were carried out using phototrophs in biofilm mode of growth and LED lights. In these studies, phototrophic biofilms thrived well under blue LEDs, whereas green and red LEDs had biostatic effects (Sanmartín et al. 2018b). Phototrophs responded differently to exposure to different coloured light: the biofilms developed under blue light predominantly comprised algae, and those exposed to red and green light mainly comprised cyanobacteria (P. Sanmartín, unpublished results). Regarding the duration (number of hours daily) of LED illumination, a period of 4 hours proved sufficient to reduce colonization under red and green LED lights, while a period of 8 h proved optimal for further growth of organisms under blue LED light (P. Sanmartín, unpublished results). Finally, among cross-sectional studies, from project Light4Heritage, on the effects of UV-A and UV-B on biological

colonization, another study showed UV-B irradiation to be potentially useful for eradicating green algal biofouling from granite stone (Pozo-Antonio and Sanmartín 2018).

A preliminary part of the laboratory research work has been finalized. However, not all of the laboratory-based work on biofilm study was completed in that project and it did not include studies with poikilohydric organisms, such as lichens and bryophytes, or vascular plants. It is important to establish the basis for laboratory scale evaluation in order to facilitate posterior fieldwork. In addition, experimental, laboratory-based simulation enables results to be obtained within a much shorter time than in the field. For example, in the laboratory a mature biofilm can be formed in 30 days on a membrane support (Gambino et al. 2019) and in about 45 days on an acidic, relatively non-porous substratum such as granite (Prieto et al. 2014), whereas in the field a subaerial biofilm will only begin to be formed by phototrophs after around six months on granite walls exposed to rainfall (Sanmartín et al. 2012) and more than a year in areas protected from rainfall (Sanmartín et al. 2020b).

4 In What Form Public Lighting Can Be Turned Into a Green Method?

The choice of the type of lighting system used to illuminate monuments in the urban fabric is completely arbitrary and is not scientifically based, nor presents a specific regulatory framework (Rodríguez Lorite 2016). The choice is not made in relation to the findings of studies on energy efficiency, environmental biodiversity or building conservation, from which the first negative data in relation to the novel night illumination systems are beginning to emerge. For instance, external lighting of cultural heritage monuments causes 5% to 20% of total light pollution (Mohar et al. 2014), which is listed among the ten main factors endangering biodiversity (Hölker et al. 2010).

There are some social and scientific concerns regarding the side effects of night-time lighting, such as urban light pollution, negative impacts on wildlife (i.e. bats, moths) and the potential new threat to pollination (Hölker et al. 2010; Mohar et al. 2014; Knop et al. 2017; ECOLIGHT project). In the framework of a LIFE project, Mohar et al. (2014) developed a lamp to improve the existing lighting of 21 pilot churches in Slovenia, reducing the negative impact of illumination on moths and bats and the energy consumption by 40% to 90%. According to these authors, blue coloured light (Fig. 7.3) interrupts melatonin (also known as sleep hormone) in humans and animals, even at low illumination levels. Likewise, reducing intensity of illumination and avoiding light with shorter wavelengths, especially in the blue, the reduction in the observed number of specimens and species results is improved. A key recommendation of this project is that lighting of cultural monuments should be omitted as much as possible, especially when they are located outside urban areas.

Fig. 7.3 Façade of the San Fiz de Solovio Church in Santiago de Compostela (Galicia, Spain) illuminated in blue light in 2018. Source: Justo Arines

Another important recommendation is that after 23.00 hours, lighting should be switched off in order to attract fewer moths.

Furthermore, the energy consumed by the lighting systems increases the level of CO₂ in the atmosphere. Although the simple change of incandescence (e.g. metal halide and sodium vapour lamps) to LED technology in public lighting would be reduced by up to 90% this emission. An example is the lighting of the Puerta de Alcalá in Madrid, which until 2014 had a total consumption of 41,470 W and at present uses 4660 W of energy (Rodríguez Lorite 2016). In Spain, consumption of 1 kWh of energy is equivalent to emitting 430 g of CO₂ into the atmosphere (San Martín Páramo and Ferrero Andreu 2008 *apud* Rodríguez Lorite 2016), so that the illumination of this monument every night causes the release of 3440 g of CO₂ to the atmosphere, one tenth of what was issued until 6 years ago.

Regarding the biodiversity of higher plants, in the ECOLIGHT project mentioned above, constant artificial light was also found to increase the rates of foliar damage due to ozone in three clover species and in *Lotus pedunculatus*, which produced 10% to 25% fewer flower heads under simulated street lighting, which in turn led to reduced numbers of the aphid *Acyrtosiphon pisum* (Bennie et al. 2016, 2018). These researchers also value positively the implementation of LED technology in public lighting to achieve an environmentally sustainable system.

5 Current Perspectives and Future Directions

So far, it has been demonstrated at laboratory scale that the combined use of suitable lighting can promote or inhibit the development of biofilms and also shape their colour. Thus, an advancement regarding the practical application of the research findings is necessary. The objective will be to determine the criteria that would enable the use and technological implementation of outdoor lighting for effective control of biological colonization of buildings. These criteria will aim to contribute to the long-term management of public illumination on monuments and other structures, while reducing negative impacts caused by biological colonization and also preventing any further increase in light pollution. Technical solutions that will provide more energy-efficient and environmentally-sound, targeted illumination that also controls biofouling formation on buildings shall be designed. This will be achieved through the development of a pilot project and the construction of improved lighting prototype systems.

Concerning the latter, a wide range of options is offered by current light technology. It would be highly desirable, test new commercially available lights (both LED and ultraviolet lights) and examine the influence of other technological elements such as density filters, band-pass filters, and filter holders mounted on a common light source. This information will be used to identify the emissive material of the prototype lighting system. Furthermore, current recommendations regarding visual comfort, light pollution, and illumination regulations need to be taken into consideration in order to design the system. On the other hand, in the pilot project and the studies launched, a method based on the quantitative determination of colour for early detection (even before it is visible to the human eye) and real-time monitoring of epilithic phototrophic biofilms on the surface of structures (Sanmartín 2012; Sanmartín et al. 2012) could be used. The method is non-invasive, portable (can be used on-site), inexpensive, and easy to apply (enabling unskilled operators with minimal training to perform the measurements) and provides immediate results (Fig. 7.4). Likewise, the chlorophyll-a fluorescence (ChlaF) parameter F_v/F_m (maximum quantum efficiency of PSII), previously reported to be suitable for ascertaining the vitality of organisms' remains on rock surfaces (Pozo-Antonio and Sanmartín 2018) and monitoring the quantity and physiological state of the biofilm-forming phototrophs in recolonized areas (Sanmartín et al. 2020b), could be also applied (Fig. 7.4).

The development of smart lights to reduce biological colonization on monuments (Fig. 7.5) is fully consistent with smart city strategies of efficiency, applicability and adaptation of R&D&I to problems that affect heritage cities. Thus, results will be readily scalable, efficient, and replicable in cities or environments throughout the world where the historical heritage is a distinctive feature. Findings will have a significant social and economic impact, as control over biodeterioration is an important element of built heritage management worldwide, and the development of standards or regulations for managing external lighting of built heritage may help to avoid it.

Fig. 7.4 Adrián Rodríguez (graduate student), Rafael Carballeira (expert in the field of Botany), and Patricia Sanmartín (cultural heritage conservation researcher) all involved in the Light4Heritage project, taking colour spectrophotometry and PAM fluorometry measurements on the granite-built cloister in the Monastery of San Martiño Pinario (Santiago de Compostela, Galicia, Spain). Source: Justo Arines

Fig. 7.5 Left: Adrián Rodríguez walking on the scaffolding in which two of the system lights have been placed. Right: Scaffolding system with a commercial lighting system (acquired following the guidelines outlined by Patricia Sanmartín) provided by the company Ferrovial Servicios. Source: Patricia Sanmartín

Finally, the public response to the new lighting developed and installed should be taken into account to enable evaluation of the lighting systems from a perceptual, and not only procedural, viewpoint.

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