Original Paper

Biophilic design of building façades from an evolutionary psychology framework:

Visual Attention Software compared to Perceived Restorativeness

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Abstract. *Built environments that integrate representations of the natural world into façades and interiors benefit occupant psycho-physiological well-being and behavior. However, the biophilic quality of buildings does not depend exclusively on "green", but also upon "organized complexity" in their structure. In this exploratory study we compare quantitative (Visual Attention Software) and qualitative approaches (self-rating scales) in the perception of biophilic design of building façades. Eight façades varying in their degree of biophilic design (High, Medium, Low, No biophilic qualities) were assessed on the Perceived Restorativeness Scale-11, on preference, and on a series of physical aesthetic attributes. The eight façades were scanned with Visual Attention Software (VAS). These measures show many overlapping points. VAS can be considered a way to operationalize the engagement of attention in the first 3-5 seconds of gaze in exploring building design, and self-ratings assessments a measure of to what extent the building is perceived as restorative. Higher perceived restorativeness and preference match a higher degree of biophilic design, which corresponds to a building where vegetation is integrated in an organic structure. Vegetation is not the only biophilic characteristic to be considered in biophilic design and this emerges clearly from self-ratings and VAS. Exploring organized complexity is fundamental for understanding human responses to architecture.*

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1. Towards an Evolutionary Psychology framework for biophilic design

The idea that humans are drawn to Nature-inspired architectural forms dates back several centuries. For example, in *The Stones of Venice* (1851-1853) John Ruskin pointed out three virtues of a built environment, in that: (1) it acts well, (2) it looks well, and (3) it speaks well. In the first place, a built environment "acts well" when it fulfills the human need to find a refuge. Secondly, it "looks well" when it meets traditional human aesthetic requirements. For Ruskin Nature is the model for beauty and he relied so heavily on the design seen in Nature that to him lines and shapes in architecture should stem from the natural environment. Finally, according to Berto (2019) a built-artificial environment "speaks well" when it fosters emotional attachment to it; emotional attachment appears to be an emergent property of individuals interacting with environments that are pleasing both aesthetically and functionally, because they present some properties of the environment in which humans evolved. This attachment facilitates the vision of an interaction between "form" and "function" that stimulates progressively stronger positive emotions towards the environment itself (Petrich, 2015).

Individuals seek places that support the biological needs of *making sense* and *exploring* (Kaplan and Kaplan, 1989) which, in turn, sustain environmental preference and perceived restoration (Barbiero and Berto, 2018). Since our ancestors lived in a Nature-filled environment, we feel more comfortable, more relaxed, more "like home" when we are exposed to natural environments (Barbiero and Berto, 2021). Biophilic design contends exactly that humans have developed affinities for naturalistic forms in their surroundings over the course of evolutionary history; therefore, naturalistic patterns in architecture are preferred over synthetic forms never seen in our ancestral world (Barbiero, 2009; Coburn et al., 2019). Moreover, there is accumulating evidence that Nature-inspired architectural features foster important psychological benefits (Berto, Barbiero and Nasar, 2022; Joye, 2007; Salingaros, 1998).

Biophilic design is closely related to restorative design, an approach that focuses on the promotion of restoration from stress and/or mental fatigue as a key component of the individual's relation with the environment (Hartig et al., 2008). Restoration may stem from the presence of plants and other natural elements, but it can also occur in places that do not have obvious natural elements (Berto, 2019). Restorative design may be considered a more general form of biophilic design that aims to promote restful experiences characteristic of natural environments but is not necessarily restricted to natural elements (Gifford and McCunn, 2019). Biophilic design has two separate contributions: (i) the presence of plants, animals, sunlight, and water; and (ii) very special geometrical characteristics such as fractals and nested symmetries. The best biophilic designs are buildings that embody appropriate geometrical characteristics in their tectonics and ornamentation (if there is any), and which try to add as many natural elements and plants as is practically possible (Salingaros, 2019).

Starting from the premise that the biophilic quality of buildings does not depend exclusively on green, but also upon the "Geometry of Nature" in their structure, the experiment presented here wants to verify the role of "organized complexity" and "green" in preference and perceived restorativeness of building façades, using a mixed methodology made up of quantitative and qualitative instruments. From our point of view, the exploration of organized complexity is fundamental in understanding human responses to architecture from the evolutionary perspective. To address this issue properly, first a brief hint of evolutionary aesthetics introduces the role of natural selection in recognizing the aesthetic qualities of an environment. Then how the Geometry of Nature is responsible for aesthetics and fascination in Nature will be explained. The introductory section closes with an overview on environmental perception and the difficulty in managing the perception of real-world scenes.

1.1. Evolutionary aesthetics

Humans are able to experience a broad array of phenomena in terms of "beauty" and "ugliness" (e.g., tastes, smells, humans, artifacts, places, etc.) and it is safe to assume that the pleasure response is "immediate" and "functionless" (Voland, 2003). However, this does not imply that aesthetic judgment has no function as a biological trait. Sexual selection favors fitness indicators that help select the best possible partner for reproduction (Miller, 2001). For example, whenever we see other human beings, we instantly judge their attractiveness; this automatic evaluation of attractiveness uses all the information available about the other person: their body shape and size, their facial symmetry, their movement, their odor, their voice, etc. (Grammer at al., 2003). These visual cues might indicate "good genes", i.e., a genetic endowment which is able to cope well with the current environment, indicating "functional optimality" (Rhodes, 2006). The aesthetic terms of "beauty" and "ugliness" therefore refer to a first level of selection linked to reproduction.

Natural selection can also play a role in aesthetic evaluation. The ability to search for resources and shelters is a behavioral trait that has arguably long been favored by natural selection in the fight against the hostile forces of Nature (Buss, 2016, pp. 68-99), and which promoted the evolution of a cognitive system that arranges the phenomena of our world using aesthetic judgments (Voland and Grammer, 2003). This mechanism explains why the kind of places we find intriguing, and which we gravitate towards, are rooted in our evolutionary history (Berto, 2019; Kaplan and Kaplan, 1982). Humans' predisposition to recognize the aesthetic qualities of a certain habitat reflects the adaptations designed by natural selection aimed to help us to choose a place to inhabit (Kaplan, 1992; Orians and Heerwagen, 1992) and it could be an adaptation that is the result of several cycles of ex-adaptations (Barbiero and Berto, 2021).

1.2. Nature's restorativeness, fractals, and biophilic design

Abundant evidence favors the proposition that Nature is restorative. Nature improves cognitive functioning, productivity, mood, vitality, speed of recovery in hospital: it reduces stress and anger, and these benefits hold for being in Nature, for merely having some Nature in a room (e.g., plants), for seeing a poster image of Nature, or even for seeing Nature through one's window (for a review see Berto, 2014). The pioneering experiments by Roger Ulrich (1981, 1984) showed that exposure to natural scenery induced positive physiological changes in people, including significant stress reduction, thus laying the foundation of Stress Recovery Theory (SRT; Ulrich et al., 1991). In the meantime, Rachel and Stephen Kaplan (1989) explored humans' innate preference and fascination for Nature. Later, Stephen Kaplan introduced Attention Restoration Theory (ART; 1995) and proposed that "fascination", i.e., involuntary effortless attention induced by Nature stimuli, differs from "directed attention", i.e., voluntary effortful use of directed attention usually required for demanding tasks, and that Nature's fascination restores depleted mental resources exhausted by the effort use of directed attention.

Fractals (forms that are subdivided in a regular manner going all the way down in scales; for more details see Mandelbrot, 1982) are responsible for the aesthetics and fascination of Nature. The prevalence of fractal objects in Nature (e.g., clouds, trees, mountains, cauliflowers, fern leaves, etc.) led to the formulation of the "fractal fluency model" (Taylor and Spehar, 2016; Stadlober et al., 2021; Salingaros, 2012). Whether natural or created, fractals represent a profound ingredient of our visual experiences in which human vision has become fluent and can process efficiently. The fractal fluency model predicts that increased performance of basic visual tasks during "effortless looking" will create an aesthetic experience accompanied by significant reductions in stress and mental fatigue (Taylor, 2021). Automatic fractal processing triggers initial attraction/avoidance evaluations of an environment's salubriousness, and its potentially positive or negative impacts upon an individual (Brielmann et al., 2022). Unfortunately, people are surrounded by urban landscapes and risk becoming disconnected from the relaxing qualities of Nature's fractals. To this end, designers and architects should address the individual's need to be exposed to the restorative qualities of Nature by creating fractal designs and architecture, in particular mid-*D* fractals (Abboushi et al., 2019): the visual information of mid-*D* fractals is easy to process, and fractal fluency is accompanied by a powerful aesthetic experience. In fact, the fractal qualities of the visual environment either encourage or discourage movement and navigation in urban spaces; this effect is responsible for feeling "at ease" in an urban environment. Going beyond aesthetic attraction, fractal patterns of the right dimension are shown to exert a measurable healing effect on humans (Brielmann et al., 2022), and the healing properties of environments correlate with definite characteristics: specifically, with particular geometrical qualities.

Biophilic design "is the deliberate attempt to translate an understanding of the inherent human affinity to affiliate with natural systems and processes — known as biophilia — into the design of the built environment" (Kellert, 2008, p. 3). Biophilic design takes advantage of our biological attraction to natural forms, and the special geometric patterns that mimic them. Salingaros (2019) argues that the *complex geometry* of the environment is in part responsible for the effect of design on an individual's wellbeing. Modern architecture inflicts shapes, color, spaces, texture, surfaces, etc. etc. that disconnect people emotionally from Nature (Aresta and Salingaros, 2021); much of architecture continues to be based on design that is neutral in its biophilic impact, or worse, explicitly *antibiophilic* (Salingaros, 2015).

Most buildings built by industry since the Second World War suffer from "Nature deficit *design* disorder" (Berto and Barbiero, 2017). Biophilic design can bridge the gap between human beings and Nature, by taking evolutionary biology, ecology, and environmental psychology as the basis for design. However, biophilic design is not just an exotic garden outside the building, or a piece of vertical landscape situated on a wall purely for aesthetic reasons, but rather a holistic "restorative" design that does not alienate people, as environment-friendly technological buildings very often do. Biophilic design is "cognitively sustainable" design (Berto, 2011) and can be applied at all levels of scale, creating interior and exterior revolutionary forms, private and public buildings, landscapes, and whole cities.

A radical change in design intentionality would discard architectural formalisms to adopt a completely new method of healthy design (Buchanan, 2012). Human beings require intimate contact with Nature and also a special "biophilic" geometry in the artificial built environment, i.e., patterns that trigger the same reactions as natural forms. People have clear preferences for combinations of building shape, color, and arrangement, etc. (Smith, Health and Lim, 1995; Zacharias, 1999), and a building that achieves intimate contact with Nature triggers positive emotions. More and more contemporary buildings pay attention to green, but plants satisfy only one part of biophilia — the part that depends upon proximity to Nature — and could neglect the need for biophilic geometries in the building itself. The biophilic quality of buildings does not depend primarily upon green, but upon a special type of "organized complexity" (i.e., symmetry, alignment of elements, scaling symmetries, scaled-up elements) in their structure, which contributes to an unconscious connection with Nature; together with the actual presence of Nature and/or representations of Nature's components (Salingaros, 2017).

1.3. Environmental perception

The study of human perception and aesthetic response to built environments might be central to progress in many areas of pure and applied research, in particular to architecture and design. It is the key to planning environments that sustain the individual's need of recovery from psycho-physiological stress.

In the classic perception literature, perception and cognition can be considered two distinct processes, while in Environmental Psychology the debate is still open. According to Ittelson (1976) perception and cognition cannot be considered separately, for a series of reasons: (1) environmental perception is made up of information conveyed from all the senses and not only from a specific one; (2) the environment surrounds us, therefore it has to be explored more than simply seen; (3) environmental information is more than what can be processed, therefore an intentional or automatic selection must be implemented; (4) environments have physical, social, and affective aspects; (5) environmental perception is aimed towards deciding for action. However, Gestalt psychology and in particular Lewin (1936) anticipated the modern Environmental Psychology highlighting: the active role of the subject in perceiving the distinction between physical and phenomenological environments; the need to consider the perceived object as part of its context (an object is more than the sum of its parts); human behavior (B) as a function of the environment (E) and of the person (P): $B = f(E, P)$; events must be studied in interrelation, which is a dynamic approach; the environment also has social aspects.

Gibson's approach (1966; 1979) to the environmental perception issue is completely different. Things have bad or good values (i.e., response valences evoked in the individual) that can be easily taken by the perceiver. Environmental invariants can be directly perceived without cognitive mediation - i.e., the light glazes, the spatial layout, the in/animated objects, the fixed or mobile objects, etc. All these affordances or utilities are meaningful and useful aspects of the environment that attract our attention and aim our action. Actually, it is not easy to distinguish among perception *per se*, the environment, and the individual's cognitive processes because bottom-up and top-down processes interact and overlap in environmental perception (Berto, 2011). Hochstein and Ahissar (2002) state that explicit vision advances in reverse hierarchical direction; conscious perception begins at the hierarchy's top, gradually returning downward as needed. Thus, our initial conscious percept - e.g., vision at a glance - matches a high-level generalized, categorical scene interpretation, identifying "forest before trees" - i.e., the gist of a scene is captured together with our blindness to the details (Hochstein and Ahissar, 2002).

Basically, research in human perception can be divided into three areas of investigation. *Low-level or early vision*, i.e., extraction of physical properties such as depth, color, and texture from an image as well as the generation of representation of surfaces and edges (Marr, 1982); *intermediate level*, i.e., extraction of shape and spatial relations that can be determined without regard to meaning, although this typically requires a selective or serial process (Ulman, 1996); *high level vision*, i.e., the mapping from visual representations to meaning, which includes the study of processes and representations related to the interaction of cognition and perception, including attention, the active acquisition of information, short-term memory for visual information, and the identification of objects and scenes (Henderson and Hollingworth, 1999).

To manage real-world complexity, visual attention is guided to important scene regions in real time. According to "image guidance theories", attention is directed to scene regions on the basis of semantically uninterpreted image features, i.e., attention is a reaction to the image properties of the stimulus confronting the viewer, with attention "pulled" to visually salient scene regions (Henderson, 2017). The most comprehensive theory of this type is based on visual salience, in which basic image features such as luminance contrast, color, and edge orientation are used to form a saliency map that provides the basis for attentional guidance (Itti and Koch, 1998; 2001; Harel, Koch and Perona, 2006).

An alternative theoretical perspective is represented by "cognitive guidance theories", in which attention is directed to scene regions that are semantically informative. This position is consistent with strong evidence suggesting that humans are highly sensitive to the distribution of meaning in visual scenes from the earliest moments of viewing (Biederman, 1972; Wolfe and Horowitz, 2017). According to this interpretation, attention is primarily controlled by knowledge structures stored in memory (see Schema Theory; Neisser, 1976). Those knowledge structures contain information about semantic content and the spatial distribution of that content, which is based on experience with general scene concepts and the specific scene instance currently in view (Henderson and Hollingworth, 1999). Recent literature reveals that both *meaning* and *salience* predict the distribution of attention (Henderson and Hayes, 2017), yet when the relationship between meaning and salience was examined, only *meaning* accounted for unique variance in attention. This pattern of results was apparent from the very earliest time-point in scene viewing, concluding that *meaning* is the driving force guiding attention through real world scenes.

1.4. Epistemological approaches to biophilic quality of buildings

This study is based on knowing that visual perception is a complex process and is greatly influenced by bottom-up and top-down processes. We mix quantitative (Visual Attention Software) and qualitative approaches (self-rating scales) to encompass the relation between perceived restorativeness and the engagement of attention in perceiving biophilic design of building façades. The study starts from the premise that the biophilic quality of buildings does not depend exclusively on "green", but also upon organized complexity in their structure. According to this model, exploring organized complexity is fundamental in understanding human responses to architecture.

2. Materials and Methods

2.1 Stimulus Material

Eight photographs depicting building façades were chosen from many different types of buildings. The purpose was to sample façades (two photographs per category) belonging to three approximate levels of Biophilic Design: Low, Medium and High Biophilic Design, and to compare those to "No Biophilic Design" as the control group (see Figure 1).

Figure 1. The stimulus material. From the top to the bottom: the Low Biophilic Design (Low-BD) buildings (photograph 1 on the left, photograph 2 on the right); the Medium Biophilic Design (Medium-BD) buildings (photograph 3 on the left, photograph 4 on the right); the High Biophilic Design (High-BD) buildings (photograph 5 on the left, photograph 6 on the right); the no Biophilic Design (No-BD) buildings (photograph 7 on the left, photograph 8 on the right).

Photographs do not differ in their environmental information ($p > .05$); this is a central issue in the engagement of involuntary attention-fascination (Berto 2011; Berto et al., 2015). The amount of information contained in photographs was analyzed at a basic level using the Lempel-Ziv-Welch lossless compression algorithm (LZW). The LZW algorithm has practically become the standard compression procedure (commonly referred to as "zip") and constitutes a simple but reliable method of comparing image information content. By removing *redundancy*, compression leaves the compressed file with only the actual or salient information content; images often contain quite redundant information or have multiple sections containing identical information. The LZW algorithm determines the amount of unique information in the information source (for more details see Unema et al., 2005; Itti, 2006). The compression *ratio* (defined as the fraction of the size of the uncompressed file divided by that of the compressed file) is expressed as a percentage: the higher the ratio, the more visual *redundancy* the image contains. The compression ratio was calculated for the eight photographs and since the LZW algorithm does not consider any pre-existing knowledge about the world, it can be safely assumed that the procedure of compression affected all the images similarly.

2.2 Self-rating scales

2.2.1 Participants

Twenty-five students (mean age = 28 years, SD = 6.06; 96% female, 4% male) at the University of Valle d'Aosta, Italy, volunteered to participate.

2.2.2 Instruments

A questionnaire was administered that required subjects to assess the eight buildings/façades using the Perceived Restorativeness Scale-11 (PRS-11) with two additional items included to assess familiarity and preference, and a list of physical and aesthetic attributes.

The PRS-11 (Pasini et al., 2014), based on the original version by Hartig et al. (1997), measures an individual's perception of four restorative factors:

I. *being-away* (BA; 3 items): a setting that allows physical and/or psychological distance from demands on directed attention;

II. *fascination* (FA; 3 items): the type of attention stimulated by interesting objects, namely a setting that provokes curiosity in the individual and fascination about things, and is assumed to be effortless and without capacity limitations;

III. *coherence* (COH; 3 items)*:* a setting where activities and items are ordered and organized; and

IV. *scope* (SCO; 2 items)*:* a setting that is large enough such that it does not restrict movement, thereby offering a sort of "world of its own".

Additional items were included in the PRS-11 in order to assess familiarity (FAM; 1 item) and preference (PREF; 1 item). Items are rated on a 0 to 10-point scale, where 0 = not at all, 6 = rather much, and 10 = completely.

In addition to the above PRS-11, it is useful to estimate to what extent the building/façade possesses the following 10 quite separate physical aesthetic attributes (Nasar, 1994): novelty, building for leisure activities, maintenance, cleanliness, representativeness, luminosity, openness, harmony, visual diversity, and vegetation. All of these attributes are rated on a 1 to 5-point scale, where 0 = not at all, and 5 = a lot.

2.2.3 Procedure

Subjects were tested individually in a distraction-free laboratory at the GREEN LEAF Groupe de Recherche en Education à l'Environnement et à la Nature, Laboratory of Affective Ecology, University of Valle d'Aosta. Subjects were seated in front of the computer and instructed to look freely at the photographs and to fill in items for the PRS-11 and rate the physical aesthetic attributes for all the photographs. The presentation order as shown on the computer screen was randomized between subjects.

2.3 Visual Attention Scans (VAS) and biophilic design

Most research on attentional guidance in scenes has focused on image salience. This exploratory research study on biophilic design of building façades also utilizes visual attention scans, performed using 3M Company's Visual Attention Software (VAS; 3M, 2020). The software produces heat maps of where the subject's unconscious attention is supposed to be distributed during the first 3-5 seconds of gaze. This result is obtained through visual rule-based simulation, not direct eye-tracking, yet is claimed by the manufacturer to be 96% accurate when compared to direct eye-tracking experiments. The software does not recognize plants or natural scenery *per se* but works strictly on the geometrical characteristics of the image. Natural scenery, and plants in particular, are characterized by a mid-range fractality (Abboushi et al., 2019). Altogether, the brain's recognition mechanism for biophilic design relies upon very similar mathematical cues as those programmed into the VAS software (Salingaros and Sussmann, 2020). For this reason, these scans can be helpful for analyzing the biophilic design content of images. The reason that VAS works so well to measure biophilic design is that it ignores the difference between living components, such as plants or animals, and human made components. Therefore, one obtains a general measure of the interest the design arouses that is independent from the category/meaning the various elements present in the scene belong to.

VAS provides five different results of visualizations of an image as follows:

1. *Areas of Interest.* These can be specified by the user, and each one of them has a numeric score which is the probability that a person will look somewhere within that area during the pre-attentive period. We did not use this feature.

2. *Heat map.* This is a color-coded probability map that a certain part of the image will attract the gaze during the pre-attentive period. We used this feature in all the scans, adopting it as the most direct and useful diagnostic tool for our analysis.

3. *Hotspots.* A simplified version of the heatmap results shows only the areas that are most likely to be seen during the pre-attentive scan, with a numeric score indicating the probability that a person will look somewhere in that region during the pre-attentive period.

4. *Gaze Sequence.* This indicates the four most likely gaze locations, in their most probable viewing order.

5. *Visual Features.* This visualization gives an insight to how the algorithm works, by extracting those same features that drive pre-attentive processing in our visual system (Itti and Koch, 2001); namely edges, intensity, red/green color contrast, blue/yellow color contrast, and faces. We used this feature only in the first scan, for demonstration purposes.

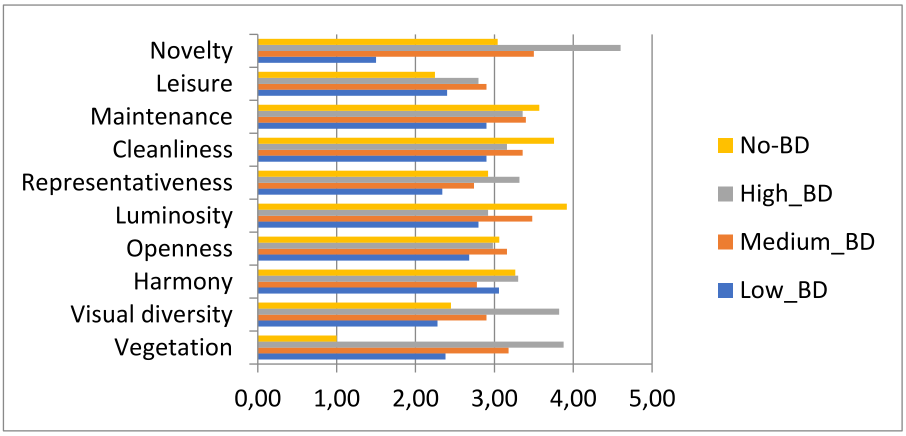
The heat maps for the eight photographs shown in Figure 1 were generated using the VAS software, and will be discussed in sequence in the rest of this paper.

3. Results and discussion

3.1 Self-rating assessments

3.1.1 Results

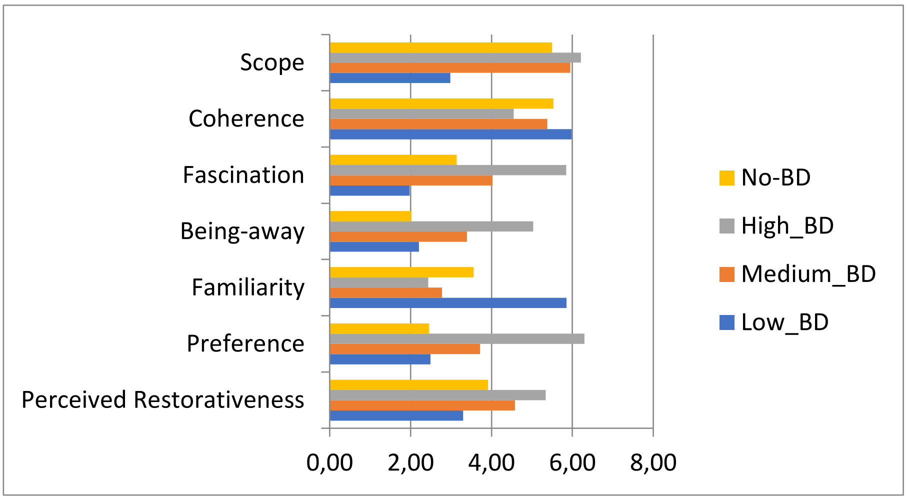
A MANOVA (multivariate analysis of variance) was run to investigate the effect of each category (fixed factor, 4 levels: H-BD, Medium-BD, Low-BD, No-BD) on the physical-aesthetic attributes, the PRS-11, PREF and FAM. A significant effect of category emerged for: vegetation, $F(3,199) = 143.74$; visual diversity, $F(3,199) = 24.89$; luminosity, $F(3,199) = 15.29$, representativeness, $F(3,199) = 6.12$; cleanliness, $F(3,199) = 9.51$, maintenance, $F(3,199) = 5.54$; leisure, $F(3,199) = 5.48$; novelty, $F(3,199) = 106.78$; FAM, $F(3,198) = 15.98$; PREF, $F(3,198) = 21.31$; PRS-11, $F(3,198) = 12.44$; BA, $F(3,198) = 14.32$; FA, $F(3,198) = 23.82$; COH, $F(3,198) = 5.76$; SCO, $F(3,198) = 21.42$; all $p < .05$.



Graph 1. Mean scores of the physical aesthetic attributes for each category: No-Biophilic Design (No-BD), High-Biophilic Design (H-BD), Medium Biophilic Design (M-BD), Low-Biophilic Design (L-BD).

In brief, the categories differ significantly on all physical-aesthetic attributes (see Graph 1), but harmony and openness, with High-BD images, score higher on vegetation, novelty, and representativeness. The categories also differ significantly on perceived restorativeness, preference, familiarity, and the four restorative factors (see Graph 2), with the High-BD score higher on perceived restorativeness, preference, scope, fascination, and being-away, but the lowest on familiarity. The Low-BD images resulted the most familiar and coherent.

 http://dx.doi.org/10.13135/2384-8677/7054



Graph 2. Mean scores of the perceived restorativeness scale, preference, familiarity, and the four restorative factors: being-away, fascination, coherence, and scope, for each category: No-Biophilic Design (No-BD), High-Biophilic Design (H-BD), Medium Biophilic Design (M-BD), Low-Biophilic Design (L-BD).

To verify further differences between photographs within each category (Low-BD, Medium-BD, High-BD and No-BD) independent sample t-tests were performed on the physical aesthetic attributes, PRS-11, PREF, FAM, BA, FA, COH and SCO. In the Low-BD category (photograph 1 vs 2) significant differences emerged for: vegetation, $t(48) = 4.10$; novelty, $t(48) = -2.45$; PREF, $t(48) = -2.18$; all $p < .05$ (see Table 1). In the Medium-BD category (photograph 3 vs 4) a significant difference emerged for: vegetation, $t(48) = 3.13$, diversity, $t(48) = 2.21$, novelty, $t(48) = 2.82$, FAM, $t(48) = 2.31$, COH, $t(48) = 2.44$; all $p < .05$ (see Table 1). In the High-BD category (photograph 5 vs 6) a significant difference emerged for: vegetation, $t(48) = 2.52$; PREF, $t(48) = 2.67$; BA, $t(48) = 2.16$; FA, $t(48) = 3.31$; COH, $t(48) = 3.05$; SCO, $t(48) = 3.05$; PRS-11, $t(48) = 2.02$ ($p = .049$); all $p < .05$ (see Table 1). In the No-BD category (photograph 7 vs 8) a significant difference emerged only for novelty, $t(48) = 4.22$, $p < 0.05$ (see Table 1).

	Low-BD		**Medium BD**		**High BD**		**No BD**	
	Photo 1	Photo 2	Photo 3	Photo 4	Photo 5	Photo 6	Photo 7	Photo 8
Vegetation	**2.00 *** (0.64)	2.76 (0.66)	**2.76 *** (0.92)	3.60 (0.86)	**3.84 *** (0.62)	3.92 (0.81)	1.04 (0.20)	0.96 (0.20)
Visual diversity	2.40 (0.76)	2.16 (0.86)	**2.60 *** (1.04)	3.20 (0.86)	4.16 (0.74)	3.48 (1.12)	2.32 (1.18)	2.64 (0.95)
Harmony	3.20 (0.91)	2.92 (0.95)	3.00 (1.08)	2.56 (1.15)	3.28 (1.06)	3.32 (1.10)	3.44 (1.00)	3.12 (1.05)
Openness	2.76 (1.01)	2.60 (0.81)	3.32 (0.94)	3.00 (0.86)	2.96 (0.93)	3.00 (1.04)	3.00 (1.11)	3.13 (0.94)
Luminosity	2.80 (0.81)	2.80 (0.86)	3.56 (0.91)	3.40 (0.86)	2.88 (1.01)	2.96 (1.17)	3.80 (0.91)	4.08 (0.90)
Representativeness	2.60 (0.95)	2.08 (1.22)	2.64 (1.07)	2.84 (1.10)	3.48 (1.32)	3.16 (1.34)	3.12 (0.97)	2.72 (1.17)
Cleanliness	2.84 (0.74)	2.96 (0.67)	3.48 (0.77)	3.24 (0.92)	3.08 (0.75)	3.24 (0.92)	3.56 (0.91)	3.96 (0.78)
Maintenance	2.96 (0.67)	2.40 (0.62)	3.52 (0.91)	3.28 (0.97)	3.20 (0.92)	3.52 (0.91)	3.64 (0.75)	3.52 (1.00)
Leisure activities	2.20 (0.70)	2.60 (0.95)	3.00 (0.91)	2.80 (0.95)	3.12 (1.01)	2.48 (0.96)	2.16 (1.02)	2.32 (0.82)
Novelty	**1.68 *** (0.55)	1.32 (0.47)	**3.16 *** (0.98)	3.84 (0.68)	4.68 (0.55)	4.52 (0.87)	**2.44 *** (0.96)	3.68 (1.10)
Familiarity	5.72 (2.79)	6.08 (3.54)	**3.56 *** (2.14)	2.12 (2.26)	2.60 (2.54)	2.28 (2.50)	4.24 (2.68)	2.88 (2.71)
Preference	**3.28 *** (2.59)	1.84 (2.03)	3.16 (2.79)	4.12 (3.46)	**7.36 *** (2.27)	5.24 (3.24)	2.20 (2.00)	2.72 (2.85)
Being-away	2.71 (2.68)	1.75 (1.54)	2.88 (2.80)	3.77 (2.78)	**5.95 *** (2.89)	4.12 (3.07)	2.01 (2.15)	2.03 (2.08)
Fascination	2.47 (1.97)	1.63 (1.61)	3.43 (2.51)	4.55 (2.75)	**6.99 *** (1.99)	4.72 (2.77)	2.76 (2.01)	3.52 (2.29)
Coherence	5.83 (1.46)	5.99 (1.51)	**5.88 *** (1.41)	4.91 (1.35)	**3.81 *** (1.57)	5.29 (1.83)	5.64 (1.90)	5.43 (1.76)
Scope	3.38 (2.17)	2.72 (1.72)	5.50 (2.35)	6.36 (2.30)	**7.42 *** (1.94)	5.00 (2.36)	4.92 (2.32)	6.08 (1.84)
Perceived Restorativeness	3.56 (1.76)	3.05 (1.17)	4.38 (1.91)	4.76 (1.89)	**5.92 *** (1.74)	4.76 (2.25)	3.73 (1.50)	4.10 (1.38)

Table 1. Mean scores (and standard deviation in parenthesis) of the physical aesthetic attributes, the perceived restorativeness scale, preference, familiarity, and the four restorative factors: being-away, fascination, coherence, and scope for the two photographs of each category. ***** = significant statistical difference: $p < .01$

To assess the direction and strength of the relationship between PRS, PREF, and FAM, a Pearson's correlation was run between these variables considering first all subjects and all categories together, and then each category separately. The following correlation turned out significant: for all categories together: PRS*PREF, r = .84 (p < .01); for L-BD, PRS*PREF: r = .68 (p < .01); PREF*FAM: r = .36 (p < .01); for M-BD, PRS*PREF: r = .87 (p < .01); for H-BD: PRS*PREF: r = .89 (p < .01); PRS*FAM: r = .37 (p < .01); PREF*FAM: r = .38 (p < .01); for No-BD: PRS*PREF: r = .76 (p < .01); PREF*FAM: r = .31 (p < .01).

The strength of the correlation between PRS and PREF for each category appears to follow the strength/level of the biophilic quality value assigned to that category. Considering the correlation results, FAM may affect both PRS and PREF for the H-BD and the No-BD categories. The significant correlations revealed between PRS and PREF and between PREF and FAM for all the categories were not unexpected; on the other hand, this study keeps showing a significant correlation between PRS and FAM that recently appeared in literature (see Berto et al., 2018).

Pearson's correlations were also run between the PRS score for each category and the physical aesthetic attributes. Table 2 shows the significant correlations between the variables addressed.

	L-BD	M-BD	H-BD	No-BD
Vegetation	.216	.656**	.313*	.172
Visual diversity	.327*	.580**	.518**	.316*
Harmony	.477**	.680**	.661**	.562**
Openness	.445**	.555**	.449**	.650**
Luminosity	.400**	.503**	.578**	.688**
Representativeness	-.039	.726**	.407**	.324*
Cleanliness	.334*	.531**	.544**	.534**
Maintenance	.396**	.530**	.398**	.391**
Leisure activities	.387**	.684**	.625**	.226
Novelty	.414**	.649**	.357*	.255

Table 2: Pearson's correlations between the Perceived Restorativeness Scale score (PRS), and the physical-aesthetic attributes scores for each category: High-Biophilic design (H-BD), Medium-Biophilic Design (M-BD), Low-Biophilic Design (L-BD), No-Biophilic Design (No-BD).
* = significant statistical difference: p < .05 **= significant statistical difference: p < .01

Results that catch the eye include the non-significant correlations for the Low-BD category between PRS and vegetation, and between PRS and representativeness; for the High-BD category the low correlation value, though significant, between PRS and vegetation; and for the No-BD the non-significant correlation between PRS and vegetation, between PRS and leisure activities, and between PRS and novelty (see Table 2).

3.1.2. Discussion

Results show that High-BD buildings are not characterized by all physical aesthetic attributes, in particular these buildings scored low on luminosity, cleanliness, and maintenance; these characteristics distinguish the No-BD buildings the most from the other buildings. The presence of dense and widespread vegetation, typical of High-BD buildings, which makes them representative, novel, and different from usual buildings, does not go hand-in-hand with luminosity and cleanliness; vegetation is perceived as a potential problem for the building maintenance. Nevertheless, High-BD buildings are perceived as the most restorative among all the buildings: they offer a temporary escape from "urban visual routine" (being-away), they allow the engagement of involuntary attention (fascination), which is attracted in the first place by vegetation (Kaplan, 1995), and secondly, by shapes with the right amount of complexity that attract visual interest (scope). High-BD buildings score the least coherent and familiar, thus accordingly high preference for these buildings might be sustained by their novelty (see The Schema Discrepancy Model; Purcell, 1986).

Results show that Medium-BD buildings are the most suitable for leisure activities; their articulated shape together with the opportunity they allow to see through the stained-glass windows make these buildings comprehensible enough to plan activities.

The results also show that Low-BD buildings scored the lowest in perceived restorativeness, even lower than No-BD buildings. Low-BD buildings are low in fascination and scope, and the presence of a lawn and water do not necessarily correspond to a biophilic and/or restorative visual experience. Nevertheless, the Low-BD buildings are the most coherent and not surprisingly the most familiar, and in fact they are rated as the least novel.

3.2 Visual Attention Software outputs

3.2.1. Heat maps of the Low Biophilic Design buildings

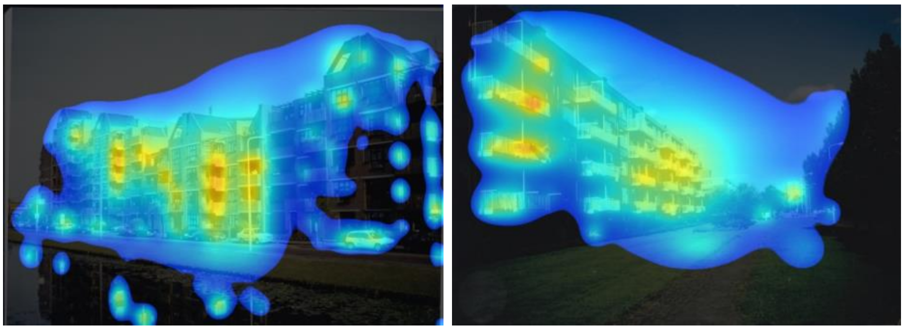


Figure 2. Heat maps of photograph 1 (on the left) and 2 (on the right).

Photograph 1. In these apartments, the attention is drawn to the contrast of the balconies against the rest of the building. The visual interest is not triggered by the trees and plants on the building, as one might expect if there was indeed a biophilic effect, this response is simply due to visual contrast. Furthermore, visual interest fails to identify the building's entrances. As an aside, the strip of lawn in front reveals itself as an extremely weak biophilic element, thus disproving universal efforts to raise the biophilic qualities just by adding some flat lawn. A common misconception is that biophilic design requires some lawn because that is an organic element, but its visual complexity is far too low to have any significant effect. One has to incorporate more complex elements for a setting to become an effective biophilic design.

Photograph 2. These apartment buildings show hotspots on their balconies. While visual interest is drawn throughout the façade, there is no significant design or functional reason for the hard focus on the balconies except for the vertical structure in the middle of each balcony. The overall impression is comfortable without in any way being notable. The lawn in front fails to draw any visual attention, hence is a very weak biophilic element in the overall composition.

3.2.2. Heat maps of Medium Biophilic Design buildings

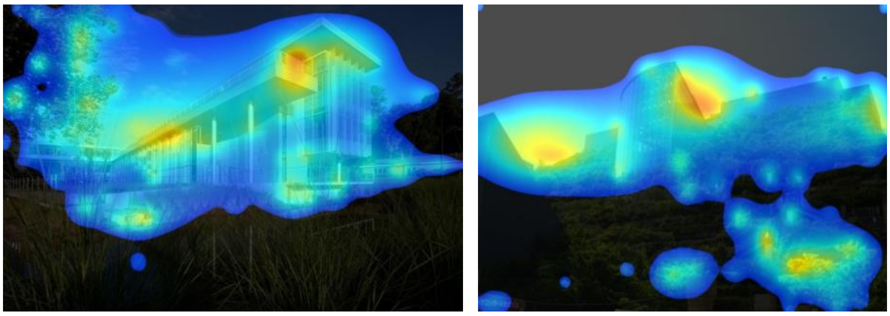


Figure 3: Heat maps of photograph 3 (on the left) and 4 (on the right).

Photograph 3. The trees, bushes, and tall grass in front are wholly biophilic, but the building's structure is not, and it therefore contrasts with its setting. There is visual interest throughout the building because the structural subdivisions offer some degree of organized complexity. Nevertheless, design flaws become evident since the attention is drawn to two hot spots: the edge of the canopy supported by the columns, and the join of the same canopy to its support. Those regions are irrelevant. They do not visually anchor the building's design or function, nor do they enhance its entrance or circulation realms. What would at first appear to be a building with a biophilic design (because of the preponderance of vegetation) reveals problems on closer examination of the scan.

Photograph 4. Here we see the failure of a glass façade to engage with the viewer's interest. This building is entirely devoid of organized complexity. The attention is drawn only to irrelevant edges on the skyline and not to the actual building. Furthermore, this attention occurs because of the light contrast, not the design; this might support the lack of spread interest. Of course, the vegetation below provides an attractant, but the overall visual interest does not extend to the material structures, which remain separated, apparently out of interest. This example appears as a non-biophilic building that is situated in a richly biophilic setting.

3.2.3. Heat maps of the High Biophilic Design buildings

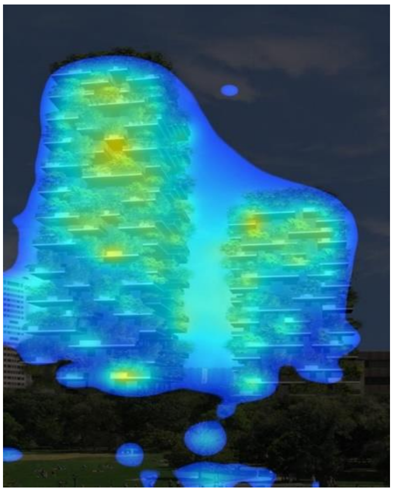
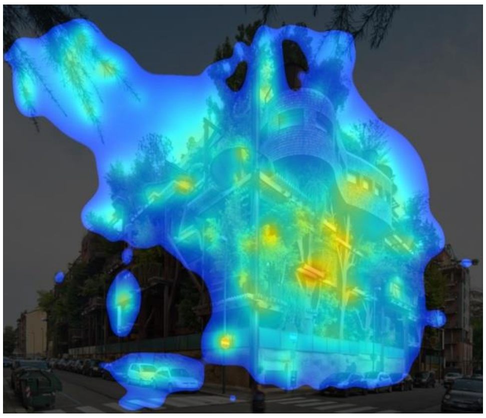



Figure 4. Heat maps of photograph 5 (on the left) and 6 (on the right).

Photograph 5. As expected from skyscrapers where trees grow on every balcony, these high-rise buildings appear to be highly biophilic. The visible material structure blends with and does not detract from the biophilic design offered by the multiple trees. There is a void in the VAS scan where the building meets the ground, whereby the ground floor and entrance are invisible to a potential viewer. This is a design flaw common with many high-rises that neglect the importance of a visual ground connection. Since these buildings are skyscrapers, attention is drawn higher, and on the asymmetrical balconies where vegetation abounds.

Photograph 6. This building draws considerable attention, which is fairly well distributed over the better lit façade to the right. The uniform blue glow indicates that the design and structural details engage attention in a wholistic manner throughout the visual field (Salingaros and Sussman, 2020). Note two artifacts of the scan that reveal some interesting background about attention: (a) The interest is drawn to a branch that enters the picture on the top left; (b) Two parked cars draw attention away from the building itself, despite the building's considerable organized complexity.

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3.2.4. Heat maps of the No Biophilic Design buildings

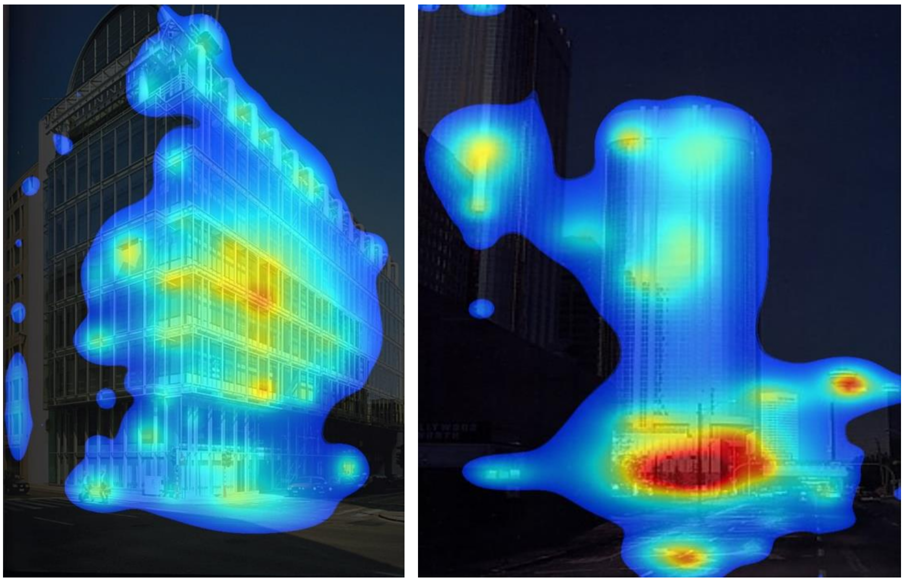

Figure 5. Heat maps of photograph 7 (on the left) and 8 (on the right).

Photograph 7. The repeating subdivisions of this glass building are enough to attract interest to its middle. It has a certain degree of organized complexity, although not high enough to distinguish its design. But the actual point of interest that is the hot spot in the scan (the windows somewhere in the middle of the façade) is not particularly relevant from an architectural and urban point of view. Also, the entrance is ignored because it fails to stand out through its articulation.

Photograph 8. There is a considerable hot spot of attention at the base of this building, but this is where the skyscraper contrasts with another building in front that appears to be built of "solid" materials. The VAS scan is empty, which reveals that there is no interest for a potential viewer. This glass skyscraper has no biophilic design qualities, since its design does not follow any organic complexity, and the building does not contain or support any vegetation.

3.3. Comparison between self-ratings assessments and VAS heatmaps

VAS analysis shows that vegetation *per se* does not always draw interest. Vegetation engages attention when it is integrated within an articulated structure. VAS doesn't disclose, as self-ratings do, that vegetation might act to the detriment of the building when it removes luminosity, compromises maintenance, and make it appear less clean. Indeed, dense and widespread vegetation might work against "cognitive sustainability" (Berto, 2011) and VAS clearly reveals that disarticulated and chaotic vegetation is not that attractive. Self-ratings assessments and VAS show that people are not used to vegetation "on" the buildings, and on the contrary, they are familiar with lawns, which VAS shows are mostly neglected. VAS highlights that the base/entrance of the building rarely catches the focus of attention, as if the building is an object on its own, independent from the context (the problem here is that 20C design philosophy does promote buildings as detached objects). This result makes sense if one considers that the photographs depict buildings detached from their context. VAS shows that attention follows the building structure horizontally or vertically and holds when a visual discontinuity occurs, e.g., in material, color, shape, direction, symmetry, etc. VAS shows that buildings articulated in a more organic manner draw the most interest, while in a parallel demonstration the self-ratings assessments show that these buildings are the most restorative hence preferred. VAS doesn't show that transparent buildings are associated with leisure activities, which is what emerges from self-ratings assessments.

If VAS can be considered a way to operationalize the engagement of attention in biophilic design, and self-ratings assessments a measure of to what extent the building is perceived as restorative, then it can be concluded that these measures show many overlapping points. Higher ratings for biophilic design match higher perceived restorativeness and preference, corresponding to a building where vegetation is integrated into an organic structure. Vegetation is not the only biophilic characteristic to be considered in biophilic design and this conclusion emerges clearly from self-ratings and VAS.

3.4. Content, process, and structure

The experience of Nature through human evolution has left its mark on our minds, our behavioral patterns, our physiological functioning, in what we pay attention to in the environment, how we respond to stimuli, and what that experience means to us (Barbiero, 2014). The Biophilia Hypothesis tells us that, as a species, we still respond strongly to Nature's forms, processes, and patterns (Kellert and Wilson, 1993; Kellert, Heerwagen and Mador, 2008). The dynamic qualities of Nature scenes, e.g., the curvilinear forms, the continuous gradation of color and shapes, the blending of textures, changes associated with seasons, etc., are highly effective in holding our interest/attention effortlessly, and this is reflected in eye movement patterns (for a review see Berto, 2014). The involuntary process can be engaged when environmental information is fascinating, i.e., if it doesn't overload the attentional system (Kaplan and Kaplan, 1981). Therefore, fascination with Nature derives not only from natural elements, but also from the qualities and attributes of Nature that people find aesthetically pleasing when reproduced in the built environment as well.

Fascination is not only a matter of *content* (natural vs. built), but also of *process* (top down vs. bottom-up process). Fascination is derived and tied to particular stimulus patterns, whereas the directed attention component is generic and content free (Kaplan and Kaplan, 1981). While fascination is elicited bottom-up, directed attention is top-down; researchers refer to directed attention as endogenous attention, and to fascination as exogenous attention (Corbetta and Shulman, 2002). Attention works best when something in the environment can fascinate, and the highest fascination occurs when content (the stimulus pattern) and process (the involuntary mode) operate together (Kaplan, 1978).

Currently research is directed towards finding out what is common to environments that engage fascination from a perceptual point of view. It may be that variations in both preference and fascination of scenes depend on their underlying geometry, with a high preference and fascination being associated with Fractal Geometry. It is important to recall that the perceived visual complexity of a fractal is determined by the contribution of fine-scale structure, with more ordered fine structure generating higher complexity. This complexity is determined by the *D* value (the fractal dimension), which controls the ratio between fine and coarse structure, and by the range of scales over which the fractal is observed; increasing this range increases one measure of the visual complexity (for more details see Abboushi et al., 2019; Salingaros, 2018). VAS is an attempt to verify the inherent structure of environmental stimuli which are supposed to engage pre-attentive process, i.e., the "scene structure" (see also Lavdas, Salingaros and Sussman, 2021), going beyond the debate between process and content. VAS provides the opportunity to determine visual patterns that produce optimal perceptual responses.

To better explain this point, VAS heat maps were generated for two images of natural environments, i.e., sunrise beaches with no green vegetation (see photographs 9 and 10). It is reasonable to say that here content and process might

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overlap, but VAS works on the structural features that attract attention the most at first glance, regardless of meaning.

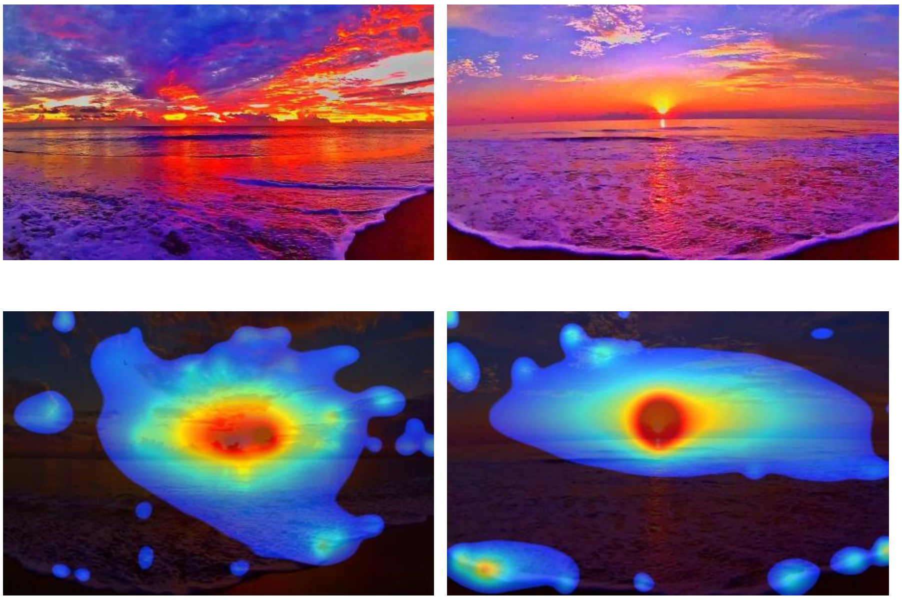

Figure 6. Photograph 9 (on the left) and 10 (on the right) and the corresponding heat maps below. Photographs credit: Rip Read.

A visual attention scan of a natural landscape, in this case two views out to sea, reveals unexpected features of our attention. These are very different from highly organized complex scenery like the building façades, which draws the eye's attention more or less uniformly (as would be revealed in a uniform blue glow in the VAS heatmap). The scans of Figure 6 confirm that in watching Nature scenery the eye moves effortlessly from one feature to another (Berto, Massaccesi and Pasini, 2008). Attention focuses on the sun on the horizon, and on the other visually interesting elements seen on the sea's surface, on the beach, in the clouds, in the curvilinear forms, in the continuous gradation of color and shapes, in the blending of textures, and in shadow features associated with light. It is not by chance that these surrounding visual elements are fractals to some extent. Clouds and waves are characterized by fractal dimensions that receive greatest preference (see Table 1 in Taylor et al., 2021), i.e., they are much smoother than natural

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scenery composed of trees, bushes, and other landforms such as weathered rocks.

The hotspots in heat maps coincide with functional/evolutionary points of interest, which can facilitate the exploration and understanding of the environment and, consequently, the search for adaptation solutions to obtain psychological benefits (Barbiero and Berto, 2021). In fact, from an evolutionary point of view, it makes sense that the sun attracts our attention the most, and attention falls on certain characteristics, e.g., where the water meets the sand, or where cloud shapes let you see what is behind. The beach is the meeting point of the three matrices of Gaia, which allow the biosphere to flourish: the lithosphere (beach), the hydrosphere (sea), and the atmosphere. The fascination that a natural beach arouses could drive the correct interpretation of the quality and quantity of environmental resources (Barbiero, 2021). The perception of "beauty" would be an adaptation to recognize places rich in resources at "first glance". These outputs suggest that these images might engage fascination because they are characterized by structural features that are supposed to engage the involuntary process, at least at "first glance", as VAS shows.

Identifying features of natural environments capable of arousing fascination makes it possible to mimic or replicate these features even in artificial environments. In this way, the search for topics that have a plausible evolutionary matrix (Bolten and Barbiero, 2020), and that engage the involuntary process at "first glance", could be the goal of biophilic design. For example, an essential topic for building human places is that an analysis of the geometry tells us if we are heading in the right direction. We need to see fractal scaling, organized complexity, and repeating symmetries in natural settings first, to build restorative biophilic places. Here we see that the predicted pre-attentive visual scan behaves exactly as expected, confirming an innate reaction to this geometry, which drives our pre-attentive response to necessary features. Biophilic design aims to utilize the beneficial effects of natural geometry, and to transform those patterns into the built environment.

4. Conclusions

Human evolution is central to understanding the modern human relationship with the environment (Berto and Barbiero, 2017; Berto, 2019). From an evolutionary point of view, competence in appreciating beauty appears to be a universal trait in late species of the genus *Homo*. Both *H. neanderthalensis* (Abadía and González Morales, 2010) and *H. sapiens* possessed the ability for appreciating aesthetic qualities in objects, movements, sounds, in natural objects and events, such as sunsets on a beach, whales' songs, or flights of birds (Cela-Conte and Ayala, 2018). Humans' predisposition to recognize the aesthetic qualities of a given habitat reflects the adaptations "designed" by natural selection aimed to help us choose a place where to live (Kaplan, 1992; Orians and Heerwagen, 1992). Humans are programmed by natural selection to handle a wide range of challenging environments, but this has its limitations in terms of the psychophysiological resources. After a stressful event, resources need to be recovered, and the best way to recover them is through exposure to an environment perceived as safe. Since our ancestors lived in natural environments only, the ability to recognize and prefer a safe natural environment conferred an adaptive advantage (Kaplan, 1987). Focusing on the positive valence of aesthetic appraisal, Brown et al. (2011) hold that "such a system evolved first for the appraisal of objects of survival advantage, such as food sources, and was later coopted in humans for the experience of artworks for the satisfaction of social needs". According to Barbiero and Berto (2021) aesthetic appraisal evolved also to support our informational needs (making sense, exploring solutions for adaptation), and steered us towards psychological benefits (e.g., stress recovery and attentional restoration). The present study suggests that the perception of "beauty" should be an adaptation to recognize environments rich in resources, at "first glance". Such an adaptation engages the process of involuntary attention and can be a useful guideline for both explaining and implementing biophilic design.

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Competing Interests

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