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Assessment of the Historical Gardens and Buildings Lighting Interaction through Virtual Reality: The Case of Casita de Arriba de El Escorial

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Abstract: Green areas and parks are places where people's quality of life improves, places of recreation and relaxation, in which to carry out various social activities. Among these, the historic gardens represent the union between green areas and historic architecture. Light is considered one of the main factors influencing the perception of such spaces at night; therefore, lighting solutions should be properly balanced. Immersive virtual reality is a tool that allows for lighting design management from different viewpoints. This study investigates how the lighting of a monumental garden affects people's perception of its architecture at night. With this aim, a detailed 3D model of the western part of Escorial's monumental complex in Spain was built in DIALux evo 11 and Unreal Engine 4.27 and used to propose six different lighting scenarios. Participants viewed the scenarios through a head-mounted display and provided subjective feedback on the perceived light strength of the environment and architecture. Results highlight that illuminating surrounding areas affects the environment and building perception, as well as the order in which elements capture observer attention. In particular, lit elements between the observer and the façade can reduce façade importance.

Keywords: park lighting; architectural lighting; floodlighting; virtual reality; building perception; subjective assessment; monumental complex; Casita del Infante

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1. Introduction

Light is one of the main factors influencing the perception and use of urban spaces [1,2]. Good lighting solutions can improve the quality and enjoyment of urban areas during the night, improving the users' experience [3] and safety [4–6]. Lighting design has to consider these aspects to ensure an appropriate use of these places at night. In particular, green areas have played a significant role for sociality in urban areas during day and night hours. Differently from urban green areas, the historical gardens, with their architecture, allow for the combination of vegetational areas for social cohesion [7] and rehabilitate mental fatigue [8,9], with historical architecture representing moments of history, evidence of an artistic period or idea [10,11]. The challenges for architectural lighting (or floodlighting) solutions are to make the building perceptible at night as it is perceived by day and to make architectural details stand out concerning fewer characteristic parts. In contrast, the lighting design of vegetational areas aims to attract users even at night and ensure safe places [12,13]. Lighting needs to be properly balanced so the user can perceive places correctly [14]. In this scenario, advanced digital tools, such as virtual reality (VR), have enabled the management of lighting design, the verification of design parameters [15–19], and the evaluation of people's satisfaction. Over the years, virtual reality has been used in many fields, such as the investigation of multisensory interactions, the collection of user preferences on environmental conditions and design solutions [20–22], the reproduction of real environments [23,24], or the use as a participatory lighting design tool [25–28]. At the same time, virtual environments for lighting purposes can be considered a good reproduction of real ones if the light distribution is correct from a photometrical point of view and people feel like being there. In recent years, more and more research began seriously focusing on using VR as a tool for the lighting design of internal and external environments [29–31].

1.1. Architectural Lighting

Architectures with historical and artistic interests need to be enhanced at night through adequate lighting systems. Two lighting methods are usually considered for architecture, each with specific objectives: (i) planar and (ii) accent. The planar lighting method allows for the uniform illumination of a façade [32–34] and is indicated as the most effective method when the architecture is a monument with few architectural details in the façade or when it is not possible to install luminaires directly on the building. Indeed, the luminaires are installed far from the architecture, avoiding direct interventions on the façade. On the other hand, this lighting methodology requires a high luminous flux (resulting in a high electrical power supply) and can cause glare [35,36] (being the luminous flux perpendicular to the monument itself). In recent years, the planar method has been used for façades with many elements [37].

The accent lighting method permits the illumination of specific elements of a façade [38,39]. This lighting solution is recommended for façades with details since they can be individually enhanced with respect to the whole building [35], or for large architectures developed especially in height [36]. In this case, a greater number of luminaires of low electrical power are installed directly on the façade of the building, guaranteeing better control of the emitted luminous flux. Using this lighting method, a lot of attention has to be placed on preserving the horizontality and verticality of the architecture. Skarżyński et al. [40] used the accent method to enhance the Belweder Palace, home of the President of Poland. The design idea was to highlight both sides of the façade with recessed wide beam spotlights placed in front of the structure, as well as the balustrades in the roof and the gable through small narrow beam spotlights. Carleo et al. [41] used accent lighting to enhance the cultural heritage and improve the fruition of the Casa de Vacas (Retiro Park in Madrid, Spain). Starting from an on-site survey, a detailed virtual model was built to emphasize the morphological aspects of the architecture and the decorative elements of the façades. Different lighting design scenarios were developed, and the best solution to meet the lighting needs and the integration with the surrounding context was identified.

Considering the increasing interest in outdoor lighting, more and more applications are being developed to evaluate the distribution of illuminance and luminance values, as well as energy consumption and light pollution [42–44].

The review points out that floodlighting is mainly performed using simulation software to obtain photorealistic images of the lighting solutions, verify compliance with the standard and law for the illuminance and luminance values on the façade, and reduce light pollution. The literature suggests that virtual reality is not usually used for this kind of research.

1.2. Park and Green Areas Lighting

Urban parks and green areas have become important areas of the city that affect citizens' lives and the city's appearance during the day and night. Indeed, studies point out that green spaces increase the quality of life, positively impacting citizens and workers both physically and psychologically [45–47]. Additionally, they serve as a location for people to exercise, spend their leisure time, unwind, and create connections between various sections of the city [7,48]. For this reason, it is necessary to design appropriate lighting systems that ensure a high sense of security [5] and an adequate enhancement of the spaces [49–52] in the evening. However, problems related to light pollution [53] and the disturbance of the existing fauna [54] have to be avoided. According to the literature, the effects of light conditions on people's perceptions and preferences are investigated using on-site tests [2,3,6] or virtual reality [55–58].

Wickremasinghe et al. [3] assessed how correlated color temperature (CCT) and illuminance values, as well as the type and design of luminaires, affect the sense of safety and the perception of lighting quality in urban parks. The evaluations were carried out through on-site subjective tests using questionnaires in five urban parks. The results pointed out that path lighting is assessed positively if the average illuminance is greater than 10 lux with a CCT of 3500 K. Smith et al. [2] evaluated the lighting quality in different urban park areas, considering average illuminance values, CCT, and context. A subjective on-site analysis was carried out with several users who had the possibility to vary both the emitted luminous flux and the CCT. Visitors generally preferred average illuminance levels between 20 and 30 lux and CCT values of 4200 K for service areas and 3000 K for the remaining areas. Zhang et al. [6] instead analyzed the visitors' psychological and behavioural factors in a real urban park through a survey to evaluate their lighting preferences. The results underlined that visitors prefer luminaires with a more refined design, a reduced height (avoiding using poles for street lighting), and a less-visual impact on the surrounding environment.

Masullo et al. [55] assessed how gazing behaviors, subjective reports, and individuals' emotions are impacted by the overall illuminance levels and CCT of the illuminated environment in an urban park. A detailed model of an actual city park in southern Italy was modeled into Unreal Engine and used to simulate various lighting conditions. Users were asked to view the virtual environments through an HMD and respond to a questionnaire to evaluate the perceived quality of the outdoor lighting. In Tabrizian et al. [56], an urban park and square were modeled in virtual reality to evaluate the effect of the vegetation arrangement (number of trees and shrubs) on people's perception of safety. Different portrayal methods were used in [57] to evaluate the psychological impact of various outdoor lighting solutions on people. The results underline virtual reality's effectiveness in comparing and judging different lighting solutions. Using the Unreal Engine, Lee and Lee [58] built a virtual urban plaza to investigate the effectiveness of virtual reality simulation for qualitative analysis of landscape lighting design.

On the one hand, the review highlights the potentiality of VR to assess lighting scenarios for outdoor; on the other hand, achieving a realistic light environment in virtual reality is still challenging due to the inaccurate reproduction of light distribution. Similarly, without a correct reproduction of the light luminous intensity distribution in the VR, it is impossible to perform a quantitative assessment of the light's uniformity and quantity. In recent years, some methods have been proposed to ensure a correct artificial light distribution from the photometrical point of view in the virtual environment [30,59].

In addition, only a few studies have investigated the effects of outdoor lighting using virtual reality, and they mainly consider urban parks or urban areas.

1.3. Mutual Influences among Lighting Systems for Different Applications

Although the lighting of buildings and parks is an essential element for modern society, research carried out to date has been aimed at evaluating one or the other separately. This approach prevents the evaluation of reciprocal influences and integrations, especially in places such as monumental complexes, where a clear separation between the architecture and the surrounding vegetation areas is impossible. To the best of the authors' knowledge, only one study [60] evaluated the interaction between road and park lighting close to historical buildings, verifying the possibility of using it as an additional component for façade lighting design from both photometrical and energy points of view by using DIALux. In particular, the study evaluated the luminance variations on the façade upon varying the road and park lighting typology, as well as the distance from the façade.

1.4. Aim of the Research

In recent decades, virtual reality (VR) has had numerous applications, from industrial design [61] to healthcare [62]; however, VR is still not widely used for lighting design, especially in the context of historical gardens and buildings.

This research aims to examine the relationship between the lighting for historical gardens and listed architecture. Specifically, it seeks to determine how the lighting of the elements of the garden affects people's perception of the architecture during the night. With this objective, a detailed 3D model of a monumental complex located in Spain was built and imported into DIALux evo (DIALux) and Unreal Engine 4 (UE4). The 3D model was developed based on an accurate on-site survey performed using a laser scanner. DIAlux was used to develop and optimize different lighting scenarios upon varying the lighted element of the garden, while the architecture is lighted with a planar lighting method. Then, each lighting scenario was reproduced in UE4 and shown to participants through an HMD. Participants were asked to see the virtual scenario and answer a questionnaire about the perceived light strength of the whole virtual environment and the architecture.

Therefore, the area considered, the use of VR to evaluate different light scenarios for outdoor, and the assessment of the interaction between garden and façade lighting represent the novelties of this paper compared to the current literature [63,64].

2. Materials and Methods

The present work starts with detailed geometrical and photographic on-site surveys of architectures and vegetational areas to create virtual models as similar as possible to the real environment from geometrical and visual points of view. The model is used to develop six different lighting scenarios, considering the garden lighting as a variable. Each scenario was presented to a group of volunteers who were asked to judge the interaction between the garden and architectural lighting. The process is reported in Figure 1.

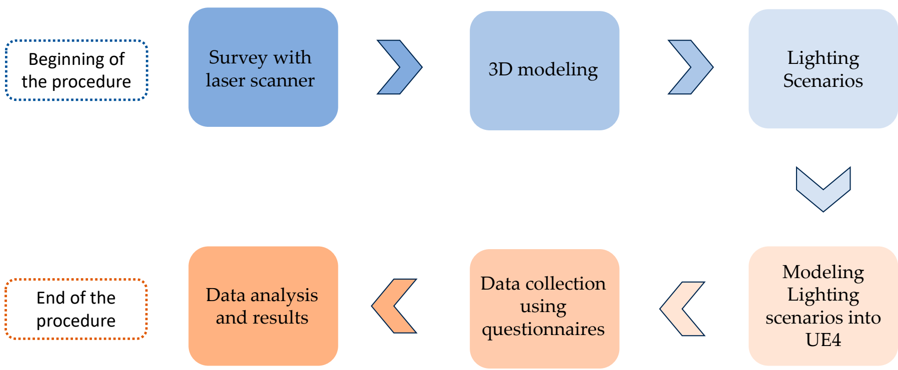


Figure 1. Scheme of the methodological process.

2.1. Material

2.1.1. Three-Dimensional Models Development

The area under investigation is the western part of Escorial's monumental complex (Spain) [65], which includes the Casita de Arriba or Casita del Infante (Casita) and its surrounding Jardines. The site is considered an example of a Spanish garden with the greatest consistency with the idea of a compact and central residence around which recreational gardens are developed [66]. Figure 2 shows the plan of the site's current state (measured in 2022) with the identification of the area under investigation in this research (see red rectangle), namely, the Casita and the part of the Jardines between the architecture and the principal gate to the site. A 24 m-long and 7.50 m-wide main pathway connects the main gate with the Casita. On the left and right sides of the main pathway, secondary pathways link the main pathway with secondary gates to other terracings composing the site. The Casita is located on a base and is accessible from the main pathway via three steps. Two sphinxes on bases are placed on the sides of the steps; the sphinxes are connected to the wall that separates the base of the Casita from the main pathway. The surface of the area is about 1276 m^2 and is characterized by rich vegetation composed of trees of different heights and low hedges that limit the paths. A protruding central body characterizes the north facade of the Casita. The architecture is symmetrical, with the symmetry axis coinciding with the steps and the main pathway axes. The principal door and four of the eight windows on the north façade are placed on the protruding body.

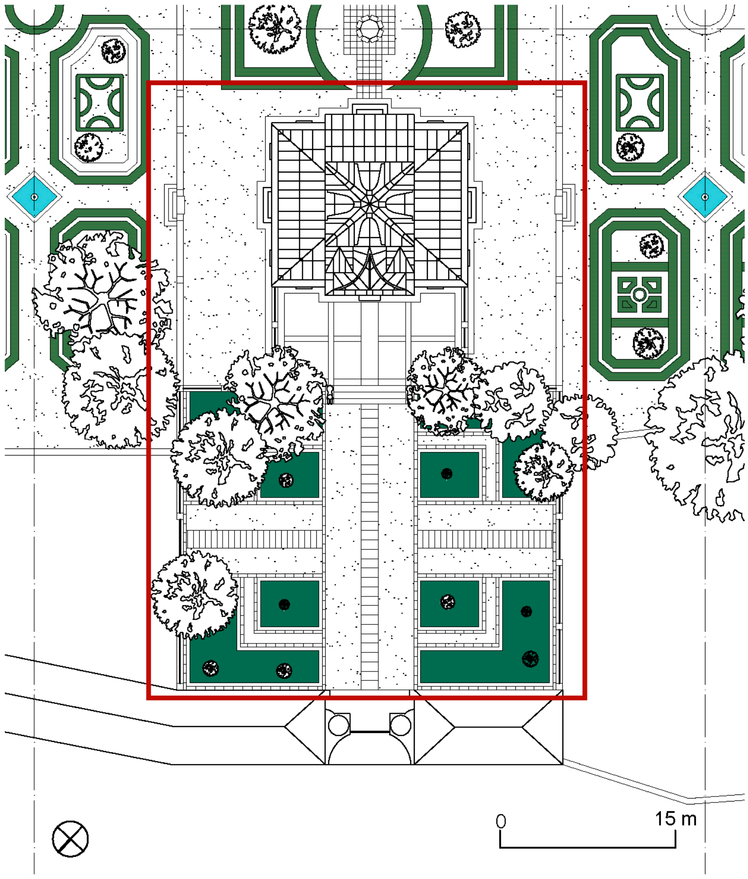


Figure 2. The Casita de Arriba and the Jardines, plan of the current state with identification of the area under investigation.

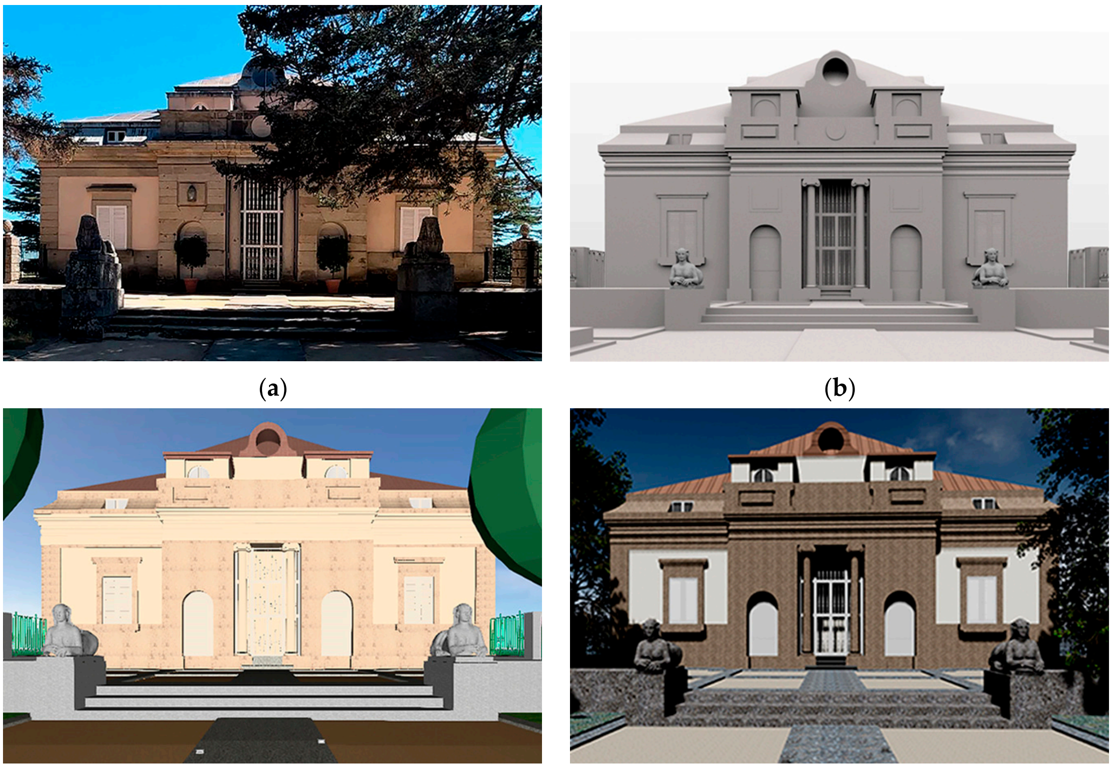
The geometric survey was carried out by using the laser scanner "Leica RTC360". A total number of 43 scanning positions were needed to measure the entire area. The measurements in each scanning position were aligned and assembled to obtain a dense point cloud of the whole area, as reported in Figure 3. A geometrically detailed 3D model of the Casita and the area of the Jardines considered in this research has been inferred from the dense points cloud. Specifically, the dense point cloud was imported into CAD software 2021 and used as a reference by which to draw the surfaces that will constitute the 3D model of the site. At this stage, the users can decide the accuracy of the 3D model according to their needs. The greater the number of surfaces drawn to constitute the 3D model, the greater the accuracy of the 3D model. Later, surfaces made of the same material were grouped in the same layer. A total of ten levels, one for each material detected in the real environment, were considered. Then, the 3D model is separately imported into DIALux evo and 3ds Max 2021 for subsequent processing.

Once imported into DIAlux, the virtual model was further processed before being used for lighting design, assigning the material to the surfaces and adding vegetation. The materials were selected from the DIALux database to be as visually similar as possible to the real ones. The vegetation was modeled respecting both the position and the size of trees, hedges, and shrubs.

Figure 3. Dense point cloud of the Casita de Arriba and Jardines.

The 3D model was separately imported into the "3ds Max" software for managing the surfaces and textures before importing the model into UE4. Once imported in UE4, the model was further manipulated to insert vegetation (respecting the geometric position and size of trees, hedges, and shrubs) and material textures. The color and texture of surfaces were chosen based on the photographic survey to make the model as similar as possible to the real site.

Figure 4a–d show a picture of the real site, the accurate 3D model inferred from the dense point cloud, the virtual model in DIALux, and the virtual model in UE4, respectively.



(**a**) (**b**) (**c**) (**d**)

Figure 4. La Casita de Arriba and Jardines: (**a**) picture of the real site; (**b**) detailed 3D model; (**c**) 3D model in DIAlux; and (**d**) 3D model in UE4.

2.1.2. Lighting Scenarios

The peculiarity of the site has strongly influenced the lighting design, specifically the choice of luminaires. Being a monumental garden, the luminaires have to ensure proper illuminance values and impact as little as possible on the view of visitors during the day. These requirements suggest steplights and floodlights instead of conventional solutions like poles or bollards.

Alongside the façade of the Casita de Arriba (Façade), four further characteristic elements of the Jardines were distinguished, namely, the main pathway (MP) and secondary pathways (SP), sphinxes (SH), and steps (ST), which were considered and combined to define the lighting solutions. The main pathway and the steps were considered since they connect the area of the garden with the architecture. The secondary pathways represent the connection with the other areas of the Jardines. Finally, the sphinxes were illuminated for their historical value inside the garden.

The Casita de Arriba was illuminated using a planar method to attain uniform illumination on the entire façade. Four floodlights [67] (optic: wide beam 102°; fitting luminous flux: 1598 lm; CCT: 3000 K; color rendering index (CRI): =90; fitting efficiency: 90 lm/W) were positioned at a distance of 7.5 m from the building to ensure an average illuminance value of about 20 lux (corresponding to an average luminance value of about 5 cd/m^2) on the facade to comply with Spanish legislation zone E3 [53].

Six different lighting scenarios were considered for the Jardines to highlight the different scenic elements identified in the area of the garden under consideration:

- Scenario 1 (S1): the Jardines are not lighted (only the Casita façade is lighted);
- Scenario 2 (S2): the main pathway is lighted;
- Scenario 3 (S3): the main pathway and the secondary pathways are lighted;
- Scenario 4 (S4): the main pathway and the sphinxes are lighted;
- Scenario 5 (S5): the main pathway, the secondary pathways, and the sphinxes are lighted;
- Scenario 6 (S6): the main pathway, the secondary pathways, the sphinxes, and the steps are lighted.

The software DIALux was used to model and optimize the lighting systems for each scenario. Whatever the scenic element is, the typology and position of the luminaires have been chosen to limit their visual impact on the surrounding environment during the daytime as much as possible.

The main pathway was illuminated with 23 steplight lamps [68] (optic: 360° symmetrical optic; fitting luminous flux: 374 lm; CCT: 3000 K; CRI: ≥80; fitting efficiency: 45 lm/W), positioned alternately on the right and left of the main pathway. This lighting solution allows for illumination of the main pathway and the adjacent areas, and it also achieves an average illuminance value on the pathway of about 30 lux [2,3]. Sixty-four steplights with the same characteristics were used for the secondary pathways to ensure average illuminance values of about 35 lux.

Each sphinx was lit using two floodlights (optic: wide beam 40°; fitting luminous flux: 470 lm; CCT: 3000 K; CRI: ≥80; fitting efficiency: 67 lm/W) [69], positioned at about 2.50 m and slightly inclined to illuminate the sphinx and its base.

The steps were lighted up with six spotlights [70] (optic: wide beam 34°; fitting luminous flux: 284 lm; CCT: 3000 K; CRI: = 90; fitting efficiency: 71 lm/W) placed on the staircase's left and right side walls to ensure, on each step, average illuminance values equal to about 25 lux [71].

In addition, to emphasize the secular trees in the area, they were illuminated with spotlights [72] placed at their base (optic: ultra-wide beam about 108°; fitting luminous flux: 1505 lm; CCT: 3000 K; CRI: = 90; fitting efficiency: 75 lm/W).

The position of the luminaires in relation to the scenic elements, as well as the area illuminated in each scenario, are displayed in Figure 5a–f, while Figure 6a–f show the six optimized lighting scenarios modeled in DIALux.

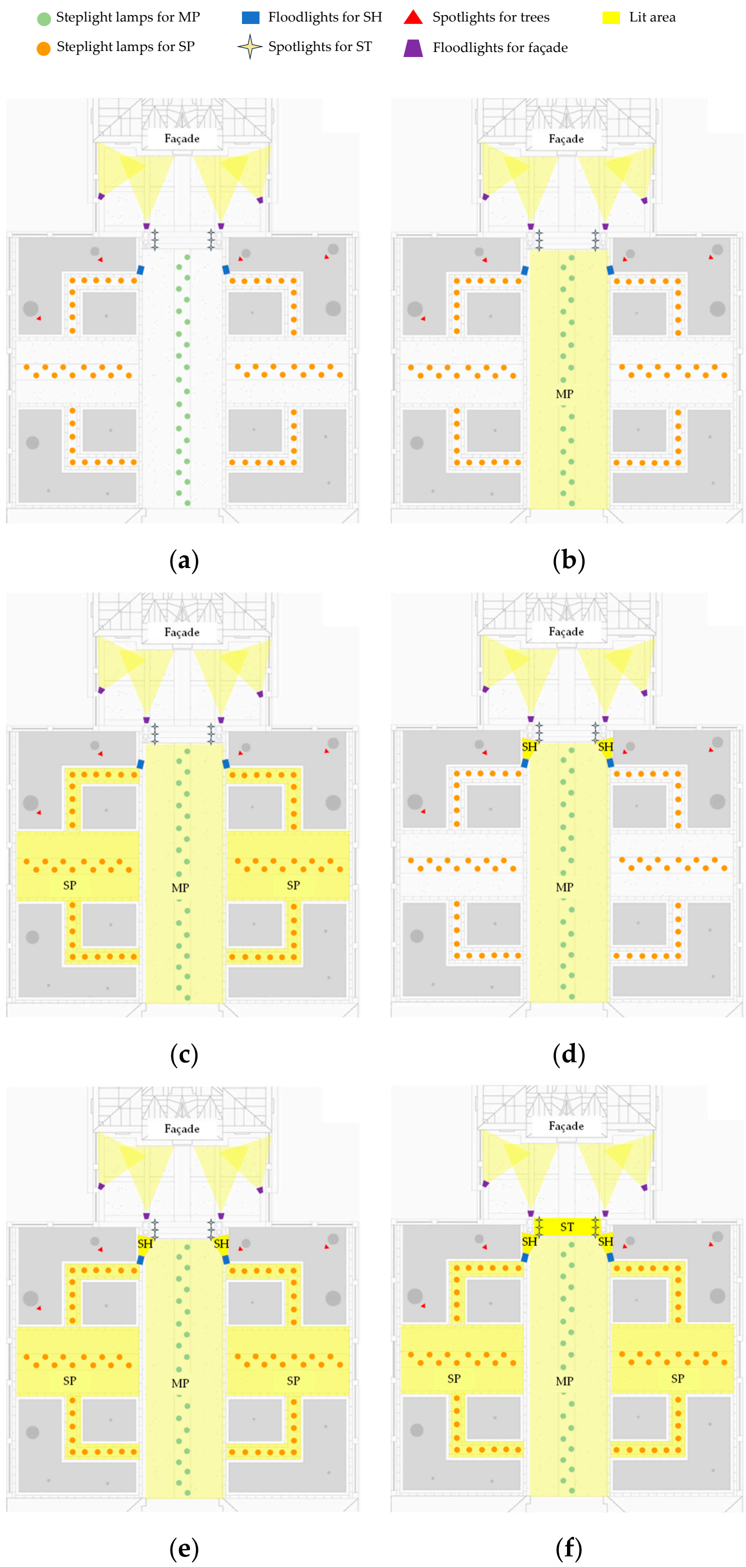
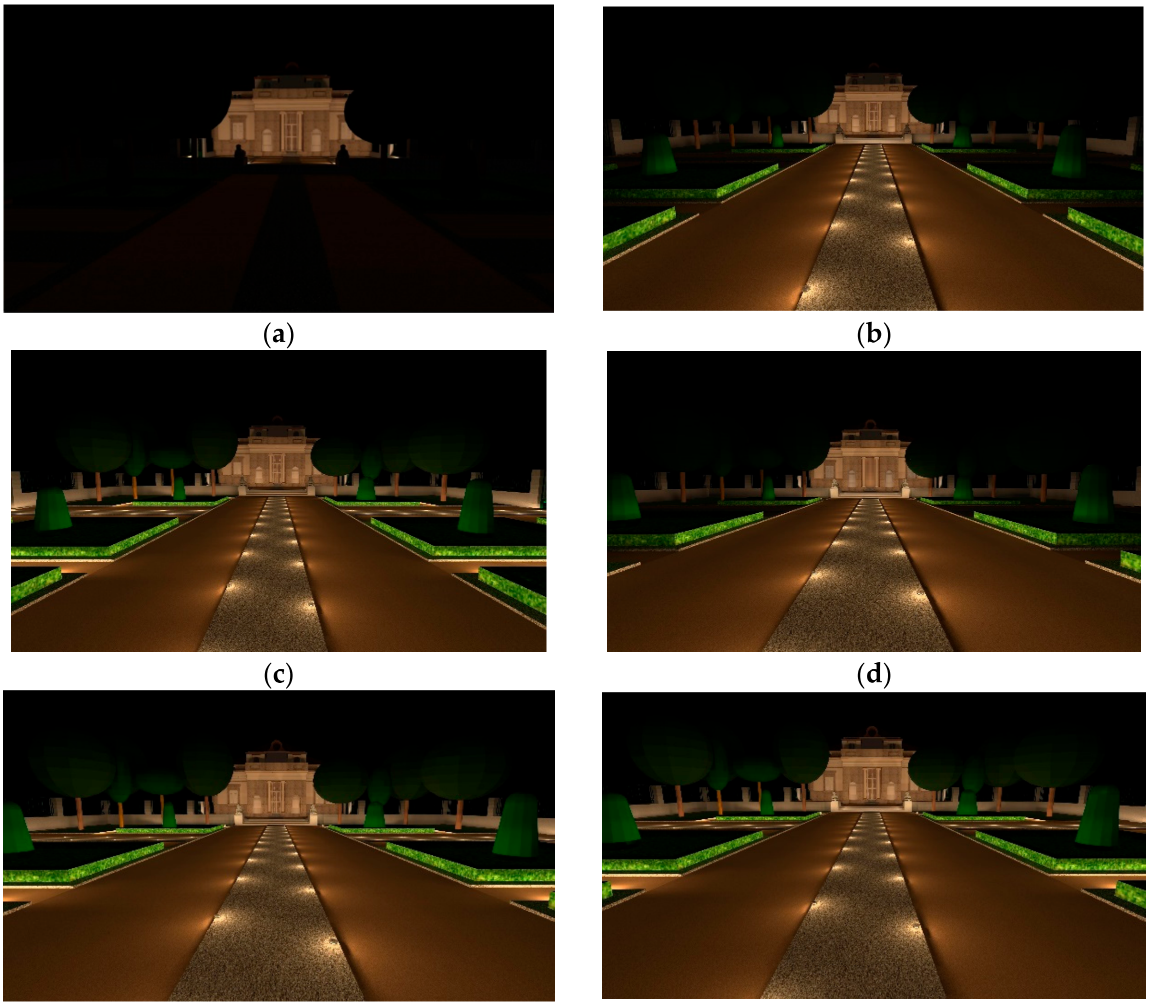


Figure 5. Layout of the luminaires' position and the illuminated areas of the garden upon varying the scenic elements: (**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3; (**d**) Scenario 4; (**e**) Scenario 5; (**f**) Scenario 6.



(a) (b) (c) (d) (e) (f)

Figure 6. Lighting scenarios optimised in DIALux: (**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3; (**d**) Scenario 4; (**e**) Scenario 5; (**f**) Scenario 6.

The information about the position, size, orientation, luminous flux, CCT, and luminous intensity distribution of the luminaires was deduced from the optimized lighting scenarios in DIALux and used to reproduce the scenarios in UE4. Each type of luminaire was modeled in UE4 with light sources "spot light" set as "static" and calibrated according to the procedure described in [59]. In particular, the calibration procedure provides for activating the "inverse squared falloff" function and assigning appropriate values to the parameters "Inner/Outer cone angle" and "Luminous flux". The ideal values of the Inner/Outer cone angle to set in UE4 ($\gamma_{I/O\ angle}$) were calculated using the following equation:

$$\gamma_{I/O\ angle} = 1.135 \cdot \gamma_{hf} + 3.1, \quad (1)$$

where γ_{hf} is the half luminaire field angle of the selected luminaire.

The optimal value to use in UE4 for the parameter "Luminous flux" was identified by modeling in DIALux and UE4 a black-painted simplified room, placing in it the selected luminaire, and comparing the luminance values on white high diffusing markers computed by both simulation software upon varying the luminous flux in UE4. The value that minimizes the differences between DIALux and UE4 luminance values was chosen as the value to use in UE4.

Geometrical information about luminaires' position and orientation was also reproduced in UE4 to ensure that luminance values in UE4 were similar to those computed in DIALux. In addition, the luminaires' models (shape, general structure, and color) were imported to improve the model quality. A spherical image for each scenario was obtained from the virtual model in UE4 using the plugin "Nvidia Ansel" to be displayed in the HMD. Figure 7 shows the six virtual environments.

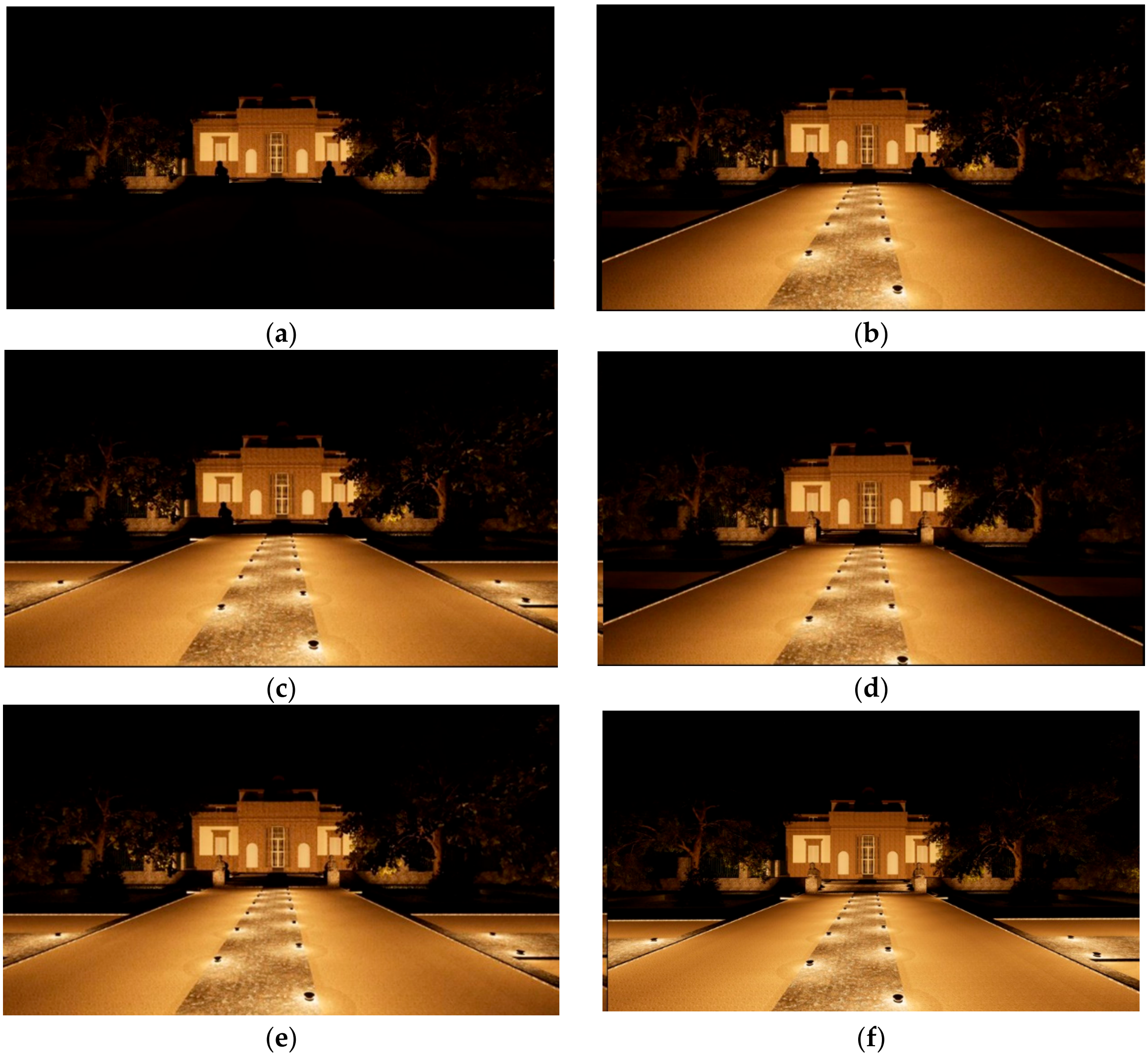


Figure 7. Lighting scenarios modeled in UE4 based on the information deduced from DIALux: (**a**) Scenario 1; (**b**) Scenario 2; (**c**) Scenario 3; (**d**) Scenario 4; (**e**) Scenario 5; (**f**) Scenario 6.

The accuracy of lighting scenario reproduction in UE4 was evaluated by comparing the luminance values measured in UE4 with those in DIALux on thirteen control points. Figure 8 shows the position of control points, which remain fixed upon varying scenarios. The comparison underlines a percentage difference between −4.8% and 5.2%. Table 1 lists the luminance values in UE4 on the control points for each of the six lighting scenarios. The values in the table confirm that: (i) the luminance values on the Casita de Arriba façade (control points from M8 to M13) are not influenced by the lighting system in the Jardines, keeping the values measured in S1; and (ii) the illumination of the different areas does not affect each other.

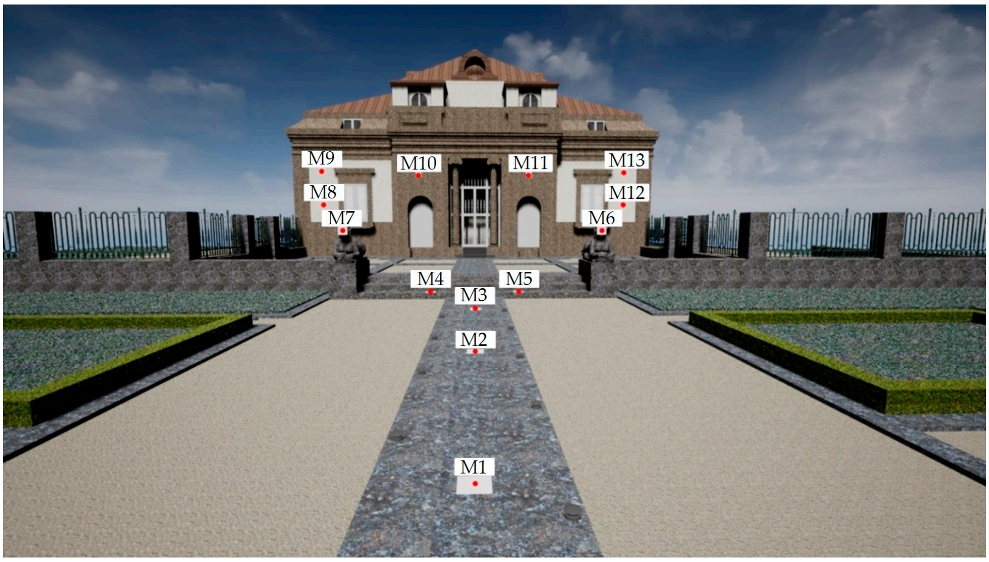


Figure 8. Control points considered to verify the luminance distribution in DIALux and UE4 models upon varying the lighting scenarios.

Table 1. Luminance values in UE4 on the control points upon varying the lighting scenarios.

Scenario	Luminance cd/m^2												
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**	**M13**
S1	0.09	0.08	0.06	0.04	0.04	0.07	0.09	5.33	4.69	6.02	6.03	5.42	4.58
S2	4.38	4.43	4.99	0.09	0.09	0.16	0.13	5.34	4.69	6.02	6.03	5.42	4.58
S3	4.40	4.43	5.04	0.09	0.09	0.17	0.14	5.40	4.71	6.03	6.09	5.46	4.59
S4	4.48	4.61	4.81	0.09	0.09	9.43	9.20	5.44	4.71	6.06	6.10	5.47	4.59
S5	4.50	4.61	5.01	0.09	0.09	9.56	9.76	5.45	4.73	6.08	6.11	5.48	4.60
S6	4.50	4.70	5.32	1.48	1.63	10.01	10.03	5.46	4.73	6.10	6.12	5.48	4.60

2.2. Method

Each scenario was shown through the Oculus Meta Quest 2 HMD, with a fast-switching LCD, resolution of 1832 × 1920 pixels per eye, and refresh rate of 90 Hz. Once wearing the HMD, the participants were asked to stand (to simulate a person visiting the garden) and watch the scene (rotating the head) for more than one minute to familiarize themselves with the scenario. After this period, the participant was invited to answer a questionnaire verbally. The duration of the test was about 10 min. The questionnaire aims to investigate people's perception of the Casita de Arriba façade when different strategies to illuminate the Jardines are considered. View perception was evaluated through perceptual impressions [29,63]. The *Perceived Light Strength* was evaluated for the whole scene, asking people to answer questions about the perception of brightness through the words "strong", "light", "brilliant", and "clear", as well as the direction of light with word "focused", indirectly linked to brightness perception [13,55,73,74]. After this first part, participants were asked to focus their attention on the building façade (visual task assigned) and answer the questions about the perceived light strength again. The quality and realism of the proposed lit scenarios were evaluated with the reported *Presence* [29,63]. A 7-point Likert unipolar scale was used (1 = not at all; 7 = very much) for each item. In addition, participants were asked to give the three elements that most attracted their attention in the scenario in order of importance. The questionnaire was in the Italian language (both English and Italian versions of the questionnaire are reported in Appendix A).

The research was based mainly on a mixed-design. The lighting scenarios, with six levels (scenarios 1 to 6), were used as between-subject factors. The watching way, with two levels (no visual task and visual task assigned), was used as the within-subject factor. Twenty-five volunteers were exposed to one of the six scenarios, for a total of 150 participants between 16 and 60. A statistical power of 0.80, considering a significant level (α) of 0.05 and an effect size f = 0.30, was calculated with G*Power [75].

The statistic descriptors mean values (M) and standard deviation (SD) were used to compare the participants' responses. One-way ANOVA analysis and a post hoc test with Bonferroni correction were used to assess statistically significant differences among the between-subject factors, while repeated one-way ANOVA and a post hoc test with Bonferroni correction were used to assess statistically significant differences among the within-subject factors.

3. Results

The first phase of the research aims to combine digital tools for the survey and representation to obtain accurate three-dimensional digital models of monumental gardens and historical buildings for lighting investigations. The second phase intends to evaluate the interaction between lighting for two applications through virtual reality and to use subjective assessment to investigate the impact of garden lighting on the perception of both the environment as a whole and the lit building. Six virtual lit scenarios were designed with different lighting solutions for the Jardines, while the façade of the Casita de Arriba is illuminated following the planar lighting method.

3.1. Effects of Lighting Scenarios on the Sense of Presence

The sensation of physically existing in a virtual environment is known as the sense of *presence* and was evaluated through three items: *realism*, *sense of being there*, and *spatial awareness*. One-way ANOVA revealed no significant differences among groups on the *presence* items: *realism* (F(5,144) = 1.086, p = 0.370); *sense of being there* (F(5,144) = 1.288, p = 0.272); and *spatial awareness* (F(5,144) = 0.757, p = 0.582). The mean values and standard deviation for each item and group are reported in Figure 9. Results underline that the virtual environments are evaluated positively, with mean values generally greater than 4.00.

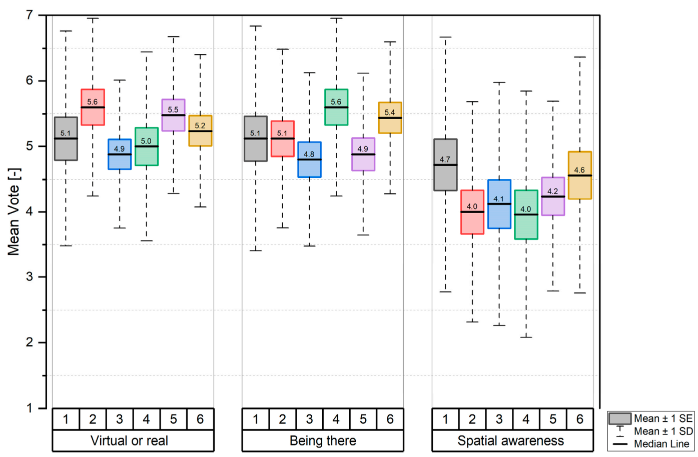


Figure 9. Mean and standard deviation values for the sense of presence upon varying the lighting scenario.

3.2. Effects of Lighting Scenarios on the Perceptual Impression

Regarding the *perceptual impression*, significant differences were found for *complexity* (F(5,144) = 2.757, p = 0.021), while no significant differences were found across the scenarios for the items: *pleasantness* (F(5,144) = 1.114, p = 0.355); *satisfaction* (F(5,144) = 1.189, p = 0.317); and *familiarity* (F(5,144) = 0.619, p = 0.685). From the data displayed in Figure 10, it is possible to infer the following:

- Regarding the complexity, S1 (M = 3.96, SD = 1.91) and S2 (M = 4.00, SD = 1.44) are judged as less *complex*;
- Participants generally express a high rate of *pleasantness* and *satisfaction* with all scenarios, with mean values greater than 4.56 and 4.68, respectively, even if no specific trend can be deduced;
- No familiarity with the scenarios was expressed by participants (mean values between 2.68 and 3.48).

However, the low values obtained for the sense of familiarity show that users were unfamiliar with the scenarios presented. This result can be linked to the fact that the participants did not know the real site, that not all users had a clear idea of the monumental site, or that some participants had never seen VR scenarios.

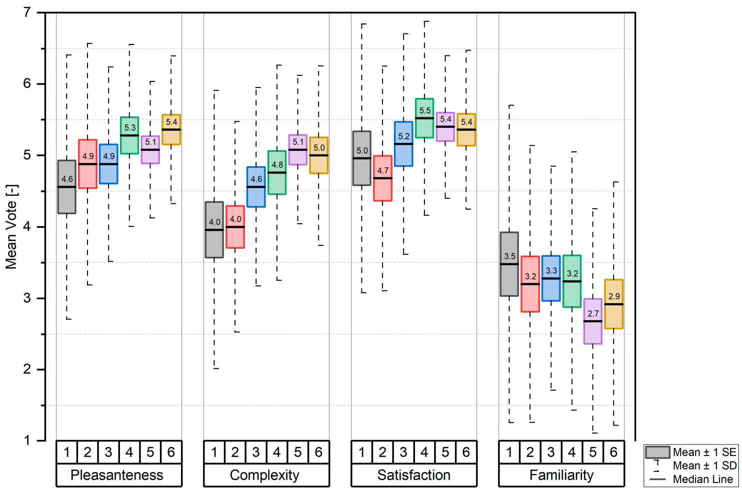
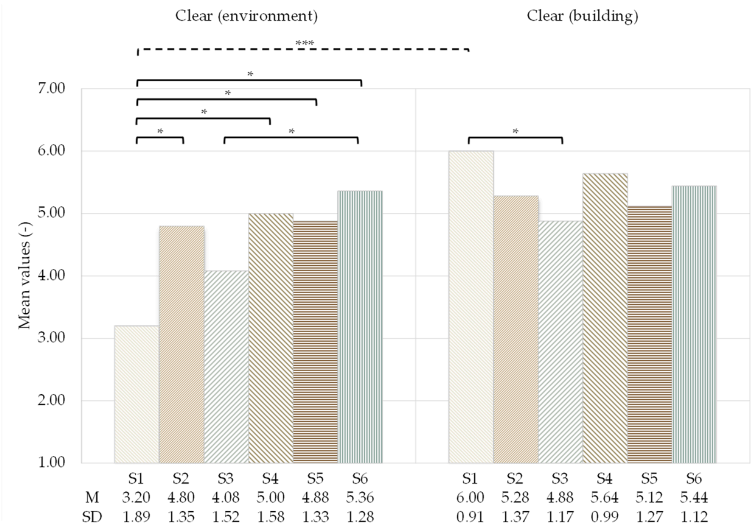


Figure 10. Mean and standard deviation values for the perceptual ompressions upon varying the lighting scenario.

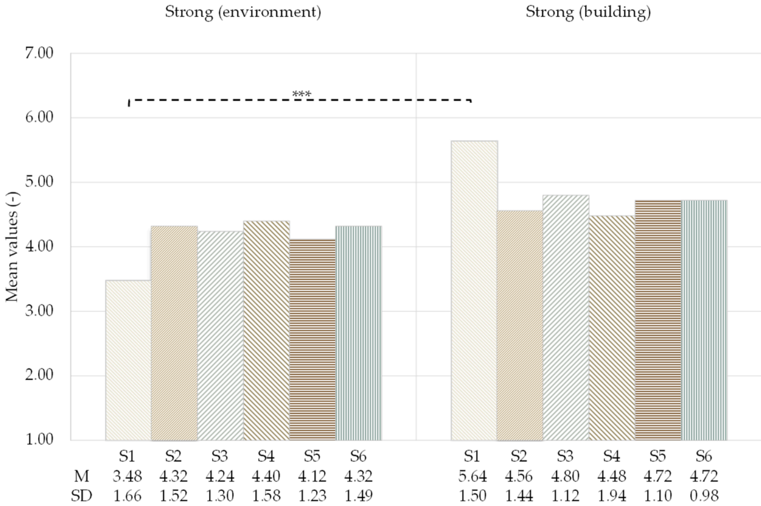
3.3. Effects of Lighting Scenarios on the Perceived Light Strength

This section reports the results of the effects of the between-subject and within-subject factors on the perceived light strength.

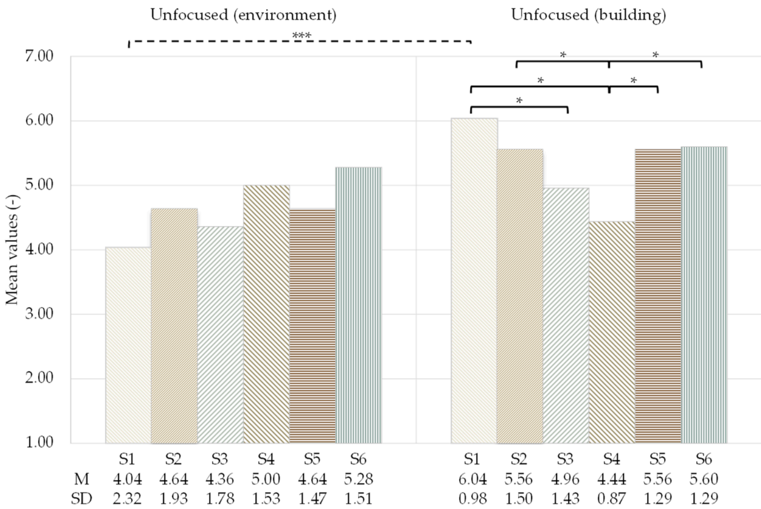
Clear (see Figure 11a): Results related to between-subject factor showed that a main effect of the light scenario on the item *clear* referred to the entire virtual environment ($F(5,144) = 6.741$, $p < 0.001$). Specifically, when participants answer the item for the whole environment, their judgment increases as the number of elements illuminated increases. The post hoc test underlines a different impact of illuminated elements on the participants' rating. In particular, Scenario S2 (with the main pathway illuminated) is perceived as more *clear* (M = 4.80, SD = 1.35) than S1 (M = 3.20, SD = 1.89). The illumination of sphinxes, S4 (M = 5.00, SD = 1.58), and steps, S6 (M = 5.36, SD = 1.28), increases the scene's perception as clearer compared to scenario S1. On the contrary, the contribution of secondary pathways illumination is negligible in S3 (M = 4.08, SD = 1.52) compared with S1. The results are entirely different after asking people to focus on the building façade, underlining that the significant effects of the light in the scenario on the item *clear* referred to the building ($F(5,144) = 2.960$, $p = 0.014$). In this case, the rating values are higher than those obtained when participants judged the entire environment, whatever the scenario is. The post hoc test reveals a negative effect of secondary pathway illumination on the perception of the scene as *clear* in S3 (M = 4.88, SD = 1.17) compared to S1 (M = 6.00, SD = 0.91). The results of within-subject analysis point out the significant effects of task assignment on the item ($F(1,144) = 36.43$, $p < 0.001$). The post hoc test reveals a significant increase in the mean value from the not-assigned to the assigned task for S1 $p < 0.001$.



(**a**)

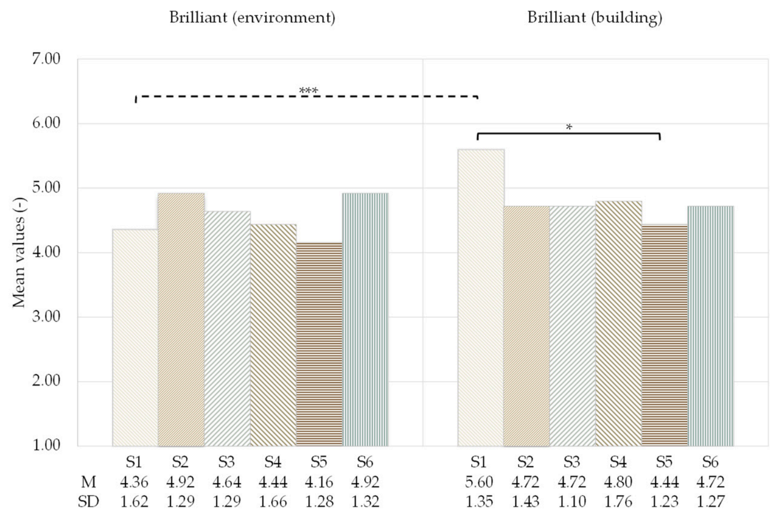


(**b**)

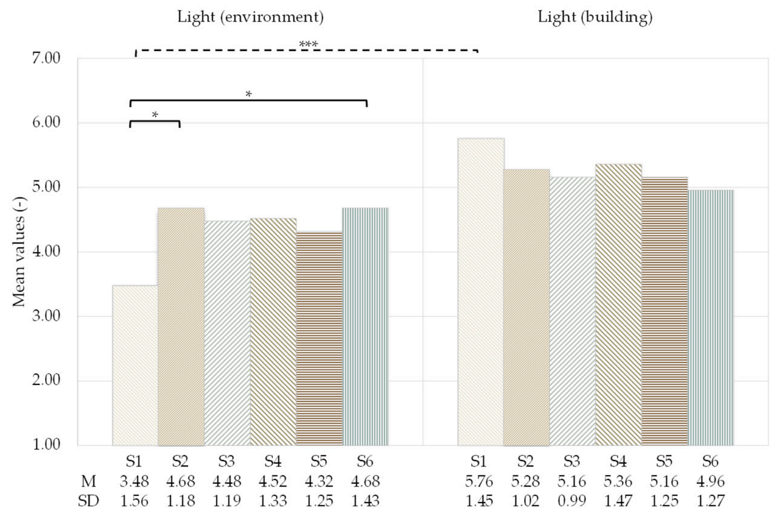


(**c**)

Figure 11. *Cont*.



(**d**)



(**e**)

Figure 11. Comparison between the perceived quality of the light strength for the whole scene and the architecture upon varying the lighting scenario for the item: (**a**) *clear*; (**b**) *strong*; (**c**) *unfocused*; (**d**) *brilliant*; and (**e**) *light*. Significant differences are indicated with an * ($p < 0.05$) or *** ($p < 0.001$).

Strong (see Figure 11b): The between-subject analysis results highlight no significant effects of light scenario on the item *strong*, neither related to the entire virtual environment ($F(5,144) = 1.333$, $p = 0.254$) nor when participants were asked to focus on the building façade ($F(5,144) = 2.283$, $p = 0.049$). The results of the within-subject analysis point out the significant effects of task assignment on the item ($F(1,144) = 30.05$, $p < 0.001$). The post hoc test reveals a significant increase in the mean value from the not-assigned to the assigned task for S1 $p < 0.001$.

Unfocused (see Figure 11c): Results of the between-subject analysis highlight no significant effects of light scenario on the item *unfocused* related to the entire virtual environment ($F(5,144) = 1.535$, $p = 0.182$). On the contrary, they showed a main effect of the light scenario on the item *unfocused* when participants were asked to focus their attention on the building façade ($F(5,144) = 5.154$, $p = 0.000$). The post hoc test discloses that the mean value significantly reduces for scenarios S3 (M = 4.96, SD = 1.43) and S4 (M = 4.44, SD = 0.87) compared to S1 (M = 6.04, SD = 0.98), while it improves for scenarios S5 (M = 5.56, SD = 1.29) and S6 (M = 5.60, SD = 1.29) compared to S4 (M = 4.44, SD = 0.87). The highest mean value for S1 (M = 6.04, SD = 0.98) could be linked to the planar lighting method adopted for the building façade. The lowest mean value obtained for S4 could be explained by the fact that the illumination of the sphinxes generates focused lighting at the center of the observer's field of view, who is engaged in observing the building. The within-subject analysis displays a significant effect of task assignment on the item (F(1,144) = 18.02, $p < 0.001$). The post hoc test reveals a significant increase in the mean value from the not-assigned to the assigned task for S1 $p < 0.001$.

Brilliant (see Figure 11d): The between-subject analysis highlights no significant effects of light scenario on the item *brilliant* related to the entire virtual environment (F(5,144) = 1.186, $p = 0.319$). No significant results were observed when participants focused on building façade (F(5,144) = 2.076, $p = 0.072$). In this case, the post hoc test reveals that Scenario S5 (M = 4.44, SD = 1.23), with MP, SP, and SH lit, is evaluated as significantly less *brilliant* than Scenario S1 (M = 5.60, SD = 1.35). The within-subject analysis discloses a significant effect of task assignment on the item (F(1,144) = 5.27, $p < 0.023$). The post hoc test reveals a significant increase in the mean value from the not-assigned to the assigned task for S1 $p < 0.001$.

Light (see Figure 11e): The between-subject analysis exhibits significant effects of the lighting scenario on the item related to the entire virtual environment (F(5,144) = 2.882, $p = 0.016$). The post hoc test discloses a significant difference between S1 (M = 3.48, SD = 1.56) and S2 (M = 4.68, SD = 1.18) and between S1 and S6 (M = 4.68, SD = 1.43). No significant results were observed when participants focused on building façade (F(5,144) = 1.167, $p = 0.328$). All the scenarios are evaluated as *light*, with main values being higher than 4.96. The within-subject analysis discloses a significant effect of task assignment on the item (F(1,144) = 56.04, $p < 0.001$). The post hoc test reveals a significant increase in the mean value from the not-assigned to the assigned task for S1 $p < 0.001$.

3.4. Effects of Lighting Scenarios on the Order of Elements Perception

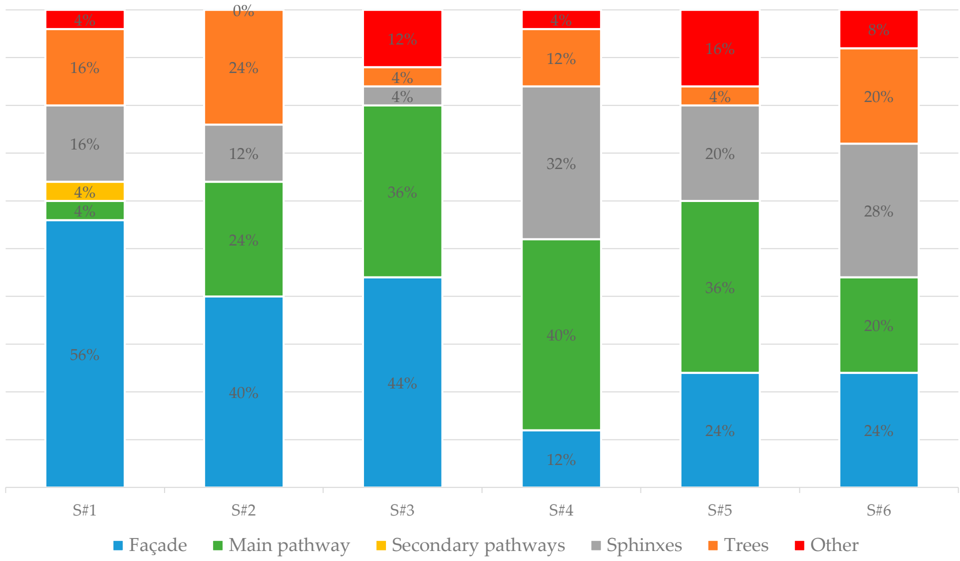
The relationship between the different design solutions for the Jardines and the planar lighting solution used for the façade of the Casita de Arriba was also investigated by asking participants to give three elements, in order of importance, that attracted their attention throughout the scenario.

Figure 12a shows the frequency distribution of the first element selected by users upon varying the lighting scenarios. The figure underlines that most participants are attracted by the façade in S1, S2, and S3, as well as that the percentage of people attracted by the façade decreases with the increase in the number of illuminated park elements. Regarding Scenario S1, although the façade is the sole lit element, participants indicated being attracted by shapes that look like trees and sculptures. This could be explained by considering the strong contrast between the scene's dark elements (not lit) and the bright area of the façade. This hypothesis is supported by the fact that the participants were not able to distinguish what element was actually involved but provided indications of what seemed to be the case. In addition, the results suggest that a completely dark environment surrounding an illuminated façade can distract the observer's attention from the facade itself.

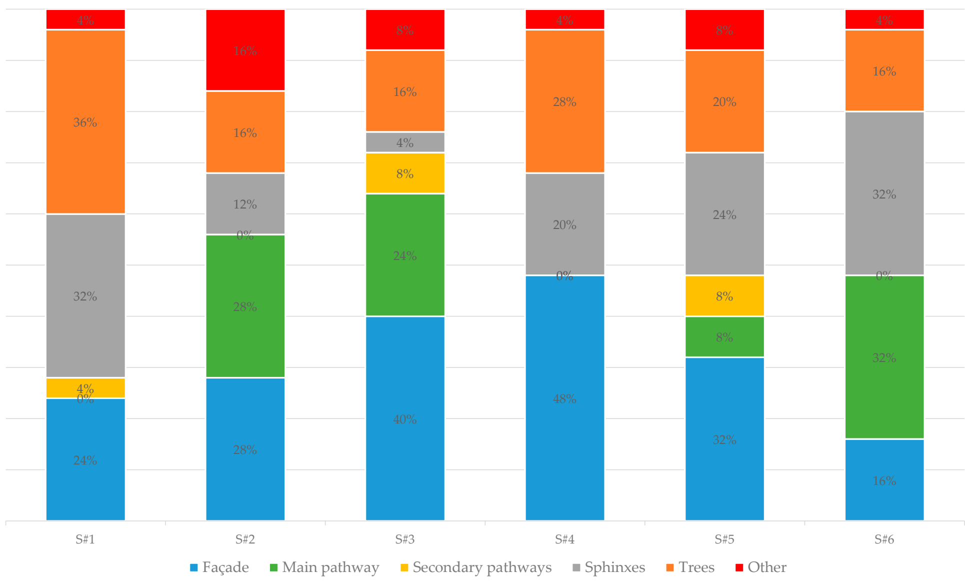
In S2, even though the façade remains the first element perceived, the MP and TR's lighting change the perception of the scenario, reducing the attention on the sphinxes. Although in S3, most users point to the façade and the main pathway as the most attractive elements, the lighting of the secondary pathways seems to divert users' attention to secondary elements of the scene, to the detriment of sphinxes and trees. In S4, the perception of users begins to change; the first element chosen remains the MP but there are changes to the perception of vertical elements. In fact, the facade loses importance to the advantage of vertical elements located between the volunteer and the façade, namely, the sphinxes. In S5, the MP remains the most attractive element, even though the SP's lighting influences the scene's perception, compared to S4, by shifting the users' attention from SH and TR to the façade and "other" elements. Finally, in S6, the ST's lighting brings participants' attention back to the elements between the user and the façade, such as façade, MP, SH, and TR.

Figure 12b displays the frequency distribution of the second element (in order of importance) indicated by users upon varying the lighting scenarios. The figure highlights that the highest and the lowest value of people indicating the façade as the second perceived element are reached in S4 and S6, respectively. In addition, results advise that the elements located between users and the façade (such as the main pathway and sphinxes) attract more participants' attention when not indicated as the first elements.

No specific trends can be deduced from the frequency distribution of the elements indicated as the third element perceived.



(**a**)



(**b**)

Figure 12. Frequency distribution of the elements attracting participants' attention in order of importance: (**a**) first place; (**b**) second place.

4. Discussion

The study examines how different illumination scenarios of a historic garden surrounding a listed building affect people's perception of the environment and architecture. With this aim, six different lighting scenarios (S1, S2, S3, S4, S5, and S6) were built in virtual reality and shown to the users through HMD.

The statistical analysis of the between-subject factors reported in Figure 11a–e shows that the strategy used to light the areas surrounding architecture can influence the perception of the space and architecture. When people look at the entire virtual environment (visual task not defined), illuminating the garden's elements leads to a more positive evaluation of how *clear* and *light* was the scene perceived. Notably, the results underline the critical role of some elements of the garden located between the observer and the architecture, such as MP, PH or ST, in modifying the light strength perception when no visual tasks are assigned. Indeed, S2 and S6 exhibit significant differences with Scenario S1.

When people judge the scene by looking at the building façade (visual task assigned), the illuminated areas in the garden lead to negative effects on how *clear*, *unfocused,* and *brilliant* the environment appears. In this case, the SP seems to be the element that, if lighted, involves a reduction in people's rating, specifically S3 for the items *clear* and *unfocused*, as well as S5 for the item *brilliant* compared with S1.

Regarding the within-subject factor, the outcomes displayed in Figure 11a–e point out that giving participants a visual task (namely, focusing their attention on the lit façade) significantly affects their perception of the virtual environments. In particular, the scenarios are judged as more positive when people are looking at the lit façade.

Concerning the relative order with which the elements in the scene attract people, the results in Figure 12 imply that among the scenarios with the garden's elements lit, S3 allows the façade to be the most attractive element in the scene, while the lowest value of people indicating the façade as the first perceived element is reached in the S4. In addition, the results identify the SP's lighting as the element that mainly influences the scene's perception, although it is never indicated (except for S1) as the first element attracting attention. In general, avoiding lit elements between the observer and the architecture ensures that a lot of people point to the façade as the first or second attractive element of the scene.

The outcomes confirm the benefits of using VR in research to evaluate people's perception of different lighting solutions for outdoor applications. In addition, they suggest the use of VR as a tool for participatory planning to improve the acceptability of design choices. However, some limitations need to be addressed. One of these is the limited ability to achieve high luminance values with the HMD [76,77]. Moreover, it is not clear how the luminance distributions are transferred from the software to the HMD, and how they are shown to participants through the headset display. Additionally, participants were not able to move around freely in the virtual environment.

Future works will aim to investigate, in depth, the physiological concerns surrounding the visual connection between the participants and the immersive virtual environment shown through the HMDs, the relationships among diverse methods to illuminate the façade and the garden lighting, the effects of different lighting strategies for the same element (i.e., accent lighting method for the façade), and the effects of walking in the virtual environment on people's opinion.

5. Conclusions

Starting from a detailed on-site geometrical and visual survey of the historic garden Jardines and the Casita de Arriba in the western part of the monumental complex Escorial in Spain, accurate virtual environments were realized in the simulation software DIALux evo and Unreal Engine 4 to investigate how the garden lighting can interact and influence the perception of the architecture. With this aim, six optimized lighting scenarios were displayed to 150 volunteers, divided into six groups. Lighting scenarios were obtained by combining the elements of the garden lit, while the façade of the historical building in the garden was lit with a planar method. Each group was asked to see one of the six scenarios and judge the perceived strength of light. A calibration methodology for luminaires [59] was used to ensure the designed illuminance and luminance distributions in the virtual lit environments. The results highlight the following:

- Illuminating the surrounding areas of the architecture can influence its perception and change the importance that people give to the building in the environment;
- Lighting the mean pathway, the sphinxes, and the steps can help in improving the perception of how *clear* or *light* the scenario is compared to Scenario S1, when people see the virtual scenario in its entirety;
- Illuminating the secondary pathways leads to a reduction in perceiving the scene as *clear*, *unfocused,* or *brilliant* in comparison to S1, when participants are asked to focus on the lit façade (visual task assigned);
- Assigning a visual task significantly modifies how participants perceive the virtual scene;
- The secondary pathways also influence the order in which the elements of the scene are perceived;
- Avoiding lit elements between the observer and the façade helps maintain the importance of the façade in the scene.

Despite the encouraging results obtained from using VR to investigate the combined effects of garden/park and architecture lighting on the participants' preferences, further research is needed in order to extend knowledge in this field.

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Informed Consent Statement: Participants are verbally informed about the objectives of the research. In addition, they are informed that the participation is voluntary, the questionnaire is completely anonymous, no data can be attributed to a participant, and they can easily exit at any time without penalties for either the researcher or themselves. Taking part in the research, the participant agrees to proceed and participate in the survey.

Data Availability Statement: The materials and the data that support the findings of this study are available from the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

This appendix presents the English and Italian versions of the questionnaire used in the research.

Parameter	Italian Questions	English Questions
Perceptual impressions (Impressioni percettive)	Quanto considera piacevole questo scenario? Quanto considera complesso questo scenario? Quanto è soddisfatto alla vista di questo scenario? Quanto ritiene familiare la vista di questo scenario?	How pleasant is this scenario? How complex is this scenario? How satisfied are you with the view of this scenario? How familiar are you with the view of this scenario?
Perceived quality of the light strength for the whole scene (Qualità percepita della forza luminosa per lo scenario)	Quanto giudica chiara l'illuminazione in questo scenario? Quanto giudica cupa l'illuminazione in questo scenario? Quanto giudica forte l'illuminazione in questo scenario? Quanto giudica debole l'illuminazione in questo scenario? Quanto giudica concentrata l'illuminazione in questo scenario? Quanto giudica uniforme l'illuminazione in questo scenario? Quanto giudica fioca l'illuminazione in questo scenario? Quanto giudica brillante l'illuminazione in questo scenario? Quanto giudica scura l'illuminazione in questo scenario? Quanto giudica luminoso questo scenario?	How clear is the lighting in this scenario? How drab is the lighting in this scenario? How strong is the lighting in this scenario? How weak is the lighting in this scenario? How focused is the lighting in this scenario? How unfocused is the lighting in this scenario? How subdued is the lighting in this scenario? How brilliant is the lighting in this scenario? How dark is the lighting in this scenario? How light is the lighting in this scenario?
Perceived quality of the light strength for the architecture (Qualità percepita della forza luminosa per l'architettura)	Quanto giudica chiara l'illuminazione in facciata? Quanto giudica cupa l'illuminazione in facciata? Quanto giudica forte l'illuminazione in facciata? Quanto giudica debole l'illuminazione in facciata? Quanto giudica concentrata l'illuminazione in facciata? Quanto giudica uniforme l'illuminazione in facciata? Quanto giudica fioca l'illuminazione in facciata? Quanto giudica brillante l'illuminazione in facciata? Quanto giudica scura l'illuminazione in facciata? Quanto giudica luminosa l'illuminazione in facciata?	How clear is the lighting on the façade? How drab is the lighting on the façade? How strong is the lighting on the façade? How weak is the lighting on the façade? How focused is the lighting on the façade? How unfocused is the lighting on the façade? How subdued is the lighting on the façade? How brilliant is the lighting on the façade? How dark is the lighting on the façade? How light is the lighting on the façade?
Influence of lighting on the order of elements perception (Influenza dell'illuminazione sull'ordine di percezione degli elementi)	In ordine di importanza, quali sono i tre elementi nello scenario che hanno attratto la sua attenzione?	In order of importance, what are the three elements in the scenario that attracted your attention?
Reported presence (Presenza riportata)	Quanto le è sembrato reale lo spazio virtuale? Quanto si è sentito come "essere lì" nello spazio virtuale? Durante questa esperienza, quanto spesso ha pensato di essere realmente in un parco?	How much did the virtual space look like the real space? How much did you feel like "being there" in virtual space? During your experience, how often did you think you were actually in a park?

References

1. Brock, K.; den Ouden, E.; van der Klauw, K.; Podoynitsyna, K.; Langerak, F. Light the Way for Smart Cities: Lessons from Philips Lighting. *Technol. Forecast. Soc. Chang.* **2019**, *142*, 194–209. [CrossRef]
2. Smith, B.; Hallo, J. Informing Good Lighting in Parks through Visitors' Perceptions and Experiences. *Int. J. Sustain. Light.* **2019**, *21*, 47–65. [CrossRef]
3. Wickremasinghe, L.L.S.; Hettiarachchi, A.A. *An Assessment of User Preference in Artificial Pathway Lighting in Urban Parks*; Cases from Greater Colombo Region; University of Moratuwa: Moratuwa, Sri Lanka, 2021; pp. 150–159. [CrossRef]
4. Peña-García, A.; Hurtado, A.; Aguilar-Luzón, M.C. Impact of Public Lighting on Pedestrians' Perception of Safety and Well-Being. *Saf. Sci.* **2015**, *78*, 142–148. [CrossRef]
5. Boyce, P.R.; Eklund, N.H.; Hamilton, B.J.; Bruno, L.D. Perceptions of Safety at Night in Different Lighting Conditions. *Light. Res. Technol.* **2000**, *32*, 79–91. [CrossRef]
6. Zhang, R.; Piao, Y.-J.; Cao, L.-S.; Cho, T.-D. The Research on Lighting Design of Parks. *J. Environ. Sci. Int.* **2014**, *23*, 1013–1020. [CrossRef]
7. Kaźmierczak, A. The Contribution of Local Parks to Neighbourhood Social Ties. *Landsc. Urban Plan.* **2013**, *109*, 31–44. [CrossRef]
8. Berto, R. The Role of Nature in Coping with Psycho-Physiological Stress: A Literature Review on Restorativeness. *Behav. Sci.* **2014**, *4*, 394–409. [CrossRef]
9. Kaplan, S. The Restorative Benefits of Nature: Toward an Integrative Framework. *J. Environ. Psychol.* **1995**, *15*, 169–182. [CrossRef]
10. Tural, M.; Yener, C. Lighting Monuments: Reflections on Outdoor Lighting and Environmental Appraisal. *Build. Environ.* **2006**, *41*, 775–782. [CrossRef]
11. Balafoutis, T.; Zerefos, S.C. Designing Lighting for Historical Buildings Using a Modular Methodology: The Case of the Work of Ernst Ziller in Greece. In Proceedings of the Balkan Light Conference, Athens, Greece, 16–19 September 2015.
12. Lindh, U.W. *Light Shapes Spaces: Experience of Distribution of Light and Visual Spatial Boundaries*; University of Gothenburg: Göteborg, Sweden, 2012; ISBN 9789197999328.
13. Johansson, M.; Rosén, M.; Küller, R. Individual Factors Influencing the Assessment of the Outdoor Lighting of an Urban Footpath. *Light. Res. Technol.* **2011**, *43*, 31–43. [CrossRef]
14. Żagan, W.; Krupiński, R. A Study of the Classical Architecture Floodlighting. *Light Eng.* **2017**, *25*, 57–64.
15. Peña-García, A.; Gómez-Lorente, D.; Espín, A.; Rabaza, O. New Rules of Thumb Maximizing Energy Efficiency in Street Lighting with Discharge Lamps: The General Equations for Lighting Design. *Eng. Optim.* **2016**, *48*, 1080–1089. [CrossRef]
16. Wojnicki, I.; Kotulski, L.; Sędziwy, A.; Ernst, S. Application of Distributed Graph Transformations to Automated Generation of Control Patterns for Intelligent Lighting Systems. *J. Comput. Sci.* **2017**, *23*, 20–30. [CrossRef]
17. Ocana-Miguel, A.; Andres-Diaz, J.R.; Hermoso-Orzáez, M.J.; Gago-Calderón, A. Analysis of the Viability of Street Light Programming Using Commutation Cycles in the Power Line. *Sustainability* **2018**, *10*, 4043. [CrossRef]
18. Ernst, S.; Łabuz, M.; Środa, K.; Kotulski, L. Graph-Based Spatial Data Processing and Analysis for More Efficient Road Lighting Design. *Sustainability* **2018**, *10*, 3850. [CrossRef]
19. Rabaza, O.; Gómez-Lorente, D.; Pérez-Ocón, F.; Peña-García, A. A Simple and Accurate Model for the Design of Public Lighting with Energy Efficiency Functions Based on Regression Analysis. *Energy* **2016**, *107*, 831–842. [CrossRef]
20. Nasar, J.L.; Bokharaei, S. Lighting Modes and Their Effects on Impressions of Public Squares. *J. Environ. Psychol.* **2017**, *49*, 96–105. [CrossRef]
21. Maffei, L.; Masullo, M.; Pascale, A.; Ruggiero, G.; Romero, V.P. Immersive Virtual Reality in Community Planning: Acoustic and Visual Congruence of Simulated vs Real World. *Sustain. Cities Soc.* **2016**, *27*, 338–345. [CrossRef]
22. Jiang, L.; Masullo, M.; Maffei, L.; Meng, F.; Vorländer, M. How Do Shared-Street Design and Traffic Restriction Improve Urban Soundscape and Human Experience? —An Online Survey with Virtual Reality. *Build. Environ.* **2018**, *143*, 318–328. [CrossRef]
23. Sanchez-Sepulveda, M.; Fonseca, D.; Franquesa, J.; Redondo, E. Virtual Interactive Innovations Applied for Digital Urban Transformations. *Mixed Approach. Future Generation Comput. Syst.* **2019**, *91*, 371–381. [CrossRef]
24. Martinez, K.P.; Untalan, M.Z.G.; Burgos, D.F.M.; Ramos, R.V.; Germentil, M.J.Q. Creation of a Virtual Reality Environment of a University Museum Using 3D Photogrammetric Models. In Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives, Göttingen, Germany, 5 June 2019; Volume 42, pp. 841–847.
25. Chen, Y.; Cui, Z.; Hao, L. Virtual Reality in Lighting Research: Comparing Physical and Virtual Lighting Environments. *Light. Res. Technol.* **2019**, *51*, 820–837. [CrossRef]
26. Ishii, W.; Takao, M. Nightscape Assessment of Shopping District in a Virtual Reality Display. In Proceedings of the LifeTech 2021-2021 IEEE 3rd Global Conference on Life Sciences and Technologies, Nara, Japan, 9–11 March 2021; pp. 114–116. [CrossRef]
27. Rockcastle, S.; Danell, M.; Calabrese, E.; Sollom-Brotherton, G.; Mahic, A.; Van Den Wymelenberg, K.; Davis, R. Comparing Perceptions of a Dimmable LED Lighting System between a Real Space and a Virtual Reality Display. *Light. Res. Technol.* **2021**, *53*, 1–25. [CrossRef]
28. Krupinski, R. Virtual Reality System and Scientific Visualisation for Smart Designing and Evaluating of Lighting. *Energies* **2020**, *13*, 5518. [CrossRef]
29. Chamilothori, K.; Wienold, J.; Andersen, M. Adequacy of Immersive Virtual Reality for the Perception of Daylit Spaces: Comparison of Real and Virtual Environments. *Leukos* **2018**, *15*, 203–226. [CrossRef]

30. Abd-Alhamid, F.; Kent, M.; Bennett, C.; Calautit, J.; Wu, Y. Developing an Innovative Method for Visual Perception Evaluation in a Physical-Based Virtual Environment. *Build. Environ.* **2019**, *162*, 106278. [CrossRef]
31. Natephra, W.; Motamedi, A.; Fukuda, T.; Yabuki, N. Integrating Building Information Modeling and Virtual Reality Development Engines for Building Indoor Lighting Design. *Vis. Eng.* **2017**, *5*, 1–21. [CrossRef]
32. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/bibieybat/ (accessed on 8 December 2023).
33. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/duomo-di-firenze/ (accessed on 8 December 2023).
34. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/la-cattedrale-di-ragusa/ (accessed on 8 December 2023).
35. Żagan, W.; Skarżyński, K. The "Layered Method"—A Third Method of Floodlighting. *Light. Res. Technol.* **2020**, *52*, 641–653. [CrossRef]
36. Słomiński, S.; Krupiński, R. Luminance Distribution Projection Method for Reducing Glare and Solving Object-Floodlighting Certification Problems. *Build. Environ.* **2018**, *134*, 87–101. [CrossRef]
37. The Duomo Lights up in Splendour-Duomo Di Milano OFFICIAL SITE. Available online: https://www.duomomilano.it/en/article/2019/02/13/the-duomo-lights-up-in-splendour/9/ (accessed on 18 November 2023).
38. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/la-torre-rajabai/ (accessed on 8 December 2023).
39. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/nuovo-splendore-per-il-tempio-doro-ad-amritsar/ (accessed on 8 December 2023).
40. Skarżyński, K.; Żagan, W. Improving the Quantitative Features of Architectural Lighting at the Design Stage Using the Modified Design Algorithm. *Energy Rep.* **2022**, *8*, 10582–10593. [CrossRef]
41. Knowledge and Valorisation: The Casa de Vacas. In *International and Interdisciplinary Conference on Image and Imagination*; Lecture Notes in Networks and Systems; Springer: Cham, Switzerland, 2023; 631 LNNS; pp. 697–706. [CrossRef]
42. Żagan, W.; Skarżyński, K. Analysis of Light Pollution from Floodlighting: Is There a Different Approach to Floodlighting? *Light Eng.* **2017**, *25*, 75–82.
43. Skarżyński, K.; Żagan, W. Quantitative Assessment of Architectural Lighting Designs. *Sustainability* **2022**, *14*, 3934. [CrossRef]
44. Krupiński, R.; Scherzer, W.; Pracki, P.; Wiśniewski, A.; Skarżyński, K. A Smart Floodlighting Design System Based on Raster Images †. *Energies* **2023**, *16*, 4028. [CrossRef]
45. Yılmaz, S.M.S. Urban Green Areas and Design Principles. In *Environmental Sustainability and Landscape Management*; Efe, R., Cürebal, İ., Gad, A., Tóth, B., Kliment, S.T., Eds.; ST. Kliment Ohridski University Press Sofia: Sofia, Bulgaria, 2016; pp. 100–118.
46. Selanon, P.; Chuangchai, W. The Importance of Urban Green Spaces in Enhancing Holistic Health and Sustainable Well-Being for People with Disabilities: A Narrative Review. *Buildings* **2023**, *13*, 2100. [CrossRef]
47. Kozma, G.; Radics, Z.; Teperics, K. The Role of Sports Facilities in the Regeneration of Green Areas of Cities in Historial View: The Case Study of Great Forest Stadium in Debrecen, Hungary. *Buildings* **2022**, *12*, 714. [CrossRef]
48. Thompson, C.W. Urban Open Space in the 21st Century. *Landsc. Urban Plan.* **2002**, *60*, 59–72. [CrossRef]
49. Available online: https://www.erco.com/it/progetti/public/j-h-parco-divertimenti-abrahams-reserve-perth-7089/ (accessed on 8 December 2023).
50. Available online: https://www.erco.com/it/progetti/public/british-sky-broadcasting-impianti-esterni-isleworth-7846/ (accessed on 8 December 2023).
51. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/la-passeggiata-jane-e-paulette-nardal/ (accessed on 8 December 2023).
52. Available online: https://www.iguzzini.com/it/progetti/galleria-progetti/al-fay-park/ (accessed on 8 December 2023).
53. *Direccion General de Industria, Energia y Minas, Guìa de Gestiòn Energètica en el Alumbrado Pùblico*; Direccion General de Industria, Energia y Minas: Madrid, Spain, 2006.
54. Jägerbrand, A.K.; Bouroussis, C.A. Ecological Impact of Artificial Light at Night: Effective Strategies and Measures to Deal with Protected Species and Habitats. *Sustainability* **2021**, *13*, 5991. [CrossRef]
55. Masullo, M.; Cioffi, F.; Li, J.; Maffei, L.; Ciampi, G.; Sibilio, S.; Scorpio, M. Urban Park Lighting Quality Perception: An Immersive Virtual Reality Experiment. *Sustainability* **2023**, *15*, 2069. [CrossRef]
56. Tabrizian, P.; Baran, P.K.; Smith, W.R.; Meentemeyer, R.K. Exploring Perceived Restoration Potential of Urban Green Enclosure through Immersive Virtual Environments. *J. Environ. Psychol.* **2018**, *55*, 99–109. [CrossRef]
57. Greule, R.; Braun, T. *Psychological Effect of Lights in an Urban Environment*; Zumtobel: Hamburg, Germany, 2017.
58. Lee, J.-H.; Lee, Y. The Effectiveness of Virtual Reality Simulation on the Qualitative Analysis of Lighting Design. *J. Digit. Landsc. Archit.* **2021**, *6*, 195–202. [CrossRef]
59. Scorpio, M.; Laffi, R.; Teimoorzadeh, A.; Ciampi, G.; Masullo, M.; Sibilio, S. A Calibration Methodology for Light Sources Aimed at Using Immersive Virtual Reality Game Engine as a Tool for Lighting Design in Buildings. *J. Build. Eng.* **2022**, *48*, 103998. [CrossRef]
60. Wachta, H.; Baran, K.; Różowicz, S. Impact of Street Lighting Level on Floodlights. *Energies* **2023**, *16*, 5726. [CrossRef]
61. Syamimi, A.; Gong, Y.; Liew, R. VR Industrial Applications—A Singapore Perspective. *Virtual Real. Intell. Hardw.* **2020**, *2*, 409–420. [CrossRef]
62. Dunston, P.S.; Arns, L.L.; Mcglothlin, J.D.; Lasker, G.C.; Kushner, A.G. An Immersive Virtual Reality Mock-Up for Design Review of Hospital Patient Rooms. In *Collaborative Design in Virtual Environments*; Springer: Dordrecht, The Netherlands, 2011. [CrossRef]

63. Scorpio, M.; Carleo, D.; Gargiulo, M.; Chías Navarro, P.; Spanodimitriou, Y.; Sabet, P.; Masullo, M.; Ciampi, G. A Review of Subjective Assessments in Virtual Reality for Lighting Research. *Sustainability* **2023**, *15*, 7491. [CrossRef]
64. Ceccato, V.; Martin, C. Who Takes Part in Virtual Reality Studies? An Analysis of Lighting Research. *Sustain. Futures* **2023**, *6*, 100134. [CrossRef]
65. Chías Navarro, P. Building Territories and Landscapes: The Essential Knowledge of a Forgotten Cultural Heritage/La Construcción Del Territorio y Del Paisaje o El Esencial Conocimiento de Un Patrimonio Olvidado. In *Drawing and Architecture. 1986–2016, Thirty Years of Research*; Chías Navarro, P., Cardone, V., Eds.; University of Alcalá: Alcala de Henares, Spain, 2016; pp. 74–89. ISBN 978-84-16599-77-6.
66. Gargiulo, M.; Carleo, D.; Ciampi, G.; Scorpio, M.; Chías Navarro, P. *Modelli Digitali per la Conoscenza dei Complessi Monumentali Spagnoli*; FrancoAngeli: Milano, Italy, 2023; pp. 1352–1369. ISBN 9788835155119. [CrossRef]
67. Code, S. 3018W MINI-TWIST FLOOD | Simes S.p.A. Available online: https://www.simes.it/en/code/S.3018W-mini-twist-flood (accessed on 8 November 2023).
68. The Trick Radial-IGuzzini. Available online: https://www.iguzzini.com/bu10/ (accessed on 2 November 2023).
69. Cube-Cariboni Group. Available online: https://www.caribonigroup.com/en/products/catalog/variants/cube-floodlight (accessed on 2 November 2023).
70. Code, S. 3315W NANOLED WALK-OVER ROUND 85mm | Simes S.p.A. Available online: https://www.simes.it/en/code/S.3315W-nanoled-walk-over-round-85mm (accessed on 2 November 2023).
71. *UNI 11248:2016*; Illuminazione Stradale—Selezione Delle Categorie Illuminotecniche. UNI Ente Nazionale Italiano di Unificazione: Milano, Italy, 2016.
72. Code, S. 3055W MOVIT SQUARE 220mm | Simes S.p.A. Available online: https://www.simes.it/en/codice/S.3055W-movit-quadrato-220mm (accessed on 9 November 2023).
73. Johansson, M.; Pedersen, E.; Maleetipwan-Mattsson, P.; Kuhn, L.; Laike, T. Perceived Outdoor Lighting Quality (POLQ): A Lighting Assessment Tool. *J. Environ. Psychol.* **2014**, *39*, 14–21. [CrossRef]
74. Kuhn, L.; Johansson, M.; Laike, T.; Govén, T. Residents' Perceptions Following Retrofitting of Residential Area Outdoor Lighting with LEDs. *Light. Res. Technol.* **2013**, *45*, 568–584. [CrossRef]
75. Universität Düsseldorf: G*Power. Available online: https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower (accessed on 3 November 2023).
76. Toscani, M.; Gil, R.; Guarnera, D.; Guarnera, G.; Kalouaz, A.; Gegenfurtner, K.R. Assessment of OLED Head Mounted Display for Vision Research with Virtual Reality. In Proceedings of the 15th International Conference on Signal Image Technology and Internet Based Systems, SISITS 2019, Sorrento, Italy, 26–29 November 2019; pp. 738–745. [CrossRef]
77. Gil Rodríguez, R.; Bayer, F.; Toscani, M.; Guarnera, D.; Guarnera, G.C.; Gegenfurtner, K.R. Colour Calibration of a Head Mounted Display for Colour Vision Research Using Virtual Reality. *SN Comput. Sci.* **2022**, *3*, 1–10. [CrossRef]