BACTERIAL BIOLUMINESCENCE AND BIOPHILIC DESIGN

AN INTERDISCIPLINARY APPROACH TO SENSORY EXPERIENCES IN URBAN WELL-BEING

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DISCONNECTION FROM NATURE IS A CENTRAL CHALLENGE OF CONTEMPORARY URBAN LIFE, WITH DETRIMENTAL EFFECTS ON EMOTIONAL AND COGNITIVE WELL-BEING. THIS STUDY, CONDUCTED AS A DEGREE PROJECT IN THE DESIGN PROGRAM AT THE UNIVERSITY OF CHILE, INVESTIGATED THE USE OF BACTERIAL BIOLUMINESCENCE AS AN INNOVATIVE RESOURCE FOR BIOPHILIC DESIGN TO PROMOTE EMOTIONAL WELL-BEING IN CITIES. AN EXPERIMENTAL PROTOTYPE, GROUNDED ON THE ETHICAL CULTIVATION OF PHOTOBACTERIUM, WAS DESIGNED USING THE PRINCIPLES OF BIOMIMICRY AND BIO-COLLABORATION. VALIDATION WAS PERFORMED THROUGH NON-PARTICIPANT OBSERVATION, SEMI-STRUCTURED INTERVIEWS, AND EMOTIONAL ASSESSMENT SURVEYS, SUPPLEMENTED BY ELECTROENCEPHALOGRAPHY (EMOTIV EPOC EEG) AND THE PREMO SCALE. THE RESULTS INDICATED THAT INTERACTION WITH BIOLUMINESCENCE ELICITED RESPONSES OF WONDER, FASCINATION, AND CALM. THESE RESPONSES WERE LINKED TO RESTORATIVE CONTEMPLATION AND ACCOMPANIED BY A SUSTAINED INCREASE IN ATTENTION AND RELAXATION LEVELS. THE INTEGRATION OF BACTERIAL BIOLUMINESCENCE INTO DESIGN SERVES A DUAL PURPOSE: IT OFFERS AN AESTHETIC AND SUSTAINABLE ALTERNATIVE WHILE ALSO ACTING AS A SENSORY MEDIUM FOSTERING EMOTIONAL AND SYMBOLIC CONNECTIONS WITH NATURE. THIS WORK ALSO VALIDATED PROJECT-BASED RESEARCH AS A LEGITIMATE WAY TO GENERATE NEW KNOWLEDGE THAT CAN BE PUBLISHED UNDER CURRENT ACADEMIC STANDARDS.

KEYWORDS: PROJECT-BASED RESEARCH, BIOPHILIC DESIGN, BIOLUMINESCENCE, DESIGN FOR WELL-BEING, INTERDISCIPLINARITY

INTRODUCTION

Rapid urbanization over the last few centuries has reduced human access to natural environments by more than 60%, impacting physical and emotional well-being (Richardson, 2025). Research in environmental psychology and urban health indicates that disconnection from nature is associated with higher levels of stress, anxiety, and cognitive fatigue (Ulrich, 1984; Hartig et al., 2014).

Exposure to natural environments, even briefly, reduces mental rumination and brain activity associated with mood disorders, as well as symptoms of depression and anxiety (Bratman et al., 2015; Kotera et al., 2020). However, more than half of the world's population lives in cities far from these environments, which is linked to emotional and physical problems (United Nations, 2014; Stainbrook, 1973). In this context, the presence of urban green spaces significantly reduces the risk of depression and anxiety in the population (Liu et al., 2023). Even small natural integrations into urban spaces, such as indoor plants or green walls, effectively reduce stress (Gu et al., 2022).

Biophilic and biocollaborative design is, by definition, an integration of disciplines and approaches that fosters the learning of future professionals by conducting research through design (Horváth, 2007) and designing based on research-informed design (Muratovsky, 2022). In an urban housing context where the natural stimuli are often limited, these approaches offer new possibilities for exploring how living elements can contribute to well-being in everyday spaces.

The concept of biophilia, defined by Wilson (1986, p. 10) as "the innate tendency to focus on life and life-like processes", was incorporated into the field of design by Kellert and Calabrese (2015), giving rise to biophilic design, an approach aimed at reconnecting people with nature in built environments. Browning et al. (2014) systematized this proposal into fourteen biophilic design patterns organized into three categories: 1) nature in space, 2) natural analogues, and 3) nature of space. These patterns include the presence of natural processes, dynamic sensory variations, and the induction of calm and safety. Kellert and Calabrese (2015) emphasize that the effectiveness of biophilic design does not depend solely on the aesthetic representation of natural elements, but on its ability to evoke restorative emotional and cognitive experiences.

Over the past decade, biophilic design has evolved toward more rigorous and measurable approaches. An evaluation framework has proposed more rigorous measurement of the application of biophilic principles in buildings (Rabbassum & Park, 2024), and an improvement in the quality of life of older adults has been demonstrated through the integration of natural elements in community spaces (Tjia et al., 2024). Likewise, studies on affective interaction design (Rao et al., 2025) show that environments built using biophilic principles promote targeted emotional experiences, thanks to spatial and tactile sensory interaction.

However, much of current practice is limited to aesthetic representations of nature (colors or textures), without promoting restorative experiences. From different perspectives, it has been suggested that biophilia should be understood as a comprehensive approach that encompasses physical, sensory, metaphorical, morphological, material, and spiritual dimensions (Zhong et al., 2021). In response to this, warnings have been issued about the reduction of biophilic design to aesthetic stereotypes or certification criteria, leaving aside environmental, climatic, functional, and contextual factors (Qurraie & Bayram, 2025).

The current challenge, therefore, lies not only in visually integrating nature but in recovering deep emotional experiences that counteract human disconnection from their environment. Research has proved that multisensory biophilic design, which combines visual and auditory stimuli, improves cognitive performance and attention and reduces stress in work environments (Aristizábal et al., 2021). Thus, this approach transcends the visual and promotes integrated experiences that generate psychological, physiological, and cognitive responses, consolidating design as an effective strategy for mitigating the effects of natural disconnection (Yin et al., 2024).

LIGHT AS A BIOPHILIC RESOURCE

Light acts as a central mediator in human experience, regulating circadian rhythms, moods, and spatial perception (LeGates et al., 2014). Its phototherapeutic potential has been recognized as a therapeutic agent, raising the need to translate these findings into concrete applications (Brainard & Hanifin, 2005).

In this context, bioluminescence should not be conceived as a mere technical lighting resource, but as living light: interactive, organic, and unpredictable. This natural phenomenon, present in various marine organisms, insects, and bacteria, fulfills ecological functions associated with communication, defense, and attraction (Haddock et al., 2010). In species such as dinoflagellates, bioluminescence is activated by movement, generating an immediate light response that turns interaction into a direct sensory and physical experience (Ofer et al., 2021).

Bioluminescence introduces a dynamic light language that differs radically from conventional artificial lighting. Its project integration fosters interactive experiences and opens up an emerging field of interdisciplinary exploration between design and biology through research.

BIOLUMINESCENCE IN DESIGN: BACKGROUND AND LIMITATIONS

The potential of bioluminescence as a source of regenerative and interactive lighting has driven research in the fields of human-computer interaction (HCI) and interaction design (Barati et al., 2021). Projects such as Glowing Nature by Studio Roosegaarde, Bioluminescent Field by Nicola Burggraf, Abio by Teresa Van Dongen, and Biolum Due Bench have allowed users to experience this natural phenomenon firsthand. These proposals, compiled by Barati et al. (2021), demonstrate how living organisms remain active as an essential part of the experience, where light emission is indirectly regulated through interaction and the design of the environment, which ensures their vital conditions (Burggraf, 2014, as cited in Barati et al., 2021).

Beyond its aesthetic or technical value, bioluminescence can be understood as an interactive medium capable of generating restorative emotional experiences. In contrast, artificial lighting disrupts circadian cycles, negatively impacting human and ecological health (Falchi et al., 2016; Kyba et al., 2017). Bioluminescence reintegrates the organic and sensory dimension of light, enabling a more harmonious relationship between technology, nature, and well-being (Myers, 2012; Guido et al., 2017).

Despite recent advances, much of the research on bioluminescence lacks methodological frameworks to assess its emotional impact, replicating limitations present in other biophilic applications. This absence highlights the need for approaches that transcend the ornamental and consolidate design research as a conceptual and project-based tool capable of generating legitimate knowledge.

Design has a different way of thinking and communicating than science, but it is equally valid for addressing its own problems (Archer, 1979). With the development of the discipline, design research has achieved greater maturity and recognition, standing out for its broad and transdisciplinary nature (Forlizzi et al., 2009; Friedman, 2001, 2003; Zimmerman & Forlizzi, 2008). In this context, Frayling (1993) introduced the concept of Research through Design (RtD), understood as research in which design becomes a means of exploring hypotheses and generating knowledge (Findeli, 2010; Koskinen et al., 2011). These perspectives agree that design projects, when recorded and analyzed with academic rigor, constitute a valid vehicle for producing knowledge (Cross, 2001; Manzini, 2009; Redström, 2008).

On this basis, the experience presented here falls within the RtD concept, understood as a project-based process capable of generating knowledge by combining theory and practice. The objective was to examine the potential of bacterial bioluminescence as an innovative sensory resource to promote states of calm and contemplation in users from urban environments. Within this framework, the research question that guided the study was: How does bacterial bioluminescence, incorporated into a sensory design prototype, influence the emotional experience and well-being of users in urban environments?

The hypothesis that guided this work suggests that incorporating bioluminescence into design is an innovative strategy that has the capacity to promote a meaningful emotional connection with nature and thus contribute to people's well-being in urban contexts.

METHODOLOGY

The research adopted a qualitative, experimental, and transdisciplinary approach, following the logic of project-based research through design, or RtD. Transdisciplinarity made it possible to articulate and transcend the boundaries of biology, psychology, and design, generating a common language and a shared methodological framework (Nicolescu, 2002; Max-Neef, 2005). This approach was characterized by methodological hybridization, co-creation, and the construction of joint perspectives.

The methodological process was structured in three phases: (1) conceptualization and project definition, (2) prototype development through trial and error iterations, and (3) experiential validation with users. These phases are developed in a coordinated manner across three complementary dimensions: design, biology, and psychology/UX, as shown in Figure 1. The diagram outlines the operational development of the prototyping phase and shows how conceptual, material, and biological decisions contributed both to the construction of the experimental prototype and to the verification of the central hypothesis: to determine whether bacterial bioluminescence, integrated into an experimental lighting device, could promote states of calm and contemplation in urban environments.

The literature review allowed us to address the research question of how biophilic design principles and the use of bio-references can be translated into formal and material criteria within a design process. Based on this theoretical background, a formal and design exploration was developed aimed at identifying morphologies, textures, and spatial configurations capable of generating positive sensory and emotional experiences.

Figure 2 summarizes this process, articulating the literature review aimed at answering how bacterial bioluminescence, incorporated into a sensory design prototype, influences the emotional experience and well-being of users in urban environments, with the exploration of natural and design references. The formal exploration that underpinned the design decisions and subsequent development of the prototype.

The selection of the microorganism was based on specialized literature and advice from experts in microbiology, establishing that Photobacterium was the most suitable species due to its intense light emission, observable in the laboratory and reproducible under controlled conditions. It grows in standard media (Marine Broth 2216) between 18–30 °C, with an approximate salinity of 35 g/l (~35 psu), and requires media changes every 24–48 hours to maintain optimal culture. Handling and replacement procedures were applied, such as initial density adjustment, rest period after replacement, and crop repositioning to respect the circadian cycle of the species.

Although the project was developed as a degree thesis at the University of Chile, it benefited from the direct collaboration of researchers from the Center for Harmful Algae Studies (CREAN) and academics from the Coastal Marine Research Station (ECIM) of the Pontifical Catholic University of Chile, who provided active cultures and management protocols. Under the supervision of Dr. Peter von Dassow, cultivation procedures were replicated in the Biological Sciences Laboratory of the same institution, adjusting the initial density and volume of the samples and following practices learned during the process, such as sterilization of materials, temperature control, and ethical handling of living organisms.

The lighting prototype was designed according to principles of biomimicry and bio collaboration, recognizing living organisms as co-agents in the design process (Myers, 2012). Its construction was developed through an iterative process of material and formal experimentation, beginning with the exploration of natural and design references through sketches, systematized in Figure 2. These references were analyzed based on bio-inspired morphological patterns, textures, scale relationships, microorganism requirements, and sensory qualities studied in the data collection, aspects that were subsequently translated into a series of preliminary formal proposals.

These explorations allowed multiple material variations that were evaluated according to functional, biological, and experiential criteria. These included the correct containment of the liquid medium, the quality of tactile interaction, the visibility of bioluminescence, and formal consistency with biophilic principles. Based on this evaluation, the configurations that presented the best balance between technical stability, replicability, and sensory expression were selected, which led to the definition of the final form of the experimental prototype.

In biomimetic terms, the design emulates shapes, textures, and patterns found in natural organisms, such as corals and anemones. These natural references do not seek literal reproduction, but rather the abstraction of natural morphological principles that favor intuitive, smooth, and continuous interaction, consistent with sensory experiences associated with natural environments.

Through bio collaboration, the bioluminescent microorganism is incorporated as a key agent participating in the experience, whose metabolic activity and light response conditions the functioning of the prototype and the experience. The light emitted is not artificially generated, but emerges from the interaction

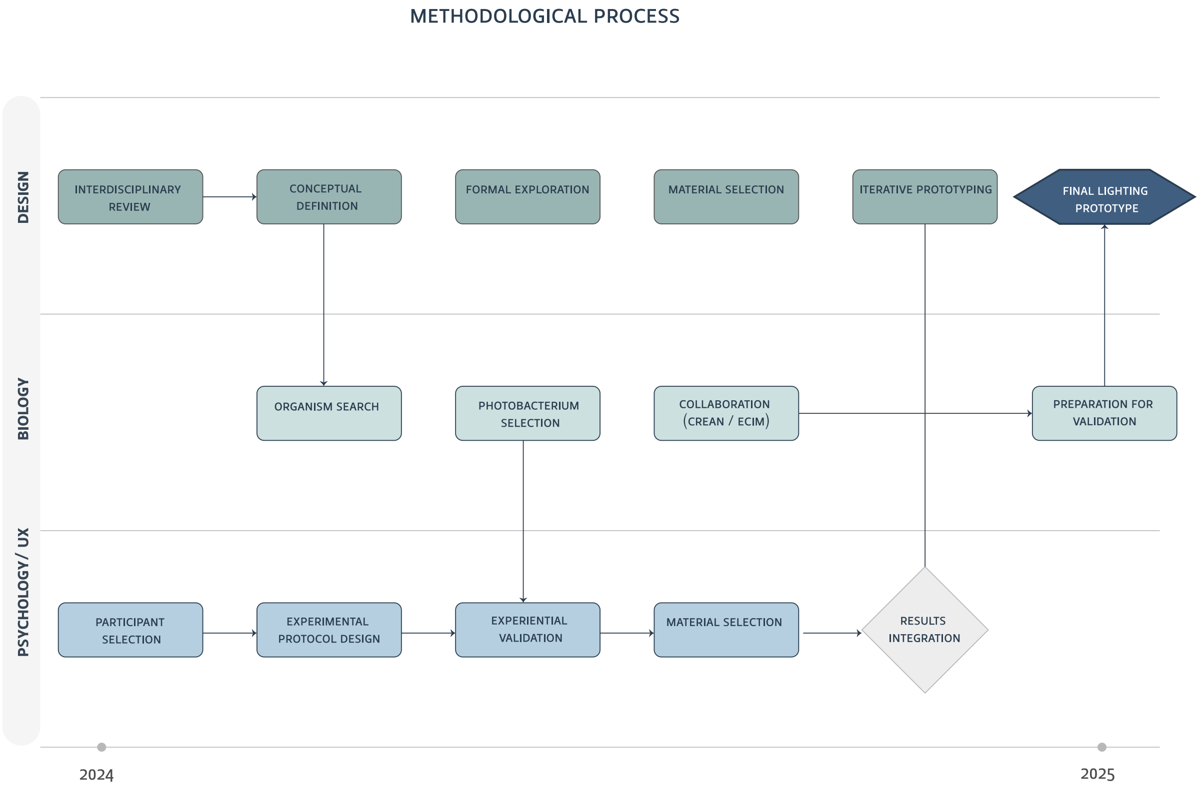


FIGURE 1. *Methodological process of the project. Development of the prototyping phase within a framework structured in three complementary stages.*

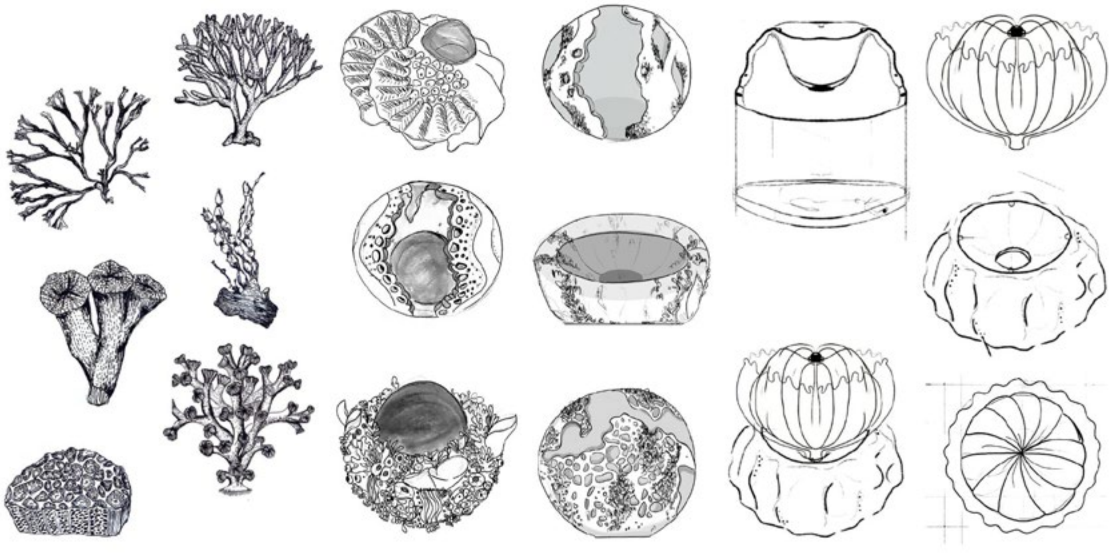


FIGURE 2. *Diagram of the prototype production process.*

between the user, the object, and the living organism, establishing a symbiotic collaborative system in which the visual result depends on the vitality and behavior of the microorganism.

The main piece was modeled three-dimensionally in Rhinoceros 3D and printed in PLA and TPU, generating a master for the manufacture of Shore 40 A silicone molds, optimizing the replicability of the piece. In addition, a piece printed in PLA filament was designed to serve as a structural skeleton, providing strength and allowing for proper interaction between all the pieces (Figure 3).

Based on the master mold, four variants of 10 Shore A silicone (transparent, white, and blue) were developed, cast in three layers: a first layer of transparent silicone, a second layer of 25 Shore A with blue pigments, and a third layer with photosensitive pigments, subsequently integrated into a final transparent cast of 25 Shore A.

The design of these variants was conditioned by technical and biological constraints necessary to ensure the viability and visibility of bacterial bioluminescence. In particular, the safe containment of the living liquid medium and the thermal stability of the culture were solved by using a double-layer borosilicate blown glass container, allowing temperatures suitable for Photobacterium to be maintained. The system also includes a nozzle for partial media replacement every 24–48 hours and a silicone cap with a microporous filter that allows oxygen exchange, preventing overcrowding of the culture and promoting stable light emission. These decisions were complemented by preliminary sensory studies, in which 10 cm diameter silicone samples with 3D-printed patterns in different materials (PLA and TPU) were analyzed, allowing the users to identify their tactile and visual preferences (Figure 4).

The bioluminescent sample container was designed and manufactured in borosilicate glass (15 × 10 × 10 cm; thickness = 3 mm), the same material used in laboratory equipment, in collaboration with glass artisans, and was adapted to allow safe interaction and ensure ethical cultivation of the sample. The silicone piece was assembled onto the structural skeleton, and the container was placed on top of the assembly (Figure 5). The process was complemented by work in the Digital Manufacturing Laboratory, where the selection of relevant materials and manufacturing processes was further explored.

Experiential validation included ten residents of the Santiago Metropolitan Region, selected through purposive sampling due to theoretical evidence of their limited access to green spaces. The sample size was defined according to exploratory research criteria, prioritizing phenomenological depth over statistical representativeness. Participants were screened according to their biological knowledge to record responses that were not influenced by technical expertise. Additionally, priority was given to participants aged 20–33, mainly women, as well as individuals who had already participated in previous validations, given the intimate nature of the experience.

The validation combined non-participant observation protocols, semi-structured interviews, neurophysiological measurements using Emotiv Epoc EEG (recording brain activity associated with states of calm and attention), and emotional assessment using the PrEmo digital tool (Desmet, 2002), allowing for the identification and quantification of emotions evoked during interaction (Güiza Caicedo, 2009).

FIGURE 3. Experimental samples of the prototype in 3D printing and silicone.

FIGURE 4. Exploratory variants of texture, shape, and material.

FIGURE 5. User interaction with the prototype.

Each participant interacted with the prototype for 5–7 minutes under controlled conditions in a semi-dark, quiet space, isolated from external stimuli. The data were analyzed as preliminary patterns, without applying inferential statistics, seeking consistency between observation, reported statements, and physiological responses, due to the limited sample size (Figure 6).

RESULTS

The main result of the project is the bioluminescent lighting prototype (Figure 4), conceived as a material synthesis of the research and experimentation process. The device operated simultaneously as a project outcome and a study tool, allowing for empirical observation of human interactions with bioluminescence and its emotional and cognitive effects (Figure 7). Likewise, the records obtained allowed us to compare users' initial metrics with the responses generated during the interaction, revealing a positive emotional impact specifically associated with the moment of bioluminescence activation.

During the initial phase, nine of the ten participants expressed surprise at the light emitted by the bacteria, expressing spontaneous reactions such as "Wow!" or "Is this real?" Eight participants kept their gaze on the prototype for more than thirty seconds, showing reduced movement and vocalization, which is interpreted as sustained attention and contemplation. In interviews, seven participants described the experience as "magical", "lively", and "hypnotic", while six associated it with marine phenomena. The choice of shapes, colors, textures, and lighting conditions for the prototype was based on previous iterations with users, ensuring that the design responded to the participants' actual emotional perceptions.

In subsequent surveys, six participants reported feelings of calm and relaxation, and five mentioned experiencing a temporary disconnection from everyday concerns. EEG recordings showed sustained increases in indicators of interest, attention, and engagement during the interaction, with an inflection point around the five-minute mark, coinciding with the light activation of Photobacterium (Figure 8).

The evaluation using the PrEmo tool showed a predominance of positive emotions (94.7%) over negative ones (5.3%), highlighting joy, satisfaction, fascination, and desire. These emotions were reported with uniform intensity (15.8% each), confirming the consistency of the observed effect (Figure 9). Negative emotions mainly corresponded to fear in a minority proportion.

FIGURE 6. (A). Participant interacting with the bioluminescent prototype (A). User equipped with the EEG helmet and is completing the emotional evaluation form (B).

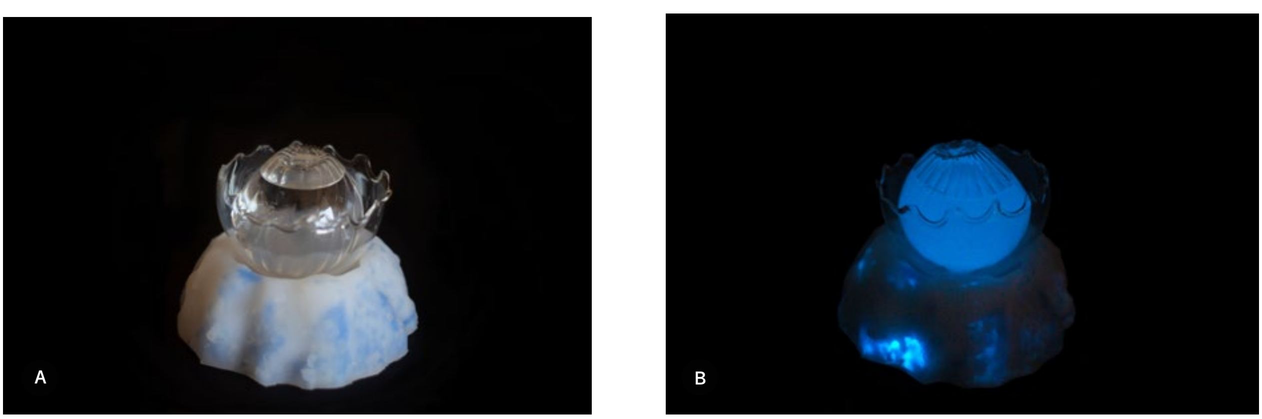


FIGURE 7. Photographic record of the prototype in natural light conditions (A) and with bioluminescence activated (B).

Taken together, PrEmo metrics, EEG curves, and subjective reports showed parallel increases in levels of interest, attention, engagement, and relaxation. Participants 4 and 5 also showed a sustained decrease in stress levels, suggesting a potential regulatory effect of bioluminescent stimulation on states of mental overload.

Technical limitations during the experiment: The light intensity of the prototype decreased over time, and environmental factors such as temperature and humidity affected the stability of the sample. Added to this was the natural instability of the microorganism, which influenced the visual consistency of the interaction.

DISCUSSION

The findings showed that bacterial bioluminescence acted as a stimulus capable of activating restorative processes associated with biophilia. The main purpose of this research was to evaluate whether a lighting prototype that integrated bioluminescence could promote states of calm and contemplation in urban contexts, and the results obtained support this hypothesis. The prototype was integrated as a natural point of contact in living spaces marked by artificial stimuli. The responses observed, including surprise and sustained contemplation, suggested a process of progressive connection with a dynamic natural phenomenon, consistent with instinctive reactions to unexpected biological stimuli.

In urban environments, characterized by a high density of artificial stimuli and a limited presence of natural stimuli, these responses take on special relevance. Sustained contemplation and observed silence point to the activation of a state of soft fascination, where attention is maintained without high cognitive demand (Kaplan & Kaplan, 1989).

The methodological triangulation between observation, interviews, surveys, and neurophysiological measurements (EEG and PrEmo) allowed subjective perceptions to be integrated with objective responses, strengthening the validity of the results. This methodological crossover also demonstrated the value of transdisciplinarity: biology provided insight into organisms and their living conditions; psychology enabled the interpretation of emotional responses; and design integrated both areas of knowledge into an interactive prototype. The integration responds to the RtD approach proposed by Zimmerman et al. (2010), in which design produces knowledge through iterative cycles of experimentation. These cycles interact with the process of constructing and adjusting the object, allowing decisions regarding form, texture, and materiality to be continuously validated with users and specialists. From this, a shared methodological framework emerges that positions design as a legitimate producer of academic knowledge (Nicolescu, 2002; Max-Neef, 2005).

Among the most relevant contributions of the project is Table 1, which establishes a relationship between textures, colors, and emotional sensations, systematizing how different bio-inspired surfaces generated responses of calm, fascination, curiosity, or discomfort, in accordance with the indirect experiences described by Kellert (2008). Its development was based on direct comparisons between tactile and visual stimuli, constituting a transferable input for future research by guiding the selection of materials and visual stimuli according to the emotional states that are sought to be promoted.

The results showed that bacterial bioluminescence fulfills key biophilic conditions, such as fascination, contemplation, and symbolic connection with nature. The exploration in the field of design requires a transdisciplinary approach capable of comprehensively understanding its emotional and cognitive effects. In line with the perspectives on product experience proposed by Hekkert (2006), which suggest the convergence of aesthetics, meaning, and sensory interaction in the user's emotional response, the prototype operated beyond a functional artifact. In this sense, it was established as a project research tool, reinforcing the experimental nature that has guided the project since the first tests with crops, materials, and manufacturing processes, and revealing deep links between living organisms, materialities, and human experiences.

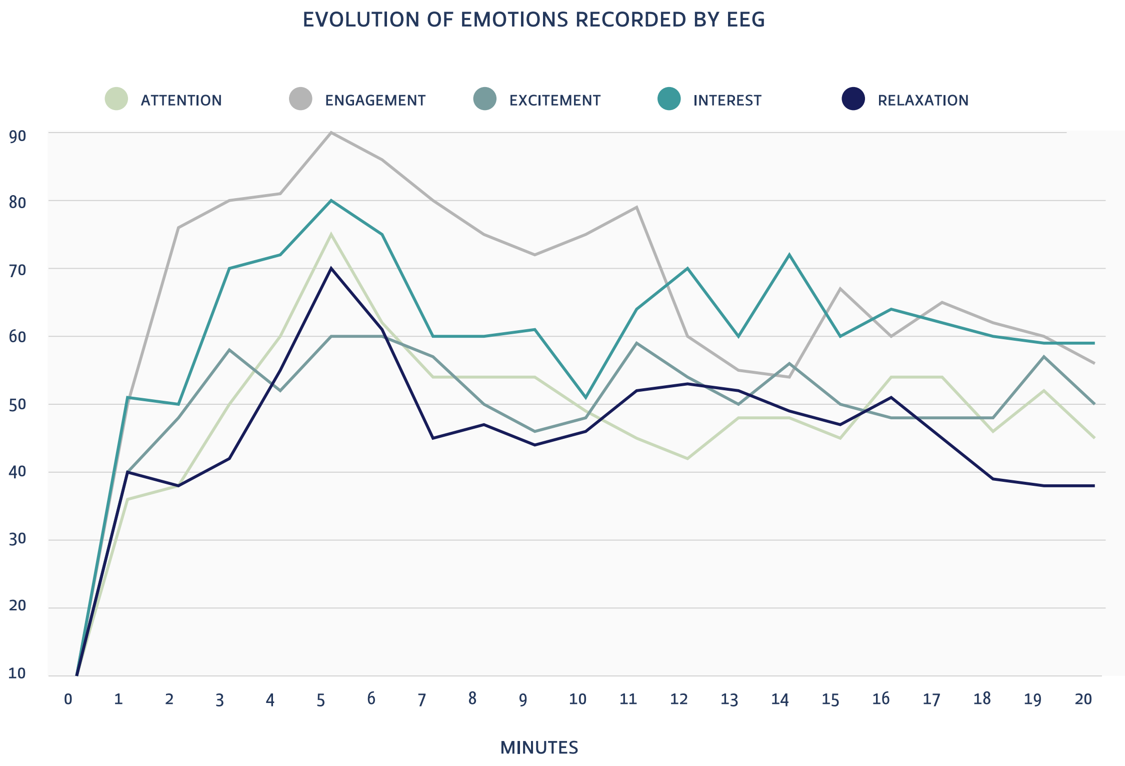
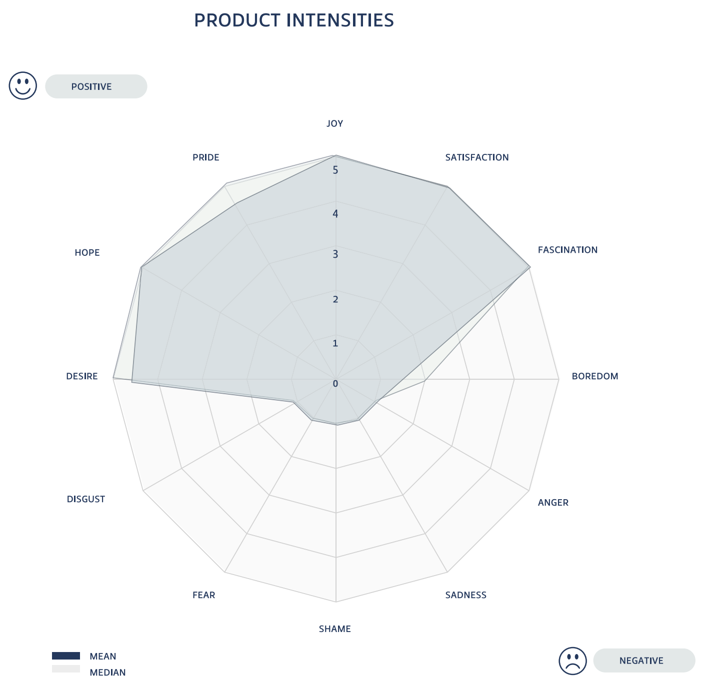


FIGURE 8. Temporal evolution of emotions recorded through interaction.



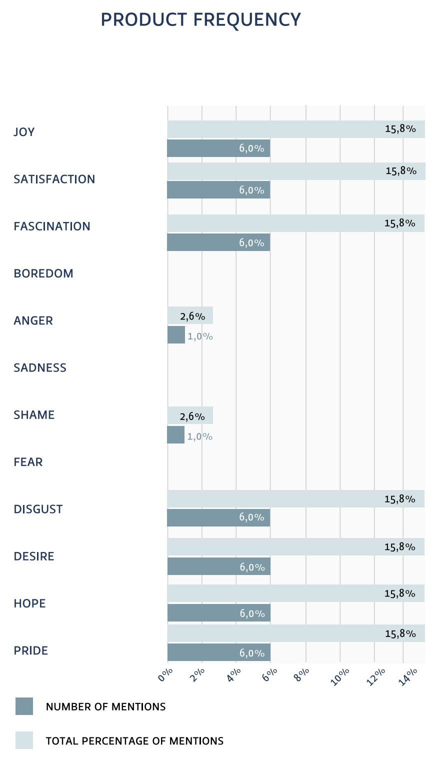


FIGURE 9. Results of PrEmo validation with users.

TABLE 1. SENSORY CATEGORIZATION OF TEXTURES BASED ON TACTILE AND VISUAL STIMULI.

NATURAL ASSOCIATION	DESCRIPTION	QUALITIES	RELATED COLOR	EVOKED EMOTION	EVALUATION
Seashells with a pearlescent sheen	Scaly, rough, shiny, and colorful patterns	Shiny, porous, with relief	Pink, purple, and green	Joy, curiosity	Positive
Dried corals and fungi	Shell fragments and mineral surfaces worn down by the sea, with irregular dots, cavities, and reliefs	Hard, rough, irregular	Off-white, beige	Discomfort, fear, rejection	Negative
Eroded wood and natural fibers	Rigid surfaces with visible grain and linear textures, characteristic of dry plant materials	Rigid, porous, with linear reliefs	Brown, beige	Calm, nostal-gia	Neutral
Anemone-like filamentous structures	Soft parts with wavy, translucent filaments, arranged radially like in sea anemones.	Flexible, soft, translucent	"Blue, purple, green."	Relaxation, curiosity	Positive
Branching corals (gorgonians)	Reticular patterns formed by fine branches and micropores, typical of gorgonian corals	Rigid, micro-porous, branched	Brown, beige	Serenity, exploration	Positive
Scaly and feathery	Materials with overlapping units, scales, or fine filaments, high gloss, and repetitive structure	Smooth, shiny, with scales	Green, pink	Discomfort, curiosity	Neutral

CONCLUSIONS

The research confirmed the initial hypothesis: bacterial bioluminescence, as a living and dynamic phenomenon, generated positive emotional responses in urban users and encouraged experiences of contemplation and connection with nature. Interaction with the prototype evoked amazement, fascination, and calm, fulfilling biophilic conditions associated with restoration, validating the device's effectiveness in inducing states of sustained attention and disconnection from everyday stress, consistent with the neurophysiological measurements obtained. The study provided a transdisciplinary methodological model that integrated biology, psychology, and design, merging conceptual and methodological frameworks into a common research process. The systematization of the relationship between textures, colors, and emotions constitutes a transferable methodological contribution that could guide future biophilic design projects toward therapeutic, educational, and environmental applications, especially in contexts where the goal is to promote emotional well-being through natural stimuli simulated or mediated by living organisms.

Administrative, technical, economic, and biological limitations highlighted the need to strengthen protocols for accessing living organisms, optimize materials, explore more efficient cultivation systems, and create facilities to provide financial support for university projects. These difficulties, together with the challenges arising from working with an unstable organism and material experimentation, highlight the importance of establishing early collaborations with laboratories and specialists, promoting more efficient processes in future research. Far from invalidating the proposal, these restrictions outline avenues for exploration aimed at continuing research into bioluminescence as a design agent capable of generating emotional benefits.

In summary, this work sets a precedent in the field of biophilic design by demonstrating that bacterial bioluminescence, rather than being merely an aesthetic resource, can operate as a sensory and symbolic mediator that diversifies the ways in which we reconnect with nature. Project-based research established itself as a legitimate contribution to academic knowledge in design, validating transdisciplinarity as a way to integrate biology, psychology, and design around urban well-being. Likewise, the educational value of degree programs is reaffirmed as spaces capable of producing meaningful knowledge when approached with methodological rigor, allowing design to expand its boundaries and engage in dialogue with other areas of knowledge to address real problems from a comprehensive perspective.

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