

The Biophilic Healing Index Predicts Effects of the Built Environment on Our Wellbeing

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ABSTRACT

By estimating certain features of the built environment, we can predict positive healing effects that spaces and structures may have on users. This can be estimated *before* something is built. Anticipating people's eventual response to a new building or urban space is a radically new tool that links design to public health. Nothing like this is performed in current practice, however, which makes no attempt to quantify assessments of future healing effects. The proposed "biophilic healing index B " —a number from 0 to 20— permits us to quickly evaluate those factors responsible for improved human health as a result of the environmental geometry. The biophilic healing index is also very useful for repair, since it identifies which aspects of an existing building or space could be improved by renovation. Different portions of a structure could have widely different biophilic healing indices. Ten factors constitute the biophilic healing 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 regions with a high value of the biophilic healing 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, wellbeing

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 & Wilson, 1995). Biophilia’s positive effects come from two distinct sources:

- (i) Close proximity and visual contact with plants, animals, and other people.
- (ii) Positive 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, Heerwagen, & Mador, 2008; Ryan & 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 (Kellert, Heerwagen, & Mador, 2008; Mehaffy & Salingaros, 2015). After an embarrassing delay of several decades, these findings have finally triggered the implementation of biophilic design guidelines for hospitals (Ryan & 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, Morales, van Hoof, & Kort, 2012; Iyendo & Alibaba, 2014; Rakel, Sakallaris, & Jonas, 2018; von Lindern, Lymeus, & Hartig, 2016). Investigations of healing environments tend to include a broader range of factors than biophilia does (such as pathogens, pollutants, and toxins), which makes causal analysis more problematic. We instead wish to focus strictly upon those effects due to the geometry and surfaces. In addition, health-care professionals are easily diverted from biophilic effects intrinsic in the built environment. Hence, they often accept architects’ designs having very poor biophilic properties without question, and this point is what the present paper tries to clear up. Due to this misunderstanding, new hospitals that claim to reduce stress and anxiety may actually be increasing 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. More research is needed to 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 & van den Berg, 2011; Ryan & Browning, 2018; Velarde, Fry, & Tveit, 2009). For example, a positive correlation exists 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 & Pretty, 2010); the overall health of those who live near forests and green spaces is statistically better (Beyer, Kaltenbach, Szabo, Bogar, Nieto, & Malecki, 2014; Engemann *et al.*, 2019; Li, Kobayashi, & Kawada, 2008); there is a significant correlation between living near forests and healthy brain structure (Kühn *et al.*, 2017) and improved mental health (Bratman *et al.*, 2019; Preuss *et al.*, 2019); and more evidence of the health benefits of closeness to green spaces (Brethour, Watson, Sparling, Bucknell, & Moore, 2007; Dravigne, Waliczek, Lineberger, & Zajicek, 2008).

The reasons behind biophilia's healing effects remain a mystery, however. This paper (consistent with a few other authors) 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 health factor for their users. This approach lends itself to immediate practical applications. A more intense type of healing environment everywhere is possible today, and accomplishing this does not 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 present-day architectural formalisms to adopt a completely new method of healthy design (Buchanan, 2012). This is imperative for the world's health. In promoting a major reorientation in architectural culture, it is useful to have a simple numerical measure for biophilia that architects can easily compute and apply, and that is provided here.

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, which will save an enormous amount of resources. This robust scientific approach contrasts with the usual assessments of architects based on dubious aesthetics. Ten factors responsible for biophilia 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 later. The whole point of the paper is to back up the following conjecture:

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

The present discussion is intended to spark interest for more experimentation to support the conjecture on healing effects (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, representing an important environmental component that affects our health. This biophilic influence on human wellbeing was important historically, and still is in traditional cultures, but was neglected after the rise of industrialism.

Table 1: Ten components of the biophilic index B

1. **Sunlight:** preferably from several directions.
2. **Color:** variety and combinations of hues.
3. **Gravity:** balance and equilibrium about the vertical axis.
4. **Fractals:** things occurring on nested scales.
5. **Curves:** on small, medium, and large scales.
6. **Detail:** meant to attract the eye.
7. **Water:** to be both heard and seen.
8. **Life:** living plants, animals, and other people.
9. **Representations-of-nature:** naturalistic ornament, realistic paintings, reliefs, and figurative sculptures — including face-like structures.
10. **Organized-complexity:** intricate yet coherent designs — and extends to symmetries of abstract face-like structures.

The proposed 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. In fact, this method was 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 as follows.

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*”, which is 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. The index thus enables us to measure the biophilic—hence healing—impact of very different buildings in a relatively objective manner.

We do not normally expect any single building to have a maximum score of the biophilic index, $B = 20$, although some of the best-loved historical buildings could approach it (Salingaros, 2006). 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 distinct ways to increase the biophilic index, as noted in the ten factors. Buildings created according to different styles will incorporate healing effects in their own individual manner, by emphasizing one or more of the 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, Heerwagen, & Mador, 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 (Bratman *et al.*, 2019; 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. Designers 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, Ryan, & Clancy, 2014; Ryan, Browning, Clancy, Andrews, & Kallianpurkar, 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 to be expected for a discipline that is still evolving. A useful checklist taken from a booklet used in courses for architecture students (Salingaros, 2015) will be further supplemented, below.

First checklist of biophilic design criteria.

1. **Sunlight** — natural light on two sides of a room (Alexander, Ishikawa, Silverstein, Jacobson, Fiksdahl-King, & Angel, 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 & Arita, 2013; Holick, 2019; Remi, 2015). Sunlight also has direct therapeutic qualities (Edelstein & 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 & Hustmyer, 1974; Kardan *et al.*, 2015; Kurt & Osueke, 2014), whereas gray and dark brown are associated with depression and remind us of putrefaction, illness, and death (Carruthers, Morris, Tarrier, & Whorwell, 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 & 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, & Ward, 2017), since minimalism triggers emotional discomfort (Leach, 2016; Salingaros, 2003; van den Berg, Joye, & Koole, 2016).
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 instinctively seek curves all around us (Bar & Neta, 2006; Berman *et al.*, 2014; Dazkir & Read, 2011; Gómez-Puerto, Munar, & Nadal, 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 & Lakshminarayanan, 2015; Salingaros, 2003). We “read” intentions in the details of an animal or human face (Leopold & Rhodes, 2010). That is why we respond positively to the details in natural materials such as wood, travertine limestone, colored marble, etc. (Rice, Kozak, Meitner, & Cohen, 2006; Sakuragawa, Miyazaki, Kaneko, & Makita, 2005).
7. **Water** — seeing and hearing water helps to calm us (Nichols, 2015; Wheeler, White, Stahl-Timmins, & Depledge, 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 & Pretty, 2010; Greven, 2017; Takano, Nakamura, & Watanabe, 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 the ten 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

The list is completed by considering two additional biophilic qualities having specifically human origins. They are more complex than the first eight biophilic factors, which are called “low-level visual features” by some researchers. (For this reason, we can refer to the two new components as “higher-level visual features”). These factors estimate representations of nature that we connect to: the first is explicit, and the second implicit. Visual representations of animals, people, and plants have a long history in human evolution, playing a defining role for the artistic and religious heritage of particular group cultures. Humans have also mimicked the mathematical properties of natural structures in their more abstract art forms, at least prior to the 20th Century (Salingaros, 2019). These qualities relate to the type of visual complexity the human brain 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, a realistic depiction of plants, animals, and people was inseparable from other aspects of architecture. That practice was indeed 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, Barton, & Gladwell, 2013; Tse, Ng, Chung, & Wong, 2002; Yin, Zhu, MacNaughton, Allen, & Spengler, 2018). Throughout history, domestic, religious, and civic architectures represented living forms as images that were 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 paradoxically central in advertising and commercial art. Also, realistic depictions have always been a vibrant expression of folk art in the form of unofficial murals. People are viscerally attracted to **Representations-of-nature**.

One promising entry into experiments to verify this component has already been achieved by discovering the innate attraction of faces. Recent neuroscience experiments reveal that mammalian brains devote considerable resources to recognizing faces in general, and known faces in particular (Chang & 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 & Ward, 2017). Empty, minimalist “design” components preferred by present-day architectural culture do not draw the eye at all—they might as well not be there!

The bilateral symmetries of an animal or human face can be reflected in an entire building to draw attention to it. People respond positively when the abstract geometry of a face is represented in a building’s structure (Sussman & Ward, 2017). Contained in the two additional biophilic factors **Representations-of-nature** and **Organized-complexity** is how closely a building entrance or façade resembles some stylized giant animal face, with characteristic vertical symmetry axis, and symmetrically distributed focal points roughly corresponding to mouth, eyes, ears, etc. (Salingaros, 2017). We feel a kind 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 of historic design practices (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 around us. 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 (with 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 & 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, or isolated bushes and trees (low degree of **Organized-complexity**). This result was surprising, considering that many studies have linked positive health effects with urban green, but is explained because of the increased *complexity* of green that is more than just flat lawn.

These last two (higher-level) biophilic factors **Representations-of-nature** and **Organized-complexity** overlap somewhat with (low-level) 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. Two separate sets of design tools combine to achieve this effect:

(a) Make real nature intimately accessible.

(b) Build by using lessons from the geometry of nature.

There are definite and important advantages to this approach of shaping the built environment. Yet a determining though subconscious motivation for healthy design is not new but timeless. A major effort at understanding healing environments was undertaken by Christopher Alexander and his associates, first in documenting “design patterns” (Alexander, Ishikawa, Silverstein, Jacobson, Fiksdahl-King, & Angel, 1977), then in uncovering the geometrical principles behind those patterns (Alexander, 2001). Newly-documented patterns are published recently (Mehaffy, Kryazheva, Rudd, & Salingaros, 2019). 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 & 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.

Here, I wish to establish the precedent set by patterns in documenting design solutions that were re-discovered during the more recent developments of biophilic design. For those readers unfamiliar with patterns, I am providing my own summary of each pattern mentioned (Alexander *et al.*, 1977). All of the components of the Biophilic Index can be correlated with patterns, as described below.

For example, the component **Sunlight** of the biophilic index comes from three Alexandrian patterns:

PATTERN 107 WINGS OF LIGHT. Rather than having a compact building whose interior needs to be artificially lit, design the footprint so that the building consists of fairly narrow wings. In this way, every wing will receive sunlight generously.

PATTERN 128 INDOOR SUNLIGHT. Take advantage of sunlight, which in the Northern Hemisphere requires a predominantly Southern exposure. A building that optimizes for this will have to be elongated in an East-West direction.

PATTERN 159 LIGHT ON TWO SIDES OF EVERY ROOM. Natural light coming from two separate directions satisfies a fundamental psychological need. Try to design the most useful rooms with this feature.

In the same way, the component **Color** comes from this pattern:

PATTERN 250 WARM COLORS. A warm light in a room (as far as color temperature) is the combined effect of outside sunlight, artificial light, and interior color surfaces. Perceiving the ambient light as warm has positive psychological consequences.

The biophilic component **Water** is related to the three patterns:

PATTERN 25 ACCESS TO WATER. The land-water interface should not be treated industrially, or left derelict, but instead developed to promote easy and positive psychological contact.

PATTERN 64 POOLS AND STREAMS. Instead of automatically covering up open water and streams, create permanent structures and paths alongside them, and bridges to cross over them. Where there is no water, create a fountain.

PATTERN 71 STILL WATER. Shape one side of a local pond so that it provides access for stepping into. Where possible, and conditions permitting, provide an open swimming pool to the community.

The biophilic component **Organized-complexity** relates to the following pattern.

PATTERN 249 ORNAMENT. Ornament serves an important connective function between architectural components. Correctly used, ornament will join the edges of two elements into one larger whole, rather than having pieces come up to one another abruptly.

... 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 concerted 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 bogus 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 & Salinger, 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 very large extent biophilic. Those self-built 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 (but contradict current design fashions).

Traditional landscape architects intuitively know many of the biophilic design rules: after all, they work primarily with plants. 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). Biophilic design works to improve a project, even within a strictly modernist style. Nevertheless, the formal intentionality of modernist design is incompatible with the other biophilic factors.

The framework for healing environments presented in this essay, which is supported by massive experimental and observational evidence, defines an old-fashioned picture for architecture and design. Not for reasons of nostalgia, but because our ancestors intuitively reached the same conclusions that today took concerted research efforts. Components of healing environments include structures on the human scale (the opposite of inhumanly-scaled giant buildings); the use of natural materials possessing fine-grained organic structure visible to the eye; and, most important of all, the ornamental traditions common to all cultures. Biophilia contradicts two standard building typologies: sterile industrial glass and steel skyscrapers, and minimalist concrete surfaces.

BIOPHILIC MEASURES USED BY OTHER AUTHORS

An architect interested in implementing biophilia in his/her design today faces some minor 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 any confusion. Open-source descriptors used by Kellert (Kellert, 2018) and the Terrapin Bright Green group (Browning, Ryan, & Clancy, 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 + Information richness	Biomorphic forms and patterns	Fractals + Curves + Detail
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 model presented here that sums up ten biophilic qualities to obtain a single number for the biophilic index. 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 as “Virtual Connection with Nature” (Downton, Jones, Zeunert, Roös, 2017).

One can correlate the above authors’ further 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 design patterns definitely 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 & Barbiero, 2014; Berto, Barbiero, Pasini, & Unema, 2017; Berto, Barbiero, Barbiero, & Senes, 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 close interaction of the user with plants (Brethour, Watson, Sparling, Bucknell, & Moore, 2007; Dravigne, Waliczek, Lineberger, & Zajicek, 2008). More and more contemporary buildings pay attention to including more green; yet anxiety-inducing industrial forms, materials, and typologies remain firmly in place as the current 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 fabric of the building itself.

For example, some contemporary architects build anti-biophilic industrial/mechanical buildings set in a garden, hence the result is schizophrenic. Superficially the plants are biophilic, but the built structures are not. Ingrained unnatural architectural styles override biophilia, and 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 opposite geometries of anxiety-inducing and healing elements, buildings with contradictory qualities are unfortunately mistaken as “good” examples.

Traditional and vernacular architectures generate fractal, ordered, and ornamented buildings. Pre-industrial design subdivided forms to define **Fractals** and **Organized-complexity**, and employed **Color** variety, ordered **Detail**, ornament, **Curves**, and **Sunlight** (Salingaros, 2006; van den Berg, Joye, & Koole, 2016). Incorporating **Organized-complexity** into a structure results in old-fashioned ornamented façades, entrances, and interiors. Those satisfy several of the criteria for biophilia, creating positive salutogenic effects. 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, therefore, 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 real 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 design solutions that rely upon the successful and sustainable use of green. Those are documented in three Alexandrian design patterns (Alexander *et al.*, 1977):

PATTERN 118 ROOF GARDEN. Design a building so that there is place for a roof garden on different storeys. Guarantee easy access to the garden from that level.

PATTERN 174 TRELLISED WALK. A garden path with a trellis over it and plants growing on it creates a special healing environment. Additionally, this typology serves to define a useful semi-permeable vertical boundary for an area of the garden.

PATTERN 246 CLIMBING PLANTS. Allow and encourage climbing plants to grow vertically on a sunny exterior wall.

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 & 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, 2009; 2016). This design development conceives the human built environment as an integral part of the natural ecosystem. Genuinely natural schemes presuppose that the climatic conditions are appropriate. Yet contemporary architectural culture often promotes the opposite: a brutal industrial imposition of “techno-green” schemes favored by supporting industries of global real-estate speculation, together with the construction and structural engineering industries. Alarming, this is what we see illustrated in many references to biophilia in the glossy architecture magazines.

BIOPHILIA AND NEUROSCIENCE

Evaluating responses to architectural environments through neuroscience is creating an important new discipline (Mehaffy & Salingaros, 2018; Robinson & Pallasmaa, 2015; Ruggles, 2017; Salingaros, 2017; Sussman & Hollander, 2015; Sussman & 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 & 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, Salingaros, & Yu, 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 & Gifford, 2001; Gifford, Hine, Muller-Clemm, & Shaw, 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 & Chen, 2017). They have therefore numbed and suppressed their innate biophilic preferences. This statement generates protests from the profession, but is supported by observations (Salingaros, 2006). It is 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.

This controversial point must be addressed; otherwise neurological research into human responses is destined for failure. A lot of research funding has already been wasted in trials that give ambiguous and confusing results. The reason is obvious. Professional designers simply cannot accept that they have been practicing anti-biophilic design, and have been misleading students and others in that choice. The health consequences for generations of users are immense. Cross-disciplinary teams investigating responses to the environment tend to include both neuroscientists and architects, but the latter inject their historical and stylistic prejudices into the design of the experiment. The neuroscientists naively trust the architects' opinion on what is a 'good' building, and could even accept some 'iconic' building as a reference for calibrating the experiment. Confirmation bias consequently invalidates all those efforts.

SUGGESTIONS FOR EXPERIMENTAL VERIFICATION

First, a simple general experiment is made possible by having available the quantitative biophilic index defined here. We can measure long-term health effects of buildings and places with 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 in the simplest hypothesis, they contribute equally to the biophilic effect, which was chosen as a working assumption. Architects interested in applying this model to their projects immediately ask: “which are the most important components of the biophilic index, so that I can neglect the others?” As yet, we have no way of knowing whether some factors might have more impact on our health than others. Any 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 later 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 yet remains unresolved. Some researchers associate the healing effect only with direct exposure to nature. (Yet this still does not explain the actual mechanism.) For them, imitations and representations of nature are secondary, and are conjectured 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 explanatory key to biophilia.

Lately, many experimental groups are joining the broad research effort into questions about salutogenic environments. However, without an epistemological basis for addressing the problem, those results tend to be interpreted in a confusing manner. The related topics of aesthetics, affective benefits, attention restoration, beauty, cognitive preferences, mental and physical health, stress reduction, etc. tend to overlap and become jumbled. In the absence of a simple and practical model—such as the one presented here—collected data is not always presented in the best format for understanding how the human body reacts to its environment. Hopefully, we will soon see greater clarity in both theory and the interpretation of experiments.

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 we 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.

The ten biophilic qualities discussed in detail here represent strong interconnections among many different aspects and scales of the human-experienced environment. Those all affect us emotionally and physiologically. Biophilic design thus raises our consciousness 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.

In particular, biophilic design 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 the multiple 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 design based upon formal abstractions, and neglected human responses to built forms (Mehaffy & Salingaros, 2015; 2018; Salingaros, 2006; 2012; 2017; 2018). Its “system” is strictly limited to the tectonic structure.

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