JBU — Journal of Biourbanism, Volume 8, No. 1 (2019), in press.

The Biophilic Index Predicts Healing Effects of the Built Environment

Nikos A. Salingaros
Department of Mathematics, University of Texas at San Antonio, United States of America

ABSTRACT

The proposed "biophilic index B " — a number from 0 to 20 — predicts positive health effects that spaces and structures may have on users. This measure can be estimated *before* something is built, anticipating people's eventual response to a new building or urban space. Nothing like this is performed in current practice, which makes no attempt to quantify assessments of future effects. The biophilic index is useful for repair, since it identifies which aspects of an existing building or space could be improved by renovation. Different portions or directions could have widely different biophilic indices. Ten factors constitute the biophilic index, and identify different ways in which nature affects our body in an intrinsic yet subconscious manner. We expect healing responses from long-term physical experience of a region with a high value of the biophilic index. Existing data support this quantitative approach to designing healing environments. Experiments are proposed to explore the mechanisms responsible for the biophilic effect.

Keywords: architecture, design, biophilia, biophilic design, complexity, fractals, salutogenesis, healing environments, neuroscience, design intent

INTRODUCTION: BIOPHILIA AND ITS EFFECTS ON PEOPLE

Biophilia denotes the human response to living things and to very special "biophilic" geometries in our environment. While biophilia was discussed by Erich Fromm (1973) and Edward O. Wilson (1984), its specific application to shaping the built environment is due to Stephen R. Kellert (Kellert and Wilson, 1995). Biophilia's effects come from two distinct sources:

> (*i*) proximity and visual contact with plants, animals, and other people, and
> (*ii*) response to artificial creations that follow geometrical rules for the structure of organisms.

People's neurological reactions to biophilic environments have a positive physiological effect, measurable by medical sensors such as heart rate, skin temperature and conductivity, adrenaline level, pupil size, etc. The primary literature presenting the experimental evidence is cited below, and in (Joye, 2007a; Kellert, 2018; Kellert *et al.*, 2008; Ryan and Browning, 2018).

Claims for the health advantages of biophilia rest upon a variety of measurements. Exposure to a biophilic environment helps speed up post-operative healing, as documented in the classic experiments of Roger Ulrich (Ulrich, 1984). Patients' recovery times were compared for those whose hospital room faced a blank wall, versus those who had an immediate view of trees. Visual contact with nature showed a significant improvement in healing for the latter group. Ulrich's results are summarized for architects in (Kellert *et al.*, 2008; Mehaffy and Salingaros, 2015). After an embarrassing delay of several decades, these findings have finally triggered the implementation of biophilic design guidelines for hospitals (Ryan and Browning, 2018; Totaforti, 2018).

The rapidly growing topics of "healing environments" and "salutogenesis" are developing without reference to biophilia, even though the basic effects are the same (Salingaros, 2015). Healing environments are reviewed from the point of view of the health-care profession in (Huisman *et al.*, 2012; Iyendo and Alibaba, 2014; Rakel *et al.*, 2018; von Lindern *et al.*, 2016). Investigations of healing environments tend to include a broader range of factors than biophilia does, which makes causal analysis more problematic. In addition, health-care professionals are easily diverted from biophilic effects intrinsic in the built environment — i.e. due to geometry and surfaces — hence they often accept architects' designs having very poor biophilic properties. (This is what the present paper tries to clear up). Due to this misunderstanding, new hospitals that claim to reduce stress and anxiety may actually increase them.

Long-term effects of biophilic design impact human health. Existing results reveal that our immune mechanism is reinforced and our stress level is reduced in biophilic environments. Research is needed to better establish the evidential basis for this effect; data suggest that our body is healed through direct exposure to natural environments (Frumkin, 2008; Frumkin *et al.*, 2017; Joye and van den Berg, 2011; Ryan and Browning, 2018; Velarde *et al.*, 2009). For example, there is a positive correlation between cortisol hormone levels and the close, direct experience of nature (Ward-Thompson *et al.*, 2012); physical activity in green places shows a measurable positive mood and increase of self-esteem (Barton and Pretty, 2010); the overall health of those who live near forests and green spaces is statistically better (Beyer *et al.*, 2014; Engemann *et al.*, 2019; Li *et al.*, 2008); there is a significant correlation between living near forests and healthy brain structure (Kühn *et al.*, 2017); and more evidence of the health benefits of closeness to green spaces (Brethour, 2007; Dravigne *et al.*, 2008).

This paper argues that the *complex geometry* of the environment is responsible for the biophilic effect, but it has to be a special type of complexity. New buildings and urban spaces that employ biophilic design promise a major, positive health effect on their users. A more intense type of healing environment is possible today everywhere, and accomplishing this cannot rely exclusively upon proximity to plants. Yet, despite the enormous implications for human wellbeing, design typologies continue to be based on abstract images that are neutral in their biophilic impact, or worse, explicitly anti-biophilic (Salingaros, 2015). A radical change in design intentionality would discard architectural formalisms to adopt a completely new method of healthy design (Buchanan, 2012). In promoting a major reorientation in architectural culture, it is useful to have a simple numerical measure that architects can easily compute.

QUANTIFYING BIOPHILIA BY ESTIMATING THE "BIOPHILIC INDEX" OF A BUILDING

Trying to quantify biophilic effects makes the assessment of architectural projects more objective. We ought to be able to predict the healing effects of specific environments *before* they are built. This robust scientific approach contrasts with the usual assessments of architects based on dubious aesthetics. Ten factors responsible for biophilia can estimate the biophilic content of any physical setting. These factors are described and justified in the next section, and discussed in detail in (Salingaros, 2015). They are very easy to estimate using the descriptions given in the next section.

Table 1: Ten components of the biophilic index B.

1. **Sunlight**
2. **Color**
3. **Gravity**
4. **Fractals**
5. **Curves**
6. **Detail**
7. **Water**
8. **Life**
9. **Representations-of-nature**
10. **Organized-complexity**

The model adds these ten biophilic criteria together into a single number. Instead of merely counting the number of biophilic factors present in a building or urban space, a simple numerical estimate permits a more accurate result (developed earlier to measure organized complexity as the analogy of "Life" in a building (Salingaros, 2006)). We can estimate an integer value from 0 to 2 for the intensity and presence of every one of the ten biophilic qualities.

Estimates: { none = 0, some = 1, a large amount = 2 }.

Definition: *"Biophilic index B"* = Light + Color + Gravity + Fractals + Curves + Detail + Water + Life + Representations-of-nature + Organized-complexity.

Range: $0 \leq B \leq 20$.

Summing the estimates for the ten individual qualities gives the "biophilic index B ", a number ranging from 0 to 20. This metric is useful in assessing the biophilic content of different buildings. We can compare buildings in distinct architectural styles, from different periods and locations, and in different shapes and sizes, independently of the usual stylistic concerns (which play no role in this model). The biophilic index works for different locations within a single building, and to compare interior with exterior spaces, open with closed spaces, etc. This index enables us to measure the biophilic (hence healing) impact of very different buildings in a relatively objective manner.

The whole point of the paper is to back up the following conjecture:

Conjecture: "*The Biophilic Index correlates with long-term healing effects of the built environment.*"

The present discussion is intended to spark interest for more experimentation to support the conjecture (but direct verification is left to future publications). A confluence of results from neurology, physiology, and environmental psychology justifies the simple quantitative model presented here. The biophilic index is immediately understandable to the general public, and represents an important environmental component that affects our health. As argued below, this influence on human wellbeing was important historically, and still is in traditional cultures, but was neglected after the rise of industrialism.

We don't expect any single building to have a maximum score of the biophilic index, $B = 20$. An architect can aim for a high value of B in his/her design, as allowed by the budget and practical constraints. There are various ways to increase the biophilic index, and buildings created according to different styles will do so in their own individual manner, by emphasizing one or more biophilic criteria. Knowing how to achieve this is key to hospital design and long-term health in living and work environments.

HOW DO WE DESIGN BIOPHILIC BUILDINGS AND ENVIRONMENTS?

Rules for biophilic design are straightforward to implement, once we understand the dual origins of this basic effect. First, human beings require intimate contact with nature and with other living beings. This part of biophilia is directly and intuitively understood as the healing influence of nature (Kellert, 2018; Kellert *et al.*, 2008). While such effects are rooted in traditional medicine in all societies, important new experimental measurements are rapidly accumulating on the healing properties of natural environments (Greven, 2017). Second, but more abstract, is to represent a special "biophilic" geometry in the artificial built environment. The intended effect duplicates the positive healing feedback that a user experiences from living matter. Practitioners create shapes that trigger the same sensation as biological forms, but without necessarily mimicking them.

The biophilic index represents a quantitative formulation of biophilic design. Similar but distinct checklists of biophilic criteria have been proposed by Stephen Kellert (Kellert, 2018), the Terrapin Bright Green group (Browning *et al.*, 2014; Ryan *et al.*, 2014), and the present author (Salingaros, 2015). The pluralism of those lists indicates that different researchers are converging on the subject from slightly different directions, which is healthy for a discipline that is still evolving. A useful checklist is taken from a booklet used in courses for architecture students (Salingaros, 2015), and will be further supplemented, below.

First checklist of biophilic design criteria.

1. **Sunlight** — natural light on two sides of a room (Alexander *et al.*, 1977). Our eyes focus better and we can use our stereo vision to see three-dimensional depth (Read, 2015). Circadian rhythms and vitamin D production need sunlight to function (Hasegawa and Arita, 2013; Holick, 2019; Remi, 2015). Sunlight also has therapeutic qualities (Edelstein and Macagno, 2012; Walch *et al.*, 2005).

2. **Color** — comes from both the hue of transmitted light, and pigments on surfaces. Many bright or intense colors affect our mood positively (Jacobs and Hustmyer, 1974; Kurt and Osueke, 2014), whereas gray and dark brown are associated with depression and remind us of putrification, illness, and death (Carruthers *et al.*, 2010; Osmond, 1966; Salingaros, 2003).

3. **Gravity** — buildings need to reinforce the vertical axis and not appear about to fall down on our head. The balance mechanism of our inner ear checks for the horizontal and vertical, and triggers nausea and vomiting whenever those reference axes are violated (Chin, 2018; Gallagher and Ferrè, 2018).

4. **Fractals** — forms that are subdivided in a regular manner going all the way down in scales. This is evident in all traditional architectures, which rely upon rich borders, frames, moldings, ornament, and the use of natural materials with ordered textures (Joye, 2006; 2007b; Salingaros, 2012; Taylor, 2006). People refuse to look at empty, non-fractal shapes and surfaces (Sussman, and Ward, 2017), since minimalism triggers emotional discomfort (Leach, 2016; Salingaros, 2003).

5. **Curves** — balanced curves in a building's structure act independently, or together with bringing the curves of plants up close to and into buildings. Our eye and brain have specific curvature sensors, thus we seek curves all around us (Bar and Neta, 2006; Dazkir and Read, 2011; Gómez-Puerto *et al.*, 2016).

6. **Detail** — meaningful and obvious details in our immediate surroundings. The eye was designed to look for and interpret details that are essential for our survival (Ramamurthy and Lakshminarayanan, 2015; Salingaros, 2003). We "read" intentions in the details of an animal or human face (Leopold and Rhodes, 2010). That's why we respond to the details in natural materials such as wood, travertine limestone, colored marble, etc. (Rice *et al.*, 2006; Sakuragawa *et al.*, 2005).

7. **Water** — seeing and hearing water helps to calm us (Nichols, 2015; Wheeler *et al.*, 2012; White *et al.*, 2010). Probably an ancestral effect from our evolution, it is used extensively in Islamic architecture to promote psychological wellbeing.

8. **Life** — lots of plants, non-threatening animals, and other people near us. Built structures blend with plants by having green courtyards, many interior mini-gardens as small as one square meter, and buildings with a meandering footprint that semi-encloses and protects outside trees so we can see them closely through windows (Barton and Pretty, 2010; Greven, 2017; Takano *et al.*, 2002; Ward-Thompson *et al.*, 2012).

Biophilic design is not a list of rigid rules, but rather a set of mechanisms that allow an infinite number of design solutions within these biophilic constraints. There is tremendous freedom in designing with biophilia while respecting the above basic guidelines. The specifics of each project are left up to the imagination and creativity of the individual architect, and in how he/she interprets and implements the above factors.

TWO ARTIFICIAL BIOPHILIC CRITERIA

To complete the list, we consider two additional biophilic qualities of slightly different character. These factors estimate representations of nature that we connect to: the first explicit, and the second implicit. Visual representations have a long history in human evolution, playing a defining role for the heritage of particular group cultures. Humans have also mimicked the mathematical properties of natural structure in their more abstract art forms, at least prior to the 20th Century (Salingaros, 2019). These qualities relate to the type of visual complexity one requires for navigating the world.

Additional criteria for biophilic design.

9. **Representations-of-nature** — a category that includes realistic depictions of plants, animals, and people either as photographs, paintings, or sculptures. While not part of architectural tectonics, all of these contribute to biophilia in a major way.

10. **Organized-complexity** — purposeful complication that is also accompanied by a high degree of organization (Alexander, 2001; Salingaros, 2006; 2018). Abstract architectural ornament in the Islamic world exemplifies this effect. There are two opposite states that diminish this factor: either empty simplicity, or disorganization.

Since the early days of humanity, realistic depictions of plants, animals, and people have been inseparable from other aspects of architecture. That was automatic before interior decoration split away from architecture, with architects left to practice only tectonics. Experiments show that images of nature have healing effects similar to direct exposure to nature (Brown *et al.*, 2013; Tse *et al.*, 2002; Yin *et al.*, 2018). Throughout history, domestic, religious, and civic architectures represented living forms as integral to the wall surfaces. Representation does not refer only to portable paintings put up on a wall (even though those do play a significant role), but to frescoes, mosaics, and sculptural reliefs forming a permanent part of the building. Traditional buildings the world over have their interiors ornamented with organic motifs.

The **Representations-of-nature** component of the biophilic index is straightforward to measure, yet the iconoclastic turn that Art took in the 20th Century towards abstraction complicates the present situation. For several decades, it is uncommon to see sponsored representational art featuring animals, people, and plants. Therefore, architects will have to resurrect an artistic interest that is all but dead in the “official” world of art, although it is central in advertising and commercial art. One promising entry into such experiments has already been achieved by discovering the innate attraction of faces, as follows.

Recent neuroscience experiments reveal that mammalian brains devote considerable resources to recognizing faces in general, and known faces in particular (Chang and Tsao, 2017). This is an essential advantage for the survival of our species, and therefore we seek faces and figures — other people, strangers and acquaintances, as well as faces represented in and on our buildings. Eye-tracking devices show that people look for other human figures in a landscape *before* focusing on any particular architectural or structural feature (Sussman and Ward, 2017). Minimalist “design” components preferred by present-day architectural culture do not draw the eye at all — they might as well not be there!

The symmetries of an animal or human face can be reflected in an entire building to draw attention to it. People respond positively when an abstraction of a face is represented in a building’s structure (Sussman and Ward, 2017). Contained in the two additional biophilic factors **Representations-of-nature** and **Organized-complexity** is how closely a building entrance or façade resembles a giant animal face, with characteristic vertical symmetry axis, and symmetrically distributed focal points roughly corresponding to mouth, eyes, ears, etc. (Salingaros, 2017). We feel some sort of deep kinship to such a building, much more than to a building with an abstract design that eschews facial symmetries.

While these last two biophilic factors can be identified in almost all traditional and vernacular architectures, with modern times we come to a schism. A strong desire to erase biophilic properties drives the surface appearances of the minimalist design style

(Buchanan, 2012; Salingaros, 2006; 2015; 2018). Just as with similarly intolerant iconoclastic movements throughout history, 20C architectural culture (starting with Bauhaus modernism) became intolerant (Curl, 2018). Industrial minimalism also erased the abstract, mathematically rich ornamentation responsible for **Organized-complexity** that is a central feature of all varieties of Islamic architecture (Salingaros, 2006; 2019).

Non-representational ornament represents a distinct approach to encoding biophilia in artifacts and buildings. The goal is to (subconsciously) mimic the complex geometry of natural forms through abstract designs. For example, the symmetrical alignment of windows in a wall could reflect the multiple subsymmetries defined by those windows. Linking different scales, the internal symmetries of traditional windows reflect larger scaling symmetries present in the building, which might be scaled-up motifs from ornament. Traditional design methods mimic the fractal geometry of natural forms. Moreover, symmetry breaking by adding variety on smaller scales prevents information collapse; i.e. information cannot be compressed below the threshold.

Organized-complexity is fundamental in understanding human responses to architectural form and environments. Our mind seeks meaningful information. Because this topic is misunderstood and not even well-defined, little useful research has been done. Using measures of organized complexity from Christopher Alexander (Alexander, 2001) and the present author (Salingaros 2006; 2014; 2018), experiments find a marked preference for **Organized-complexity** (Coburn *et al.*, 2019). The brain is set up to process complex images that are neither random (too much uncorrelated information), nor simplistic (informationally trivial). A threshold degree of ordered complexity establishes a physiological reference, and departures either way generate emotional discomfort.

The present author reported earlier that **Organized-complexity** is responsible for enhanced animal brain development in "enriched environments"; hence one can assume that the same effect probably occurs in humans (Mehaffy and Salingaros, 2012). Independent support for **Organized-complexity** comes from data on the healthy brain development of children living near green spaces (Kühn *et al.*, 2017). Those researchers found a strong correlation for people living near forests (high degree of **Organized-complexity**), but only a weak correlation with urban green areas, which tend to contain lawn, isolated bushes, or trees (low degree of **Organized-complexity**). This result was surprising, considering that many studies have linked positive health effects with urban green, but explained because of the increased *complexity* of green that is more than lawn.

These last two biophilic factors **Representations-of-nature** and **Organized-complexity** overlap somewhat with previous ones: **Color**, **Fractals**, **Curves**, and **Detail**. It's not essential to have an irreducible set of biophilic qualities, but only a useful checklist that architects can use for improving their designs before implementation. The above ten criteria cover what is important to a designer and architectural practitioner interested in biophilia. (There exist distinct biophilic descriptors proposed by others, mentioned below, and perhaps there are additional mechanisms that we are as yet unaware of.)

BIOPHILIC DESIGN WAS INSTINCTIVE IN THE PAST

It turns out that traditional architectures throughout history were driven by biophilia: *(a) Make real nature intimately accessible. (b) Build by using lessons from the geometry of nature.* Design subdivided forms to define fractals and organized complexity, and employed color variety, ordered detail, ornament, curvature, and natural light (Salingaros, 2006). A major effort at understanding healing environments was undertaken by Christopher Alexander and his associates, first in documenting "design patterns" (Alexander *et al.*, 1977), then in uncovering the geometrical principles behind those patterns (Alexander, 2001). Socio-geometric patterns repeat throughout millennia of human building activity, and are found in every traditional culture around the world. Those discovered design solutions represent invariants that help support human health.

Patterns anticipate and support biophilic design by using nature as a source of mental and physical nourishment. Design patterns predate the introduction of biophilia into architecture, and there exists an intimate connection between them (Salingaros and Masden, 2008). While not all design patterns relate to biophilia, many of the critical ones do. Human beings crave environments with a high biophilic index, as evidenced in traditional built environments. Unfortunately, at the time when design patterns were initially introduced, dominant architectural culture dismissed them as some personal preference. They certainly are preferred: when the design intention is to create a healing environment.

For example, the component **Sunlight** of the biophilic index comes from three Alexandrian patterns: 107 WINGS OF LIGHT, 128 INDOOR SUNLIGHT, and 159 LIGHT ON TWO SIDES OF EVERY ROOM. In the same way, the component **Color** comes from pattern 250 WARM COLORS. The biophilic component **Water** is related to the three patterns: 25 ACCESS TO WATER, 64 POOLS AND STREAMS, and 71 STILL WATER. The biophilic component **Organized-complexity** relates to pattern 249 ORNAMENT, and so on.

Many societies naturally mix greenery and water with the built urban fabric for a very successful biophilic effect. Traditional buildings of all kinds emphasize the vertical axis and avoid unbalanced diagonals — this choice is instinctive, and it took a serious effort to suppress sensory feedback before architects could design unbalanced and twisted buildings. Such forms still alarm the public (and will continue to do so), despite "theoretical" explanations. The physiological need for a vertical reference discredits prize-winning buildings that produce anxiety and vertigo. This criticism has triggered a huge public controversy: but not for jeopardizing human health. Instead, critics are themselves attacked for daring to question dominant design fashions (Buchanan, 2015; Mehaffy and Salingaros, 2015; 2018; Silber, 2007).

To get an idea of how our own biology directs the shape of what we build, look at the majority of built structures on the Earth, which are in fact erected without architects (Alexander, 1979). Owner-built settlements rely upon the builders' own intuition in optimizing their psychological experience, and are to a large extent biophilic (Salingaros, 2017). Those forms result from using the body's instinctive reactions to make design judgments at each stage of the process. Biophilia drives unselfconscious design. Such informal buildings historically evolved into the more formalized typologies that we find in every traditional form language (Alexander, 2001; Alexander *et al.*, 1977; Salingaros, 2015).

Traditional landscape architects intuitively know many of the biophilic design rules: after all, they work primarily with plants (Kellert *et al.*, 2008). But they seldom get to influence the urban design plan or the building's footprint, being given responsibility only for the garden. The built environment would greatly improve by giving landscape architects greater design responsibility over the architecture as well. Working together with contemporary classical architects, landscape architects have created perfectly biophilic buildings and urban spaces (usually without calling them as such, since the term is only now being adopted by design professionals).

People like buildings or not because they judge them according to their own visceral responses, and not by applying formal criteria as architects invariably do. In the great disconnect from evolved traditions that resulted in International Modernism (Buchanan, 2012; Curl, 2018; Salingaros, 2006), many biophilic design rules, which were understood but unwritten, were discarded. The major positive development, however — an almost obsessive emphasis on glass curtain walls — promotes the biophilic factor of **Sunlight**. Modernist architects recognized its health benefits (Yuko, 2018). The best-loved among early modernist buildings turn out to rely upon satisfying some of the criteria for biophilia, i.e. detail in natural materials, some color, pools of water, views onto nature, etc. (Salingaros, 2015). Biophilia works to improve a project, even within a strictly modernist style. Nevertheless, the formal intentionality of modernist design is incompatible with other biophilic factors.

BIOPHILIC MEASURES USED BY OTHER AUTHORS

An architect interested in implementing biophilia in his/her design today faces some confusion, because different authors propose slightly different sets of metrics. The intent is the same, yet, since the discipline is still evolving, there is no uniform consensus. The table below might help to offset this confusion. Open-source descriptors used by Kellert (Kellert, 2018) and the Terrapin Bright Green group (Browning, *et al.*, 2014) are compared to the ones described here. Sometimes, two or more qualities are combined in order to find the equivalent class proposed by the other authors.

Table 2: Equivalent biophilic metrics.

Kellert	**Terrapin**	**Salingaros**
Light	Dynamic and diffuse light	Sunlight
Color	—	Color
Natural geometries + Shapes and forms +	Biomorphic forms and patterns	Fractals + Curves + Detail

Information richness		
Water	Presence of water	Water
Plants + Animals	Visual connection with nature + Nonvisual connection with nature	Life
Images	—	Representations-of-nature
Organized complexity	Complexity and order	Organized-complexity

Kellert proposes a list of 25 qualities, whereas Terrapin lists 14. Those authors do not suggest combining the measures in a quantitative manner for reference. There is an advantage in the present model that sums up ten biophilic qualities to obtain a single number. It is worth noting that Paul Downton and his collaborators felt the need for **Representations-of-nature** while using the Terrapin biophilic metrics, and introduced an additional equivalent metric "Virtual Connection with Nature" (Downton *et al.*, 2017).

One can correlate the above authors' other descriptors (not listed here) to find direct or indirect correspondences. Those are not included in this paper because they are better identified as non-biophilic design patterns (in this author's opinion). Spatial patterns lead to improved wellbeing, but are not directly related to biological structure. The present approach prefers to separate biological structures from notions of spatiality described by large-scale geometries (handled by design patterns). Among such descriptors are "Prospect" and "Refuge" (combined together by Kellert, but listed separately by Terrapin). The Alexandrian pattern 114 HIERARCHY OF OPEN SPACE contains these two effects (Salingaros, 2015).

Berto and Barbiero (working with other colleagues) have registered what they call the "Biophilic Quality Index" at *Società Italiana Autori ed Editori* (SIAE) in Rome (Berto *et al.*, 2014; 2017; 2018). Apparently, their index is quantitative, just like the biophilic index introduced in this paper. Because of the proprietary nature of their model, however, there is little public information available. Neither the general public, nor interested researchers can work with an index that is kept a trade secret. The few published details of their model indicate that the number of factors is considerably larger than the 10 used for the present model.

HEALTHIER ARCHITECTURE IS POSSIBLE THROUGH BIOPHILIA

A building that achieves intimate contact with nature triggers positive emotions from a close interaction with plants (Brethour, 2007; Dravigne *et al.*, 2008). More and more contemporary buildings pay attention to green; yet anxiety-inducing industrial forms and materials remain in place as an architectural paradigm. Plants satisfy only one part of biophilia that depends upon proximity to nature, but could obscure the need for healing geometries in the building itself. Some contemporary architects build anti-biophilic industrial/mechanical buildings set in a garden, and the result is schizophrenic. Ingrained architectural styles override biophilia, so they mix positive with negative biophilic factors. This approach confuses not only the public, but also other researchers in biophilia. Failing to distinguish between the geometries of anxiety-inducing and healing elements, buildings with contradictory qualities are mistaken as "good" examples.

Traditional and varnacular architectures generate fractal, ordered, and ornamented buildings. Incorporating organized complexity into a structure results in old-fashioned ornamented façades, entrances, and interiors. Those satisfy several of the criteria for biophilia. Yet without plants and mini-gardens enclosed or semi-enclosed by the building, or views to nature, the biophilic effect remains incomplete. Implementing biophilia exclusively with inert materials can only go so far. The biophilic quality of new buildings does not depend primarily upon materials, but upon a special type of organized complexity in their structure, as well as connections to nature. Traditional architects can already do much of that — all they need is a good traditional landscape architect to work with. Biophilic buildings relax formal design to embrace nature intimately.

Traditional architecture is replete with such solutions, as documented in the Alexandrian design patterns: 118 ROOF GARDEN, 174 TRELLISED WALK, and 246 CLIMBING PLANTS (Alexander *et al.*, 1977). The problem, however, occurs when architects promote biophilic design mainly through images of far-fetched schemes of urban greening. Among interesting biophilic experiments are some typologies that look good, but are both resource-expensive and far too expensive to maintain economically in the long term. These include green roofs, vertical gardens on a wall, and trees growing in the balconies of high-rises. It now seems that those ideas have limited application, with proven successes being highly climate-specific (namely, in regions of the world with sustained high rainfall). Otherwise, such typologies can become another extremely costly, high-maintenance, high-tech gimmick to sell a project. We see them nowadays in the renderings for competition entries, but most of those are not sufficiently thought out to guarantee sustainability (Mehaffy and Salingaros, 2015).

The key considerations for these attractive biophilic elements of design are that they should be *adaptive*, *low-maintenance*, and *low-tech*. If plants can be encouraged to grow up a wall or on a roof, then that creates a positive and useful feature (Downton, 2016; 2019). This development conceives the human built environment as an integral part of the natural ecosystem: the opposite of the brutal industrial imposition of "techno-green" schemes favored by contemporary architectural culture (and their supporting industries of global real-estate investments, together with the construction and structural engineering industries). Those natural schemes also presuppose that the climatic conditions are appropriate.

BIOPHILIA AND NEUROSCIENCE

Evaluating responses to architectural environments through neuroscience is creating a new discipline (Mehaffy and Salingaros, 2018; Robinson and Pallasmaa, 2015; Ruggles, 2017; Salingaros, 2017; Sussman and Hollander, 2015; Sussman and Ward, 2017). Neuroscience confirms preferences for special geometrical structures in our environment, which were derived much earlier using information optimization, organizational principles, and from mathematical arguments anchoring biophilia (Salingaros, 2006; 2012; 2014). Evolution adapted our body to recognize and seek specific patterns and structures essential for our health and wellbeing; therefore, our normal neural responses instinctively privilege those specific mathematical patterns.

Neuroscientists who have turned to studying people's responses to environments seek the same goals as in this paper, "[to] predict what this influence [is] in the early stages of design and before the structure is built" (Edelstein and Macagno, 2012). Architectural practice could then be changed dramatically so it leads more purposefully to improved human health. As originally argued by Ary Goldberger (Goldberger, 1996), what we create reflects the structure of our brain (see also Mikiten *et al.*, 2006)). But this is only true for unselfconscious creation, which relies upon direct human feeling and feedback. Architects learn to consciously break away from the instinctive human need for biophilic geometries. Working according to the directives of contemporary architectural culture, they are taught to ignore their own body's intuitive responses, and to instead impose abstract formal criteria for design (Salingaros, 2017). It is known, though rarely publicized, that architects and laypersons have almost diametrically opposite architectural preferences (Brown and Gifford, 2001; Gifford *et al.*, 2002; Wilson, 1996).

Measuring our physiological state and cerebral responses ought to show either healing or fight-or-flight responses to objects, spaces, and environments. An unforeseen complication occurs, however, because architects have been conditioned through their training to privilege forms that generate anxiety (Salingaros, 2017; Sussman and Chen, 2017). They have numbed and suppressed their innate biophilic preferences. This statement generates protests from the profession, but is supported by observations (Salingaros, 2006). It is therefore essential for any future experiments on biophilia to identify the neurological responses of common people to environments as a baseline, and only then to test the contradictory responses from trained architects.

Many famous buildings that dominant architectural culture supposes to be paradigmatic *positive* examples elicit, in fact, strongly *negative* responses (Salingaros, 2017). But whenever experimental results supporting biophilia threaten to invalidate architectural icons, cognitive dissonance forces architects to ignore the data, or to interpret it in a biased manner. Their reactions to proposed neuroscience experiments are split into two: (*i*) disinterest in discovering what influences the human experience; and (*ii*) adopting selected results only if those prop up accepted architectural icons. Architects judge according to learned aesthetics superimposed onto their visceral responses, and already "know" the "correct" finding before an experiment is even set up.

It is crucial to address this controversial point; otherwise neurological research into human responses is destined for failure. A lot of research funding has already been wasted in useless trials that give ambiguous and confusing results. The reason is the following. Professionals simply cannot accept that they have been practicing anti-biophilic design for a lifetime, and misleading students and others into accepting those fallacious choices. Cross-disciplinary teams investigating responses to the environment tend to include both architects and neuroscientists, and the former inject their historical and stylistic prejudices into the design of the experiment. Confirmation bias consequently invalidates all those efforts.

SUGGESTIONS FOR EXPERIMENTAL VERIFICATION

First, a simple general experiment is made possible by having the quantitative biophilic index defined here. We can measure long-term health effects of buildings and places having different biophilic indices on their users, keeping in mind that this is still only one of many influences. The choice of specific physiological measurements is best left up to health-care professionals who should run the experiments. Data will show whether healthier environments have higher biophilic index, as many of us believe based upon the existing evidence. Accumulated findings should reinforce the health benefits of biophilic design.

Second, we would like to evaluate the possible relative weighting of each of the ten biophilic factors discussed in this paper. As presented now, they contribute equally to the biophilic effect, which was chosen as the simplest working assumption. But we have no way of knowing whether some factors have more impact on our health than others. A difference, if such exists, ought to be straightforward to measure by isolating each individual biophilic effect. Then, if desired, a weighted re-definition of the biophilic index B could be introduced to reflect those findings.

This second set of experiments could resolve the question of what is the actual basis for the biophilic effect. This fundamental question as yet remains unresolved. Some researchers associate the healing effect only with direct exposure to nature. For them, representations are secondary, and are conjectured (by them) to be only weakly effective in inducing the biophilic effect. Others, including this author, attribute comparable weight to natural environments and to artificial environments that contain the appropriate biophilic geometries. In this latter approach, mathematical complexity rather than some mysterious vitalistic force holds the key to biophilia.

CONCLUSION

Biophilic design promises a better built environment; one more adapted to a sustainable human future. Since biophilia is an essential part of human biology, building according to its principles automatically guarantees a more “natural” result. Doing this satisfies part of what is required for sustainability, in two ways. (*i*) The built structures are conceived as extensions of our biology and our ecosystem. (*ii*) We feel healthier in them, and therefore will be more motivated to preserve them against wear and tear and replacement. Biophilic design, therefore, presents an alternative and complementary component to resilience and sustainability of the human habitat.

Biophilic design also teaches us to think in terms of systems. By recognizing a variety of complex and dynamic factors, the principles of biophilic design define a systems approach to the built environment. This follows from considering interacting variables that affect human health and psychology: the system is composed of human users interacting with the surfaces and volumes of a building. By contrast, architectural practice has for the past several decades emphasized the abstractions of image-based design, and neglected human responses to built forms (Mehaffy and Salingaros, 2015; 2018; Salingaros, 2006; 2012; 2017; 2018). Its system is strictly limited to the tectonic structure.

The ten biophilic qualities represent strong interconnections among many different aspects and scales of the environment affecting us emotionally and physiologically. Biophilic design jumps up to a larger encompassing scale. Biophilia merges the building with its immediate surroundings: paying attention to context, position, orientation, main approach, paths, connection to urban fabric, etc. Forward-thinking people have been urging the design professions to adopt a broader systems approach as a prerequisite for solving problems in resilience and sustainability. We now have such an opportunity through biophilia.

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