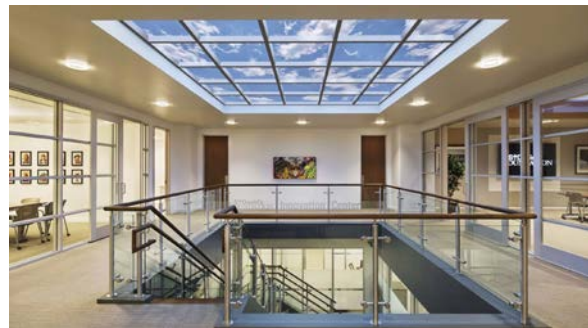
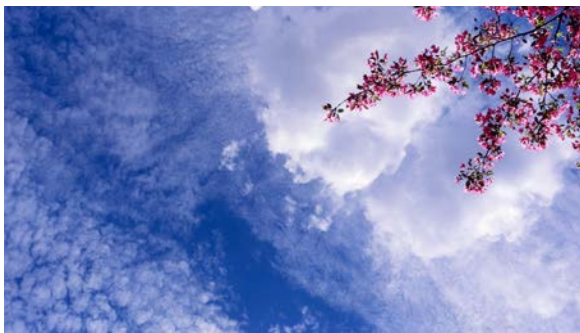


# The Restorative Impact of *Perceived* Open Space

## *A Hidden Wellness Dividend for Deep Plan Buildings*

by

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# The Restorative Impact of *Perceived* Open Space

## *A Hidden Wellness Dividend for Deep Plan Buildings*

In the last few years, an abundance of research has confirmed the extent to which building design impacts human health and productivity. However, our fascination with new architecture has obscured the more daunting challenge represented by older buildings—those not designed to maximize human performance—which make up the majority of metropolitan centers.

This paper is concerned with the impact that isolated built interiors have on human wellness and performance. The effects of partially or completely enclosed interiors on health and cognitive function have been addressed in multidisciplinary studies spanning three decades, particularly in the healthcare industry. However, one finding is striking. Due to its comprehensive restorative qualities, the most sought-after feature in the design of any building is an open view to nature.

The introduction of the WELL Building Standard® in 2014 represents an encouraging leap forward as it enables occupants and building owners to quantify and mitigate the deleterious effects of building design. Despite our progress, the wellness impact of open space on the human physiology has not been fully explored, nor has its cognitive importance in relation to biophilic retrofit solutions, been quantified.

This paper attempts to summarize a few of the most relevant studies that shed light on why a visual/spatial connection to a natural exterior—real or simulated—represent a wellness and productivity-enhancing feature for populations that spend much of their day, indoors. In addition, this paper introduces a new framework through which architects and interior designers, as well as healthcare professionals, building owners, and HR managers can understand the impact of perceived open space in the workspace on staff, patients, and other captive populations.

We also introduce the reader to an overview of how the visual process and its neural correlates give rise to our sense of space and the value thereof. This paper introduces a new technology that proposes the restorative value of *perceived* open space in its two essential orientations: *perceived* zenith and *perceived* horizon line. In contrast to how we perceive these *spatial* reference frames outdoors, in enclosed interiors where such reference frames are often not visible, we can stage architectural cues to alter our perception of interior space. Multisensory illusions can incorporate these fundamental

spatial reference frames, thereby restoring a range of wellness benefits normally associated with interiors applying biophilic design principles.

In order to also grasp the economic implications of building design, among other things, it is important to first understand how daylight, natural environments, and spatial design impact our physiology. This assessment is pertinent. Consider, for example, the United Nations estimates that two-thirds of the global population will live in metropolitan areas by 2050 (up from 50% in 2015). This migration will result in the largest percentage of humankind—*at any time in history*—who will work, study, or seek treatment in buildings with little or no connection to a natural environment.

According to the *Environmental Protection Agency*, Americans, along with most people in developed economies, spend over 90% of the day working indoors. This represents a radical departure from life in a natural outdoor environment that shaped our physiology. Given the pace of urbanization in the last century, the human physiology has undergone—in the span of a handful of generations—a dramatic shift.

As a species, we've gone from spending our entire diurnal cycle in *open space*, the environment that shaped our physiology for *thousands of generations*, to the present where we spend most of the day indoors, exposed to static artificial light and views of urban landscapes or without outdoor views at all.

Even without direct sunlight—average daylight yields between 10,000 to 25,000 lux (a measurement of light level intensity also called “illumination”) whereas the best interior office lighting offers about the same illumination generated at sunset, which equals less than 5% of prime daylight or about 500 lux.

Simply put, every day, we spend our waking hours in the equivalent of twilight. And then we go home—at dusk—essentially having lived a quasi-nocturnal existence.

On an evolutionary scale, this is an entirely new experience for our mind and body, one that carries profound implications. In order to maintain peak physiological and psychological performance, our circadian rhythm, which regulates mental alertness and other aspects of our well-being, relies on cool, blue light, found in abundance outdoors.

Furthermore, daylight intensity and wavelength are not the only factors that impact our physiology. An equally important element is the *environmental context* in which daylight appears; that is, light's interdependent relationship to outdoor open space. Therefore, it's reasonable to assume that our circadian rhythm might also be attuned to light as it relates to and is a function of *spatial awareness*.

By direct observation we experience the greatest shift in magnitude, in both daylight intensity and color temperature—outside, in *open air*, or at the very least, in the presence of a visual connection to open skies. Thus, it is reasonable to assume that our circadian rhythm might also be attuned to light as the light relates to and is a function of our *spatial awareness*.

## Circadian Cells & Spatial Mapping

Standard vision in the human eye—object recognition, color vision, motion detection—is processed by specialized neurons called cones, responsible for daylight (photopic) vision when light levels are high, and rods, responsible for night (scotopic) vision when light levels are low. Until 2002, these were all the photoreceptors the human eye was thought to have: short, middle, and long wavelength cones, plus rods.<sup>1</sup>

However, science has uncovered another unique sensory apparatus responsible for regulating biological rhythms. This fifth type of photoreceptor, located in the inner retina, has demonstrated peak sensitivity to blue light wavelengths, indicated by a slightly different absorption spectrum from the other four photoreceptors (cones and rods).<sup>2</sup> Due to their particular sensitivity to this wavelength of light, this fifth type of photoreceptor—called intrinsically photosensitive Retinal Ganglion Cells (ipRGC)—has been denominated as our physiology’s “blue sky detectors.”

It is worth noting that in evolutionary terms, when these circadian photoreceptors, which are the neural processing units of the retina that specialize in detecting Earth’s rich blue sky, signal the master circadian clock in the hypothalamus,<sup>3</sup> they have done so under the unique conditions afforded by the open space of natural environments.

This master circadian pacemaker regulates how all cells adjust their physiology according to the time of the day. Yet, it remains to be seen whether the brain’s master clock will operate in *identical fashion* in the absence of a visual connection to a natural exterior space. At this time, no one can say for certain.

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<sup>1</sup> Figueiro, Mariana. “Light isn’t for vision anymore.” The International Society for Optical Engineering 10.1117 (2006): pg. 1, Nov. 7, 2006 <<http://spie.org/newsroom/technical-articles-archive/03-0400/0304-light-isnt-just-for-vision-anymore>>.

<sup>2</sup> Ellis, E.V., Gonzalez, E.W., & Donald L. McEachron. “Chronobioengineering Indoor Lighting to Enhance Facilities for Aging and Alzheimer’s Disorder.” Intelligent Buildings International (July 2013). Retrieved Nov. 20, 2015, from <<http://www.bauarchitecture.com/research.chronobioengineering.shtml>>.

<sup>3</sup> Figueiro, Mariana. Ibid.

And while research on circadian photoreceptors in mammals is in its infancy and many of the findings are derived from other species, there are indications of significant similarities, both in the structural and functional traits of these cells, which may foreshadow how our own Melanopsin-expressing circadian photoreceptors operate. (Melanopsin is a photosensitive pigment involved in entraining our circadian rhythm to the sun cycle.)

For example, while early studies on the existence of a third class (there are three classes and five types) of mammalian photoreceptors, indicated that they “utilized a different photopigment, were much less sensitive to light, responded to light far more slowly, and had far lower spatial resolution, characteristics that fit with their primary function of signaling ambient light levels (irradiance) to the brain,”<sup>4</sup> new data by Mouland et al., has found evidence in mice that “even though the SCN receives all retinal input from cells lacking center/surround antagonism [that is, spatial receptive fields], such framework can still be somehow created within the SCN. The same could also be happening within the human SCN, but we don’t know for sure.”<sup>5</sup>

As noted earlier, when our circadian photoreceptors, which are the neural processing units of the retina that specialize in detecting Earth’s rich blue sky, signal the master circadian clock in the hypothalamus, they do so apparently *without the aid of standard receptive fields found in the other two classes of photoreceptors, cones and rods, responsible for day and night vision*, which allow these cells to distinguish between surfaces, using contrast to detect edges, and thereby create spatial maps of our surroundings.

Cones and rods have receptive fields that have certain properties called center/surround antagonism, which means that the cells respond to visual stimuli depending on where it originates. That means these cells are each responsive to light from a limited portion of space, which the brain’s visual processing function puts together, thereby giving rise to spatial cognition.

To date, the photosensitive retinal ganglion cells responsible for circadian function have not been found to have a distribution of cells that respond in this fashion. That is why they have been thought to have much lower spatial resolution or simply lack the

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<sup>4</sup> Graham, D. M. and Kwoon Y. Wong. “Melanopsin-expressing, Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs).” Webvision (August 2015). Retrieved Dec. 14, 2015, from the Introduction in: <http://webvision.med.utah.edu/book/part-ii-anatomy-and-physiology-of-the-retina/melanopsin-expressing-intrinsically-photosensitive-retinal-ganglion-cells/>>.

<sup>5</sup> K.Y. Wong (personal communication, January 10, 2016).

center/surround antagonism framework. However, a new paper by Mouland et al., reveals otherwise.

The authors note that while the accepted function of retinohypothalamic tract (RHT)—the neural input pathway involved in the circadian rhythms of mammals that begins with our circadian photoreceptors (ipRGCs)—is to bring information about background light intensity (irradiance) to the master circadian clock (SCN), there has been *little investigation of the significance of the spatial distribution of light* across the visual scene on SCN activity.

And while this study from the University of Manchester shows that circadian entrainment remains constant in the presence of diffuse or patterned light, it also underscores that “there is no empirical evidence that diffuse light sources engage the SCN most effectively. Our data suggest that displays capable of presenting visual images (televisions, computers, etc.) to which people have an intrinsic attraction, are at least as effective at engaging the SCN.”<sup>6</sup> The paper concludes “that the SCN is, in fact, very responsive to spatial patterns. Indeed, an unbiased assessment would identify spatial distribution as being at least as large an influence on SCN firing as irradiance.”<sup>7</sup>

Despite the new evidence, Mouland and company *do not show what the function of the spatial distribution of light might be*. What does the master circadian clock do with spatial data, if it does not appear to affect circadian phase resetting? (Not to the limited set of light patterns tested thus far.)<sup>7A</sup> However, in view of other indicators, it seems reasonable to assume that such information may play a valuable role. Perhaps future research will bear this out. After all, the sun beams daylight within the environmental context of a blue canopy that is, by its very nature, spatial.

Such an integrated view of our brain’s neural connections and synaptic inputs would also appear to fit well with Dr. Groh’s observations, which note that higher cognitive faculties like attention, memory, and planning share the same neural infrastructure that our sensory and motor faculties use to navigate a shifting external environment.

And while the relatively young field of circadian photoreceptors may be years away

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<sup>6</sup> Mouland et al., Responses to Spatial Contrast in the Mouse Suprachiasmatic Nuclei, *Current Biology* (2017), <http://dx.doi.org/10.1016/j.cub.2017.04.039> p.6

<sup>7</sup> Mouland et al. *Ibid.*

<sup>7A</sup> Robert J. Lucas, Lead Contact, Faculty of Biology, Medicine and Health, University of Manchester (personal communication, August 23, 2017).



from mapping out all their functional roles, their interconnectedness with the rest of the visual system demonstrates the relevance of a holistic approach to visual phenomena.

Studies have found that viewing the same object under different circumstances influences the strength of the visual signal. In other words, the neuroscience of visual processing has established that *environmental context* shapes cognitive perception. Hence, changing the environmental context of circadian light by creating a circadian effect in *enclosed* interiors, might very well trigger alertness in the physiology.

However, it is equally plausible that the artificial context in which this light intensity is perceived could also trigger other less desirable cognitive or physiological reactions in enclosed spaces. Particularly if the source of the circadian light cannot be attributed to a familiar *biophilic source* that provides a recognizable spatial reference frame, such as a blue sky naturally does outside.

While the impact of man-made circadian lighting systems on captive populations is currently under study, our intent is to point out that light triggers a spatial dimension in the environment that cues perception in ways just as fundamental and meaningful as the circadian impact of light itself.

Leading researcher Mariana Figueiro, program director at Rensselaer's Lighting Research Center at Rensselaer Polytechnic Institute, has noted that:

*"The visual system relies on accurate spatial correspondence between the environment and perception. The circadian system, however, simply responds to changes in overall retinal light exposure—although it seems more responsive to light from above the line of sight, which reinforces the notion that the circadian system is a 'blue sky' detector."<sup>8</sup>*

Taking a different approach, the above noted observation may also indicate that humankind's hardwired 'blue sky' detection system is not limited to the retina, but might also involve the brain maps created by our visual system to establish *spatial correspondence between the environment and perception*. A blue sky does not transmit circadian light to our brain on an abstract basis; it does so as humanity's most - meaningful—visceral—experience of open space.

Perhaps, in addition to mimicking the circadian oscillations of daylight in enclosed interiors, another equally important component is the spatial context in which light is

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<sup>8</sup> Figueiro, Mariana. Ibid.

transmitted; if not the sky itself, then an *illusion of a natural environment or overhead sky* that is sufficiently credible to match our biophilic (genetic) memory of the same stimuli, under similar conditions, may be of significant importance.

## Light, Space, and Memory

Research in neuroscience has also uncovered the fascinating connection between our ability to map space and memory, a fundamental building block involved in giving rise to environmental context. According to Jennifer Groh, *Professor at the Department of Psychology and Neuroscience, and the Department of Neurobiology, at the Center for Cognitive Neuroscience at Duke University*, it turns out that “not only is memory an integral part of building a sense of space, but space in turn serves as a kind of filing system for storing and accessing memories. And the brain’s memory-space connection relies on shared neural infrastructure.”<sup>9</sup>

This insight provides one of the clues that may answer the mystery behind why certain optical illusions—what we term biophilic *illusions of nature* in this paper— which provide a spatial reference frame, have such a unique impact on our psycho-physiology in comparison to standard (representational) nature art photography.

When we provide a visual stimulus that mimics a *spatial* relationship we are familiar with, the brain’s sensory and motor regions react as if the original memory itself was being re-experienced. This is consistent with a unique facet of illusions; they are capable of conjuring an experience when key cognitive cues emulate a *bone fide* past experience.

While our circadian rhythm signals various internal biological clocks, given the strong connection between shared neural infrastructure between memory and spatial cognition, it seems reasonable to assume that our most universal sense of space, the sky, would also be an elemental circadian synchronizer as it relates to the effects of daylight on our physiology.

After all, our own experience confirms that we intuitively gravitate to nature and open space because our senses come alive, enticed in ways that no man-made environment can mimic without overstimulation or sensory overload.

In nature we transcend the confines of individual awareness and merge into a deeper grandeur. Open space literally *deepens* thought.

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<sup>9</sup> Jennifer M. Groh. (2014). *Making Space, How the Brain Knows Where Things Are*. Cambridge, Massachusetts, The Belknap Press of Harvard University Press, Ch. 9, p. 189.



## I. Urban Architecture: The High Cost of Enclosed Interiors

The proliferation of skyscrapers and the deep plan building—where the horizontal distance from the external wall is many times greater than the floor to ceiling height—impairs our circadian cycle. The circadian cycle is responsible for suppressing melatonin during the day. Low light levels, typical of deep plan buildings, expose the physiology to a fraction of the light needed to suppress daytime melatonin production and thereby maintain mental acuity, emotional balance, and optimal cognitive functioning.

Deep plan floor plates, endemic to large buildings, invariably generate huge enclosed sections that do not—by virtue of their design—receive daylight.

And while the highly sought day-lit workspaces lie on the periphery of such structures, (and ironically, further isolate interior spaces from daylight), a significant percentage of the staff and the operations of a company remain in enclosed interiors, removed from a visual connection to the outside.

Meanwhile, in the last 30 years, research in fields of study ranging from evolutionary biology, cognitive neuroscience, environmental psychology, biological anthropology, social ecology, and sustainable design have all contributed to the consensus that conventional building design runs counter to what the human physiology intrinsically needs for optimal performance.

Over time, we've discovered that sustainable interiors for human occupancy are defined by a connection to open, natural spaces that provide access to unimpeded views to nature from a place of safety; what environmental psychologists refer to as Prospect & Refuge, a spatial pattern each of us intuitively recognizes and prefers.

The Biophilia Hypothesis, first proposed by Harvard biologist and Pulitzer Prize-winning author Edward O. Wilson, to describe our innate, genetic-based need to affiliate with other living systems, provides a scientific explanation for an experience we all intuitively understand:

*We are part and parcel of the natural environment and maintaining this connection in the experience of our buildings allows our physiology to resonate with a deeply ingrained spatial pattern—that of wide open natural spaces.*

These two conflicting developments, the prevalence of windowless interiors and the discovery of their effect on our mind and body, have propelled the rise of biophilic design, a field that seeks to create buildings that connect their occupants with the natural surroundings, providing a psycho-physiologically sound working environment where the opportunity for attention to be directed outdoors facilitates cognitive restoration throughout the day.

Even before the rise of biophilic design as a distinct discipline, architects, interior designers, and facility planners employed a scientific process in the planning, design, and construction of commercial buildings called evidence-based design (EBD). Starting in the 1970s, these architectural researchers studied the impact of hospital design, but it wasn't until Roger Ulrich's seminal healthcare study on the effects of a window view on patient recovery that EBD began to explore the multifaceted benefits of incorporating biophilic attributes into the built environment.

However, in spite of the rapid ascent of the key elements of biophilic design—ample daylighting, green spaces, and views to nature—in new buildings, we've developed a blind spot concerning the design of the buildings most people currently occupy, and *will continue* to occupy, for the next couple of decades.

## **The Long Goodbye of Older Buildings**

It is important to note that in 2015 any building over 20 years old dates back to a time *before* biophilic design strategies were well known, let alone implemented.

According to Edward Mazria, the visionary architect and founder of Architecture 2030, an organization dedicated to achieve carbon neutrality in new building design, the average global life span of a building is 80 years.

Unlike automobiles, airplanes, and even most applied technologies, commercial buildings have long life spans. Given their long turnover rate: how long will it be before everyone lives, works, studies, heals, and shops in newer, better-designed buildings that incorporate the basic elements of biophilic design?

The *American Physical Society* calculates new building growth rate in the United States at 1% to 2% per year, which means our cities are *many decades* away from offering the already well established benefits of biophilic design to the bulk of commercial building occupants, whether they are employees, residents, students, patients, or shoppers.

What is the cost to property owners and tenants of occupying older buildings?

## The Hidden Cost of Enclosed Interiors

According to the *Institute for Building Efficiency*, over 50% of the buildings that will still be in use by 2050 have *already* been built.

In other words, a large percentage of the work force can be expected to work in outmoded buildings for the next 35 to 50 years.

Furthermore, a 2010 survey by the *U.S. Energy Information Agency* found that nearly  $\frac{3}{4}$  of the floor stock in the U.S., equivalent to 46 billion square feet, belong to buildings over 20 years old, *before* the principles of biophilic design were well understood, let alone widely applied.

On the other side of the Atlantic Ocean, the *European Buildings Performance Institute* calculates that a substantial share of the 5 billion m<sup>2</sup> of useful floor space in the EU 27, Switzerland and Norway, is older than 50 years and that many of the renovation projects take place in buildings over 200 years old.

While green design and sustainable technologies are incorporated in new buildings, the pressing question is:

*What solutions are available for billions of square feet of completely or partially enclosed interiors that will continue to be used for decades to come?*

What can we do to create *sustainable interiors* for long-term human occupancy in older buildings that we already know are not optimal for human performance and health?

Particularly, when we consider that out of the 5.6 million commercial buildings in the U.S., the largest deep plan buildings—structures over 100,000 square feet, despite accounting for less than 2% of the building count—are responsible for 35% of the total floorspace. In other words, their impact on human wellness is substantial.

Terrapin Bright Green, an environmental consultancy and strategic planning firm based in New York City, published a remarkable white paper in 2012 called *The Economics of Biophilia*, which quantified the economic advantages of biophilic design strategies.

Among the many remarkable studies cited, Terrapin underscores the fact that there's a direct correlation between the proximity an office lies to a window with a view to nature and the amount of sick leave an employee takes. Employees in offices without views to nature take 15% more sick leave time. In other words, building design impacts human productivity through its symbiotic relationship with health and wellness.

Furthermore, an analysis by *Rocky Mountain Institute (RMI)*, a non-profit research and educational foundation dedicated to foster efficient and sustainable use of resources, indicates that salary costs are about 100 times higher than energy costs.

Given that a company's primary expense is human resources, increasing employee productivity by even a small percentage—say 10% or 15%—has a much larger impact on a company's bottom line than reducing energy costs, oftentimes the overriding goal of green design.

RMI calculated that in the U.S., an average annual salary, with benefits, is about \$75,000 with an office space allocation of 250 gross sq. ft. per employee, which takes into account common areas and corridors. Dividing the salary cost by the worker density in a standard building yields an annual salary expense of \$300 USD/sq. ft. If employees take, on average, 8 sick days out of a total of 250 working days, then about 3.2% of the overall salary cost, or \$9.60/sq. ft., accounts for the expense of sick leave time.

Along these lines, reducing sick leave time by just 15% would deliver a hidden health dividend to any company of about \$1.44/sq. ft. on an annual basis. Companies can compare this figure to the average annual energy bill of \$3/sq. ft. that most corporations pay and management can grasp the financial implications of even a modest reduction in employee absenteeism resulting from a more sustainable interior space.

It is also worth noting that the trend towards collaborative and flexible workspaces has driven the mean allocated space per worker downwards. Today, many companies average less than 50% of the 250 gross sq. ft. mentioned above. If we took the trending average of 125 sq. ft. per employee, the impact of salary costs on space would double to \$600/sq. ft., making the savings on improved productivity even more dramatic—not \$1.44/sq. ft.—but \$2.88/sq. ft., *nearly equaling the annual energy costs* of the average company (\$3/sq. ft.).

In other words, investments made to improve human productivity in the interior envelope of a building that result in gains of as little as 10-15% could ostensibly pay the lion's share of a company's annual energy bill.

*The Economics of Biophilia* also documents the difference in absenteeism rates between employees with offices overlooking green spaces (59 hours/year) versus employees in workspaces without views to nature (68 hours/year). The difference between both groups also comes out to 15%, mirroring the results obtained by RMI's absenteeism analysis.

Over the years, numerous studies have also documented improvements in staff retention, job performance (less mental stress/fatigue), and workplace satisfaction. Static office environments in particular, exacerbate *presenteeism*, a phenomenon that describes when employees clock in for work, but are mentally removed from the workplace. The lack of multisensory stimulation indoors, which views to nature easily provide, tax our ability to focus and recharge, compounding the problem as the work day advances.

Considering that attracting and retaining the best qualified personnel is a top priority in tightening labor markets, the loss of anyone due to dissatisfaction, stress and fatigue, or poor work environment could cost the organization an average \$25,875 per employee.<sup>10</sup> Such figures had not been scrutinized in relation to building design until recently.

In summary, the building you currently occupy has a direct impact on your firm's bottom line. Barring a wholesale move into a new building designed with the principles of biophilic design in mind, what can the majority of building owners and commercial building residents do to reduce this erosion on health, productivity, and profits?

While Rocky Mountain Institute's analysis focused on corporate environments, the argument applies to a number of commercial applications such as healthcare, education, and specialty retail. Each of these environments are similar in that they feature enclosed spaces that deprive occupants of humankind's innate, genetic-based need to connect with open space in nature.

In this light, government buildings, department stores, research institutes and laboratories, hospitality and retail spaces, schools and universities, hospitals and clinics—most sectors of our predominately urban society—are exposed to the deleterious effects of confined interiors on the health, productivity, and well-being of the people who reside in these structures, day in and day out.

## **LEED... Has Led Not**

While the *United States Green Building Council* (USGBC) through its *Leadership in Energy & Environmental Design* (LEED) initiative has made great strides in promoting building design that emphasizes resource conservation and the use of benign construction

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<sup>10</sup> Loftness, Vivian, Volker Hartkopt, Beran Gurtekin (2007). "Building Investment Decision Support (BIDSTM)." Carnegie Mellon University Center for Building Performance and Diagnostics. Pittsburgh, PA., as cited in Terrapin Bright Green, *The Economics of Biophilia* (Chap. 2.1.2 Presenteeism) retrieved from <http://www.terrapinbrightgreen.com/reports/the-economics-of-biophilia/#footnote-mark-29>

materials, there really hasn't been a concerted emphasis on the importance of *restorative* occupant outcomes, particularly in terms of healthy spatial design and a meaningful connection to the cyclical nature of living systems.

The healthcare sector, which has embraced green design, reveals the deficiencies in LEED when it comes to environmental features that provide lasting restorative benefits to occupants; in their case, medical staff.

In the summer of 2015, the *Journal of Hospital Administration* published an article, *Return on investment of a LEED platinum hospital: the influence of healthcare facility environments on healthcare employees and organizational effectiveness* (2014, Vol. 3, No. 6) that set out to examine the relationship between hospital environments and employee engagement, turnover, illness, and injury.

Among the methods to examine the impact of the built environment of LEED platinum hospitals versus non-LEED hospitals was a 69-question staff survey. Although the results of the study concluded that employees' perceptions of the interior environment do impact employee engagement, health, and well-being (total impact factor on organizational effectiveness was 14%), the deficiencies in building design, even for LEED Platinum projects, was apparent.

The unique challenge of infiltrating natural light into the core of the building where most employees spend their working day was noted:

*Given the LEED credit for 75% daylight penetration at the LEED Platinum hospital, access to natural light and views within the nursing station and other occupied work areas were limited; much of the natural light is located in patient environment and public corridors where healthcare employees are less likely to spend their working hours...*

*The layout of the LEED hospital is different than those of the comparison [non-LEED] facilities with patient unit pods rather than the traditional racetrack design, yet the findings indicated similar dissatisfaction with participants at the other facilities.*

*Future design of facilities would benefit from careful analysis of layout and organization of spaces with consideration to employee work processes.<sup>11</sup>*

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<sup>11</sup> Harris, D. Debra. "Return on Investment of a LEED platinum hospital: the influence of healthcare facility environments on healthcare employees and organizational effectiveness." *Journal of Hospital Administration* Vol. 3, No. 6 (2014): 51.



While the challenge for future building design remains in the hands of architects, it is apparent that even the best certification in green design has not been able to resolve the fundamental quandary of achieving long term sustainable human occupancy in enclosed interiors.

In fact, we may find that as long as deep plan buildings continue to operate, the solution to their detrimental effect may not be found within their walls as much, as within our *perception* of their surface as a spatial boundary.

Neuroscientific research has revealed how dynamic and plastic our brains are and how our ability to map out an environment is as much a function of cognitive perception as it is a function of actual sensory input. In other words, even when the built environment is fixed—like the walls and ceiling of a basement room—it is still possible to alter our *experience* of that space by modifying the environmental cues that we perceive (in this case with our eyes and brain), causing our organs of perception to arrive at a *different* interpretation of the original environment.

This change in emphasis allows us to consider visual/spatial technologies within the context of less than ideal, existing working environments.

Taking the healthcare industry as an example again, we find that the renewed focused on enhancing the patient experience due to the rise in pay-for-performance (P4P) and public release of data from the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey, has revealed the relevance of environmental design in affecting workplace outcomes. An article in *The Atlantic* magazine noted that:

*A recent Health Affairs study found comparing patient-satisfaction scores with HCAHPS surveys of almost 100,000 nurses showed a better nurse work environment was associated with higher scores on every patient-satisfaction survey question.<sup>12</sup>*

In this light, the ramifications of proper environmental design for the workplace, regardless of industry, cannot be stressed enough, considering that staff performance drives profitability as well as patient/client outcomes.

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<sup>12</sup> Robbins, Alexandra. "The Problem with Satisfied Patients." TheAtlantic.com 17 Apr. 2014 [http://www.theatlantic.com/health/archive/2015/04/the-problem-with-satisfied-patients/390684/#disqus\\_thread](http://www.theatlantic.com/health/archive/2015/04/the-problem-with-satisfied-patients/390684/#disqus_thread).

## II. Environmental Design & the Mechanics of Perception

Now, taking a historical outlook, even the first builders understood the power that human perception plays in the built environment. Architects have traditionally sought to leverage our habits of perception to orchestrate complex architectural compositions, including interior spaces designed to be experienced as environmental illusions.

Although much research in biophilic design yields insight into why we engage emotionally with the built environment, the history of human habitat itself has shown that architects and artists understood early on that human perception is malleable. By malleable we mean that by orchestrating the context in which sensory input is presented in the built environment, designers can give rise to a wide range of cognitive experiences in the observer. Typically, all good design accounts for this phenomenon in the creative process.

During medieval times, for example, the great European cathedrals like Chartres and Notre Dame in France became not only benchmarks of engineering feat, but sublime conduits of human perception. By shepherding visitors' awareness upward with gravity-defying arches and exquisitely ribbed vaults, cathedrals inspired awe with an architectural language and aesthetic fashion unequalled by even the outside environment.

One memorable occasion involved famed 19-Century architecture critic Eugène Emmanuel Viollet-le-Duc who, upon entering Notre Dame for the first time, thought the glorious organ music he heard in the dimly lit space emanated from the natural skylight framed by the cathedral's rose stained glass windows.

He was so overwhelmed with emotion that he needed to be escorted out.<sup>13</sup>

Although architecture may not always strike such a deep emotional chord, it is worth noting a cathedral, according to Stephen Murray, *Professor of Art History and Archeology* at Columbia University, is a medium intended as a transport to somewhere else, and heaven is one of those places. In other words, the built environment can be design to transport the viewer elsewhere—to a physical or metaphysical place.

Fortunately, it is not necessary to design a new building from the ground up to change how a person feels within its walls. Architecture history is also full of techniques that

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<sup>13</sup> Ruiz, Rebecca. "Europe's Can't Miss Cathedrals." Forbes.com 12 Feb. 2008  
[http://www.forbes.com/2008/02/12/travel-europe-cathedrals-forbeslife-cx\\_rr\\_0212travel.html](http://www.forbes.com/2008/02/12/travel-europe-cathedrals-forbeslife-cx_rr_0212travel.html)

altered the observer's perception of interior spaces with dramatic effect.

Trompe l'oeil's rich history in art, photography, filmmaking, and architecture has lead neuroscientists to discover that sensory illusions, whether optical or multisensory, occur due to the unique way that human perception operates. Using techniques like forced perspective, shading, and relative size, visual artists are able to influence spatial perception through a selection of materials and composition techniques—arranged as cognitive cues—that lead our brain to attribute spatial properties to otherwise flat environments in a way that *alters* our psycho-physiological response to enclosed spaces.

The advent of modern large format, ultra high resolution digital technology, leads to new opportunities to capture, design, and reproduce visual stimuli in a way that our habits of perception experience biophilic engagement, the bone fide automatic “relaxation response” that is the evolutionary advantage gleaned from natural environments.

The field of neuroscience has done much to uncover how the visual system makes inferences from the outset and fills in the gaps from missing or misleading visual input. Our brain routinely makes assumptions about sensory input. This confirms that our perception is born of a process of interpretation, not static transmission of one-to-one correlations from environmental cues.

In other words, the rich tapestry of visual experience that we cognize is actually an internal composite presented by our senses and organized by the internal algorithms (habits of perception) used to interpret and give rise to meaningful perceptions. This phenomenon, according to neuroscientists Stephen L. Macknik and Susana Martinez-Conde, authors of the fascinating book *Sleights of Mind*, is an unavoidable result born of the “sheer limitations in the numbers of neurons and neural connections underlying our sensory and mental processes.”<sup>14</sup>

We are accustomed to the notion that our perception of reality of what is “out there” is accurate, but this simply is not true. Our visual circuits are not passive transmitters of sensory input, but actively “amplify, suppress, converge, and diverge all incoming visual information,” to use Macknik and Martinez-Conde's words.

They go further and assert, “You perceive what you see as something different from

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<sup>14</sup> Macknik, Stephen L., and Susana Martinez-Conde. *Sleights of Mind* (New York, Henry Holt & Company, 2010), 13.

reality. Perception means resolving ambiguity.”<sup>15</sup> They provide a great example. Why does the full moon look enormous as it rises over the horizon among trees or buildings whereas it looks minuscule when spotted high in the sky?

The discrepancy in perceived size is due to the influence of visual context. Adjacent to trees, hills, or mountains, plus the atmospheric haze of the horizon line, our brain infers the size of the lunar disc. But it does so by actually enlarging the size we “see” based on these environmental or contextual cues. Up in the sky, with only the vastness of the sky to provide context, our visual circuits again reduce its perceived size.

Which size is “true”? Hard to say!

And this is just one example of how our perception is not as static as we believe it to be, but is a dynamic process that is sensitive to the environmental cues surrounding visual input. Furthermore, scientists have been able to categorize what we would recognize as attention—our ability to direct our focus—not as a single and uniform phenomenon, but as a number of discrete cognitive processes.

Of particular relevance to environmental design and the mechanics involved in how we experience a given space is the cognitive phenomenon of the “spotlight of attention,” the ability to regulate sensory input by bearing down on a particular region of visual space while, at the same time, tune out data or stimuli outside the “tunnel vision” of focus.

When we direct our focus to a given area, our spotlight of attention falls on what is called “retinotopic” space. As Macknik and Martinez-Conde explain, “neurons from higher levels of your visual system increase the activation of the low-level circuits and enhance their sensitivity to sensory input. At the same time, neurons in the surrounding regions of visual space are actively inhibited.”<sup>16</sup>

It is interesting to note that another neuroscientist, Dr. Steven Rose, author of *The Future of the Brain*, notes a fascinating study where the perceived sensory input actually *increases* when the context changes. That is, the same visual stimulus presented under a different context does, in fact, lead to a more or less *engaging* cognitive experience.

This is the stuff of which *unexpected* illusions are made.

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<sup>15</sup> Macknik and Martinez-Conde. *Sleights of Mind*, 12.

<sup>16</sup> Macknik and Martinez-Conde. *Sleights of Mind*, 64.

In one of his lectures discussing his book, Dr. Rose wonders what is wrong with the world around us considering that clinical depression, which the World Health Organization has called the epidemic of the 21<sup>st</sup> century, has become the malaise of contemporary humanity.

Considering what we now know about the importance of multisensory stimuli and environmental context, could the unprecedented global spike in clinical depression have an architectural origin?

Could the lack of a “neurologically complex” environment, which is the hallmark of visual access to nature, coupled with the wholesale migration to static, artificial interiors that provide little sensory stimuli be largely responsible for this dramatic change in modern humanity’s psychological well-being and neural chemistry?

Instead of living and working in natural environments, a substantial percentage of the population labors within intricate, labyrinth-like buildings in high-density metropolitan areas. Nothing could be further away from our innate biophilic need for open space. The healing canopy of open skies, one of the circadian synchronizers that help entrain or reset our circadian rhythm, is the spatial connection that artificial interiors must account for, if they’re to support occupants who spend the majority of their workday within their walls.

## **What is the biophilic response?**

Biophilic engagement is our innate response to natural environments; how our physiology reacts when we walk along the seashore, look out a secluded bluff, or dip our toes in the currents of a wild river. In other words, when our senses are immersed in a natural environment, we experience biophilic engagement. That’s why people gravitate to the outdoors.

In nature, our biometrics show optimal performance. When we are at ease, our physiology behaves differently. A cardinal aspect of this dynamic is well known as the “Relaxation Response,” the opposite of the Fight-or-Flight response. In nature, our physiology is relaxed while our mind remains alert, allowing for optimum cognitive performance.

On the reverse, when we’re stressed and fatigued our productivity plummets. Further compounding our physiological reaction to an overload of activity, prolonged periods in enclosed interiors precipitate both stress, anxiety, and fatigue.

To alleviate these symptoms, we must learn to elicit biophilic engagement in confined, artificial environments.

## Human Perception and Spatial Design

While cognition itself is a complex subject, it is enough to note that human spatial cognition is fundamental to human life. By spatial cognition Hart and Moore (1973) refer to “the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought.”<sup>17</sup>

In the healthcare industry, where the construction costs can reach \$400/sq. ft. for medium sized buildings (4-8 stories) and taller buildings easily reach 4X times this cost, it has been imperative to ensure that building design contributes to enhance, rather than hinder, clinical outcomes.<sup>18</sup> In the last 30 years, the field of evidence-based design has taken a prominent role in studying the environmental features most conducive to a healing environment, building a knowledge base that now guides architectural design in healthcare settings.

Over this period, healthcare researchers and designers have embraced the benefits of nature art imagery in providing “positive distraction” features in clinical settings.

Positive distraction is defined as “an environmental feature that elicits positive feelings and holds attention without taxing or stressing the individual, thereby blocking worrisome thoughts” (Ulrich, 1991).<sup>19</sup>

In other words, the restorative impact of nature art was attributed to the emotional response it elicits due to its representational or symbolic properties. And this affective attribute in turn was valued because, according to neuro-scientific studies, the

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<sup>17</sup> Mark, D.M., 1993. “Human spatial cognition.” In Medyckyj-Scott, D., and Hearnshaw, H. M., editors, *Human Factors in Geographical Information Systems*, Belhaven Press, 51-60.

<sup>18</sup> Carrick, Alex, 2012. RSMeans’ dollar-per-square-foot construction costs for medical facilities and a high-rise residence. <<http://www.cmdgroup.com/market-intelligence/articles/rsmeans-dollar-per-square-foot-construction-costs-for-medical-facilities-an>>.

<sup>19</sup> Ulrich, R.S., 1991. Effects of interior design on wellness: Theory and recent scientific research. *Journal of Health Care Interior Design*, 3, 97-109.



emotional response is *immediate* and can occur before other higher-level cognitive responses (Nanda, 2011).<sup>20</sup>

Interestingly enough, until recently, neither designers of nature art imagery nor the researchers involved in documenting the clinical properties of nature art have considered the cognitive implications of introducing a more profound visual phenomenon—optical illusions—in healthcare settings.

Virtual skylights are such visual illusions. When properly designed, they give rise to a powerful architectural tool—biophilic *illusions of nature*<sup>™</sup>—that incorporate both materials and techniques ranging from art and photography to filmmaking and architecture. Taken together, they become an artistic tool and a unique image technology which engage our cognitive organs in such a way that our hardwired habits of perception experience something else—they transport us somewhere else. Ultimately, they induce a restorative experience of biophilic engagement in interior spaces.

### **Biophilic Engagement in Enclosed Interiors**

Our innate, genetic-based need to affiliate with living systems, as first proposed by Edward O. Wilson in his Biophilia Hypothesis, provides the scientific premise behind why leveraging the biophilic properties of *illusions of nature* alters spatial perception.

Our genetic memory of natural environments is so robust that we can trick the eye and the brain into *experiencing* a visceral connection to outdoor space through a properly executed simulation of sky phenomena.

At The Sky Factory, we call this design framework *Open Skies Image Technology*, the ability to capture, reproduce, and reassemble static or dynamic nature events like open skies in such a way that our *spatial* perception is engaged, lending virtual skylights and windows a unique element of *perceived* depth and palpable expansion.

This unique cognitive presentation allows for a much deeper response, not only an affective or psychological one, but a broader neuro-physiological response to the *perceived* change in enclosed environments. In other words, the observer not only *engages* with the surroundings in a new way, their physiology *reacts differently* as well.

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<sup>20</sup> Nanda, U., 2011. Impact of Visual Art on Waiting Behavior in the Emergency Department. *The Center for Health Design, Acknowledgements* iv.

This is *biophilic engagement*.

The observer becomes more relaxed and mental agitation is reduced when the perceived surroundings lose their confining or claustrophobic dimensions. Using carefully crafted *illusions of nature* to trigger biophilic engagement evokes our innate predilection for comfortable spaces that afford a panoramic view of the surroundings (Prospect & Refuge Theory).

Restorative illusions not only compound the benefits of positive distraction, but also evoke how we *instinctively* feel in natural environments: engaged, relaxed and receptive.

After a dozen or so years of noting recurrent patient experiences of vastness—a palpable sensation of openness—when exposed to biophilic illusions in enclosed clinical environments, it became evident that peering into the neuroarchitecture of nature stimuli could be illuminating.

The Sky Factory partnered with Texas Tech University’s Neuroimaging Institute on a pioneering study that was, not only published in the peer-reviewed academic journal *Health Environments Research & Design*, but also earned a *Design & Health International Academy Award* for the Best International Research Project (2014).

In 2017, this pioneering study also earned a *Certificate of Research Excellence (CORE)*, granted by the *Environmental Design Research Association (EDRA)*. The study was not only recognized for its rigorous methodology, but also for its interdisciplinary nature. It shed light on a practice-based application and advanced design thinking by noting that multisensory sky images can have a tangible and restorative effect on interior architecture.

### **The Neuroarchitecture of Illusions of Nature**

The award-winning study, *Neural Correlates of Nature Stimuli: an fMRI Study*, revealed that specifically designed Sky Factory’s open sky photographic compositions not only share the characteristic neural activations present in positive images—including nature images, but also uniquely engaged areas of the brain involved in spatial cognition. Of particular interest to the researchers were the activations found in the cerebellum as it is often associated with aspects of spatial cognition or the experience of extended space.

The positive impact of nature images on health outcomes has been traditionally measured using behavioral and physiological indicators, leaving much to be understood about the neural mechanisms that explain their positive influence. The Texas Tech University study was designed to uncover the neural pathways involved in

the perception of open sky photographic compositions (representing nature stimuli) as compared to other positive, negative, and neutral images.

With a neurological understanding of the power of biophilic illusions to alter perceived space in enclosed interiors, indoor spaces can leverage a research-based approach to mitigate the deleterious impact of deep plan buildings. Using such tools, isolated areas can be adapted to provide long-term sustainable interiors for human occupancy.

There is a growing interest in studying biophilic illusions to pinpoint how they mitigate the consequences of prolonged exposure to enclosed interiors. Future studies will detail how the incorporation of biophilic illusions alter our psycho-physiological response in diverse spaces.

To this effect, it is important to note that creating an illusion rests on a combination of factors. Among these are the fidelity of the reproduced visual content, the seamless integration of compositional elements into the architectural context—including the use of architectural reveals—and the proper color temperature and intensity of light that when put together synthesize a new *perceived* sense of environment.

Essential in this cognitive palette are the fractal patterns inherent in the visual compositions (i.e., ordered details arranged in a nestled scaling hierarchy) that give rise to the signature *neurological complexity* our senses prize in natural environments.

Authors like Nikos Salingaros and Kenneth Masden III have even gone so far as to emphasize that a “neurological basis for aesthetic response is now being established.”<sup>21</sup>

Coinciding with other leading researchers, they go further and reason that “the parallel between built fractal patterns and possible cerebral organization is too strong to be a coincidence.”<sup>21a</sup>

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<sup>21</sup> Salingaros, N. A. 2006. *A Theory of Architecture*. Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Kellert, Stephen, Judith Heerwagen, and Matin Mador, eds. Wiley & Sons, NJ, 2008. 62.

<sup>21a</sup> Salingaros, N. A., and K. G. Masden III. 2006a. *Architecture: Biological Form and Artificial Intelligence*. Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Kellert, Stephen, Judith Heerwagen, and Matin Mador, eds. Wiley & Sons, NJ, 2008. 62.

In healthcare alone, research in the field of evidence-based design has “uncovered the undisputed clinical advantages of natural environments, including artificial environments mimicking the geometrical qualities of the natural environment.”<sup>22 22a 22b</sup>

Furthermore, in situations where an interior space cannot incorporate an *organic* visual connection to nature, it is still possible to mimic the geometry of natural environments by reproducing two fundamental *biophilic* spatial relationships—the zenith and the horizon line—within the architectural framework of interior spaces.

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<sup>22</sup> Frumkin, H. 2001. *Beyond Toxicity: Human Health and the Natural Environment*. Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Kellert, Stephen, Judith Heerwagen, and Martin Mador, eds. Wiley & Sons, NJ, 2008. 62.

<sup>22a</sup> Ulrich, R. S. 1984. *View through Window May Influence Recovery from Surgery*. Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Kellert, Stephen, Judith Heerwagen, and Martin Mador, eds. Wiley & Sons, NJ, 2008. 62.

<sup>22b</sup> Ulrich, R. S. 2000. *Evidence Based Environmental Design for Improving Medical Outcomes*. Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life. Kellert, Stephen, Judith Heerwagen, and Martin Mador, eds. Wiley & Sons, NJ, 2008. 62.

### III. *Perceived Zenith & Perceived Horizon Line:* The Restorative Barometer of Spatial Cognition

In any environment—natural or artificial, exterior or interior—the zenith, the point in the celestial sphere directly above the observer, and the horizon line, the apparent junction of earth and sky, serve as environmental anchors that shape our experience of space. We cannot underestimate the importance of visual input and spatial awareness to our well-being.

When we have our eyes open, vision accounts for two-thirds of the entire electrical activity of the brain, a full 2 *billion* of the 3 billion firings per second.<sup>23</sup>

In fact, 50% of our neural tissue is directly or indirectly related to vision.<sup>24</sup> Both frontal and peripheral vision automatically map out the space we occupy, but our psychophysiological relationship to space is much more than a mechanical function. Space plays a profound role in behavior, mental acuity, and performance. It should not be a surprise that interior environments enhance or detract from our ability to perform optimally in those spaces.

Environmental psychologists DeLong and Lubar (1979) have suggested that human beings perceive a strong relationship between the space that surrounds them and passage of time. In their research, it has been shown that larger spaces slow *perceived* time while smaller spaces speed up *perceived* time.<sup>25</sup>

Outside, particularly in nature, wild, open spaces create a distinct sense of comfort and expansion. An open blue-sky overhead coupled with a panoramic view of undisturbed nature—whether it's a mountain range, the savanna, a body of water or an undulating forest—provides a palpable sense of spatial infinity that registers along a vertical, horizontal and transversal axis.

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<sup>23</sup> Jensen, Eric. (2008). *Brain-Based Learning: The New Paradigm of Teaching*, as cited in *True or False? Vision Rules the Brain*. Retrieved on October 22, 2015 from <http://www.imagethink.net/imagethink-2/true-or-false-vision-rules-the-brain/>

<sup>24</sup> Ibid.

<sup>25</sup> DeLong, A. J., and J. F. Lubar. 1979. Effect of Environmental Scale of Subjects on Spectral EEG Output. *Society for Neuroscience Abstracts* 5:203. In *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*. Kellert, Stephen, Judith Heerwagen, and Martin Mador, eds. Wiley & Sons, NJ, 2008. 309.

When we feel our body, our entrained measure of scale, to be smaller in relation to the space we occupy, we perceive time to *slow down*. This clinical observation echoes the scale proportions found in views to nature that offer Prospect & Refuge where we have unimpeded visual and spatial access from a small and secure spot like a balcony, a secluded outlook or a room with windows looking out into an expansive environment. In light of this recurrent scale relationship, it is not surprising that panoramic views of nature remain a hallmark of ideal aesthetic design.

A breathtaking view to nature is not only a poetic way of describing the swing of awareness that humans find intrinsically enticing and healing. It also literally describes the physiological transformation that occurs during *biophilic engagement*. When the breath slows down or is momentarily suspended, it is the direct result of the quieting of the mind and reflects an experience of the deep connection between the observer and the observed. This visceral recognition and conscious amazement is the innate kinship between living systems, humankind and nature, that Biophilia defines.

When we perceive a small relative scale (our body) in the context of a much larger relative scale (environment or geography), the juxtaposition of contrasting scales creates an unparalleled experience of wholeness, a perceptual experience conducive to reflection, contemplation, mental clarity, and emotional balance. When we experience vastness, time appears to slow down, become abundant, and feel infinite. And in the experience of infinity, the mind finds much more than solace; it discovers its own unbounded nature and experiences deep rest.

On the other hand, smaller spaces, particularly enclosed artificial spaces, tend to crowd us in. Our perceived sense of time *speeds up*, leading to the common experience of time pressure, task-related stress, and anxiety. As a matter of fact, small, enclosed spaces make occupants feel like the walls are literally closing in, which given the research, might finally be understood as an accurate expression of cognitive perception.

In this sense, a body of research does indicate that space-time interactions in human vision are asymmetrical; spatial cognition has a larger effect on temporal cognition than the other way around (Merritt et al., 2010 as cited in Homma and Ashida, 2015).<sup>26</sup> This fundamental insight into cognitive perception provides fascinating design possibilities.

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<sup>26</sup> Homma, C. T., and Hiroshi Ashida (2015). *What makes space-time interactions in human vision asymmetrical?* *Frontiers in Psychology*, Vol. 6, article 756, Retrieved December 9, 2015 from <http://journal.frontiersin.org/article/10.3389/fpsyg.2015.00756/full>



If we account for how our neurophysiology reacts in relation to perceived space, then we can also, to an extent, modulate the occupant's subjective relationship with time, which in turn affects his or her productivity, work satisfaction, and health.

Interior environments that provide a visual and spatial connection to open, natural environments foster a calm, grounded psycho-physiology. On the converse, isolated interior spaces without a visual and spatial connection to a natural exterior will—by design—speed up time, contributing to a compressed feeling of unease.

This happens because we measure time in terms of space. After all, time is an abstract concept whereas space is a concept we can measure and quantify given that we literally map out spatial relationships in our brain. As a matter of fact, some neuroscientists like Jennifer Groh speculate so far as to declare that abstract thought is intimately linked to spatial cognition, and the way we map out our sense of space may also be responsible for the nature of human thought itself.

In order to understand this far-reaching proposition, it is important to understand that the sensory and motor processing regions of our brain overlap by a remarkable measure with the cerebral areas responsible for cognitive faculties such as memory, attention, and planning.

In her book, *Making Space, How the Brain Knows Where Things Are*, Groh asserts that, “much of the information stored in our memory systems is intrinsically spatial. We find things by remembering where to look. Many of the brain's sensory and motor regions also exhibit memory-related activity.”<sup>27</sup> She goes on to say that the parietal cortex seems to play a role in unlocking memories by calling to mind spatial frame references “based on one's imagined perspective on the scene.”<sup>28</sup>

She gives a fascinating example, from a 1978 study by Italian researchers, Edoardo Bisiach and Claudio Luzzatti, who tested patients who suffered from damage to one hemisphere of the parietal cortex, on how well they could recall familiar settings. The researchers asked the patients to “imagine themselves standing at the foot of the famous Piazza del Duomo, in Milan, and to name as many landmarks around the square as they could. The patients had trouble naming landmarks from the side of the square that corresponded to their impaired region of space.”<sup>29</sup>

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<sup>27</sup> Jennifer M. Groh. (2014). *Making Space, How the Brain Knows Where Things Are*. Cambridge, Massachusetts, The Belknap Press of Harvard University Press, Ch. 9, p. 190.

<sup>28</sup> Jennifer M. Groh. *Ibid*, p. 196.

However, the fascinating discovery came when the researchers asked the patients to “switch mental perspectives and imagine themselves standing on the other end of the square, facing the opposite direction. The change in vantage point, even though only imagined, allowed their patients to recall landmarks from the opposite side of the square! So memories were there all along.”<sup>30</sup> Conscious access to these memories was only a matter of recreating the proper spatial reference frame in the *mind’s eye* of the patients.

In similar fashion, when we create visual stimuli in enclosed interiors with the proper spatial frame reference—a design element unique to *illusions of nature* and not found in decorative photography—we reestablish a neural connection to our past experience of looking up at the sky.

Even when the environmental context is virtual, that is, simulated in an isolated interior, we can trigger spatial memories of experienced environments—our biophilic memory—because the hippocampal region has a profound sensitivity to one’s own spatial location in relation to the past memories formed under similar sensory stimuli. Certainly, it seems reasonable that if we can imagine a place and recall details of the environment (as in the Italian experiment), an illusion, being yet more concrete than a memory, should yield similar results.

These neural dynamics indicate the central role that spatial reference frames play in channeling stored (biophilic) memories of spatially similar experiences. This mechanism may explain why a biophilic illusion of open sky inside a building can also evoke the “Relaxation Response” that open natural environments so easily reveal. Our spatial memory of looking up at an open sky, or into an open natural landscape, is engaged in a multisensory fashion—visually and spatially—in such a way that our organs of perception evoke the psycho-physiology of the original spatial mapping of sky or landscape.

Again quoting Dr. Groh, we discover that research confirms this understanding. “With the advent of imaging techniques to assess human brain activity, some clues to the neural basis of this kind of phenomenon have emerged. Some studies have shown that mentally picturing a visual stimulus elicits activity in the primary visual cortex and,

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<sup>29</sup> Jennifer M. Groh. Ibid, p. 195-6.

<sup>30</sup> Jennifer M. Groh. Ibid, p. 195.

furthermore, that the extent of this activity varies with the size of the object being imagined—tying in to the visual cortex map of space.”<sup>31</sup>

These assertions provide a neurological basis to understand why natural environments have played such a fundamental role in the development of our neural circuitry and why now, more than ever, when humankind’s daily urban experience is one of limited built space rather than interconnected open space, the negative consequences to our cognitive functions like performance and wellness cannot be stressed enough.

Dr. Groh’s argument brings us back full circle to the Biophilia Hypothesis and the impact of natural environments on our ability to restore and recharge. She says, “such studies suggest that mental representations for space are not merely co-opted from the sensory and motor domains, but that those domains may in turn shape thinking in the abstract domain...The implication of this is that perhaps many aspects of our ability to think and reason may be shaped by the nature of the neural “wetware” that originally evolved in the context of sensory and motor processing.”<sup>32</sup>

Therefore, if our brain acquired its neural complexity in direct response to the natural environment that enveloped our earlier psycho-physiological experience on Earth, it is no wonder that our sense of time has a direct correspondence to the space we occupy. When we find ourselves outdoors, surrounded by nature with a palpable sense of infinite space, our minds feel expanded, serene, induced to abstract thought, daydreaming, free association, creativity, and foresight.

On the other hand, with the modern march to limited, disconnected space, society has seen the rise of urban pathologies, most notably hypertension, chronic stress, and attention-deficit affective disorder. These acquired behaviors lose much of their neurotic hold when the subject is immersed in a larger spatial frame of reference. We can literally recover our sense of self, our mental and emotional balance, when we find ourselves in the presence of a vast, visual connection to nature. Such a spatial reference frame always exhibits the unique features of Prospect & Refuge.

Terrapin Bright Green’s second white paper, *14 Patterns of Biophilic Design*, selected the most pervasive patterns in nature that bring the highest restorative value to the human physiology. According to the empirical evidence gathered by leading scholars, the two attributes of nature with the largest amount of peer-reviewed research, both

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<sup>31</sup> Jennifer M. Groh. Ibid. p. 207.

<sup>32</sup> Jennifer M. Groh. Ibid, p. 210.

quantitative and qualitative, that back their restorative qualities are:

a) **Visual Connection to Nature**

b) **Prospect & Refuge**

Both of these patterns provide multiple psycho-physiological benefits for human performance and well-being, including significant stress reduction (*i.e. lower blood pressure and heart rate*), cognitive performance (*i.e. improved mental engagement and attentiveness*), and emotion, mood and preference (*i.e. improved comfort and perceived safety*).<sup>33</sup>

On the other hand, enclosed interiors that do not offer an organic connection to a natural exterior preclude our entrained sense of scale from finding a restorative exit or “window” that can ground our senses and maintain the much needed biophilic connection to the exterior. Particularly in deep plan buildings, experiencing prolonged compression, distortion, or removal of the zenith and horizon line diminish our productivity and negatively impacts our health.

However, it is now possible to simulate these two fundamental *biophilic* spatial relationships. Extension of the interior zenith from the ceiling plane to a much more distant *perceived* zenith outside the building can also be accomplished by incorporating an illusion of nature that provides multisensory points of reference.

Sky Factory’s *Open Sky Image Technology* not only incorporates an image’s rich tapestry of visual information, but also engages our vestibular system as it pertains to balance and spatial orientation, reinforcing the spatial reference frame. A multisensory approach to image composition, among other elements of design, is fundamental in creating such a successful illusion.

The combined environmental cues tie the overhead image to its architectural context, thereby making the boundaries of the ceiling “transparent” to the eye and awareness of the observer. The closer the image appears to “belong” within the unseen, but presumed confines of the exterior envelope, the more our habits of perception reinforce *amodal perception*, the hardwired reflex of filling in the unseen portions of an occluded

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<sup>33</sup> Browning, W., Ryan, C. & Joseph Clancy. 2014. *14 Patterns of Biophilic Design*, (chapter 2.4 Nature-Health Relationships). Terrapin Bright Green, LLC. Retrieved on October 23, 2014 from <http://www.terrapinbrightgreen.com/reports/14-patterns/>

shape. If the observer sees a portion of sky or a few “windows” of the same outdoor area, a very powerful illusion is automatically induced: such an illusion conveys a perception that behind the ceiling plane there is *open space*.

The suggestive quality of the environmental cues, image composition and light quality married to architectural context, can similarly “weaken” the boundaries of interior walls. It is possible to recess the horizon line represented by interior walls by incorporating a series of virtual windows (two or more) that depict a single panoramic view separated by a calibrated distance (mullions). This architectural arrangement will automatically trigger binocular vision, which brings a powerful element of spatial cognition.

When the scale of the horizon line is recessed, thereby connecting the observer with a *perceived* natural exterior, an enclosed, interior setting can be experienced as a *restorative* environment. Such space will naturally offer the positive attributes of a view to nature possessing the wellness visual hallmarks of Prospect & Refuge.

These two spatial relationships, *perceived* zenith and *perceived* horizon line, represent a visual and cognitive technology that has just begun to be leveraged in deep plan interiors. It is particularly useful when other avenues to bring biophilic design relief indoors are not structurally possible or economically feasible. Today, by taking this cognitive framework into account in the visual design process, it is possible to have a research-based visual technology that can turn billions of square feet of enclosed interiors into comfortable, healthy, and restorative indoor spaces for long-term human occupancy.

## Fractals, Wellness, and Space

Our intent in this paper has been to summarize the well-documented, restorative benefits of nature environments and the ability of biophilic illusions to transmit, not only the visual content experienced in nature, but mimic its spatial properties. In this light, enclosed spaces no longer pose an impenetrable barrier to bring a meaningful measure of wellness, indoors. It is not so much a question of available physical space, as much as well-designed *perceived* space.

As such, management can begin to calculate the productivity savings and the wellness benefits to their workforce, particularly those relegated to the interior of deep plan buildings. By incorporating biophilic illusions in isolated offices, conference rooms, call

centers and other areas, these virtual portals to natural exteriors will reduce older buildings' drag on human performance and health. This new architectural approach to the design of interior space will allow companies to monetize the hidden wellness dividend trapped in enclosed interiors.

This knowledge is already leading to new standards for building design and is raising the bar for sustainable occupancy in interior spaces. This paradigm shift can be seen in the new WELL Building Standard® created by the *International WELL Building Institute™*, which is the first standard of its kind that focus attention solely on the health and wellness of building occupants.

The WELL Building Standard® is based on a thorough review of the research on the effects of indoor spaces on individuals, and identifies 102 performance metrics, design strategies, and procedures that can be implemented to achieve WELL Certification, spaces that marry the best practices in design and construction with evidence-based health and wellness interventions.

Among the key elements in the section devoted to lighting, WELL recognizes the fundamental impact that outdoor views and daylight have on our psycho-physiology. For this reason, in its "Right to Light" section of the Standard, WELL recommends that the lease depth (the distance between the building core and the exterior façade) *does not exceed* 7.5 m (25 ft.) for 75% of the area of all regularly occupied spaces.<sup>34</sup>

WELL also recommends that 75% of all desks are within 7.5 m (25 ft.) of an atrium or a window with views to the exterior and that 95% of all desks are within 12.5 m (41 ft.) of an atrium or a window with views to the exterior.<sup>35</sup>

This represents a paradigm shift in the importance of wellness in architectural design.

## **Buildings as Structure, Environment, and Habitat**

Up until now, urban development has relied on high-density occupancy buildings to maximize the limited space found in highly competitive metropolitan areas. At the same time, large-scale construction projects rely on economies of scale in order to make this type of construction profitable.

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<sup>34</sup> Delos Living LLC. 2014. WELL Building Standard version 1.0, (section of the Standard on Light, 61 - Right to Light, p. 101). Retrieved on April 8, 2015 from <http://www.wellcertified.com/well>

<sup>35</sup> Ibid.



What has been completely lost in this economic model is the unaccounted impact of *externalities*. In economics, negative externalities refer to economic burden affecting a 3<sup>rd</sup> party who did not choose to incur that cost.

In this case, the negative externality caused by deep plan corporate, institutional, and commercial spaces is the underreported impact on the health, productivity and well-being of captive populations in all types of commercial buildings. Developers reap the rewards of more profitable mega structures while corporate tenants and their agents, who labor in enclosed spaces, suffer the consequences of inert structural spaces that afford none of the benefits of restorative environments.

Given the emerging evidence, the time has come for buildings to be considered living environments and habitats, not static, monolithic structures. New development of deep plan buildings should be considered with a keen eye to the health implications of occupant exposure to enclosed interiors, seeking to remedy their primary design pitfall by incorporating biophilic design strategies from the outset.

Case in point, Bank of America's *One Bryant Park Tower* was designed from the outset to provide views to green spaces to 90% of their employees. The bank figured even a 1% *increase* in productivity would save 10 million dollars annually.<sup>36</sup> This is the net financial impact of building design. Calculations of this nature indicate that while new construction can lock their savings at the planning stage, older structures will have to marshal retrofit solutions for their current portfolio to stem future *projected* losses.

## **The Cost Effectiveness of Biophilic Illusions**

Here's where biophilic illusions of nature offer an innovative, cost-effective, evidence-based solution. By leveraging our ingrained habits of perception, it is possible to use imagery within an architectural context to engage the areas of our brain involved in spatial perception, devising a meaningful connection to a perceived natural exterior.

This is a distinct approach from the one taken by faux skylights, which are widely recognized for their use of representational images. Genuine virtual skylights provide the necessary cues that engage our neurophysiology, giving rise to a bone fide biophilic illusion. When designed as architectural features in enclosed interiors, virtual skylights

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<sup>36</sup> Intercongreen.com. 2009. Green Buildings: One Bryant Park. Retrieved on March 31, 2014 from <http://intercongreen.com/2009/05/14/green-buildings-one-bryant-park/>

leverage *amodal perception*. Due to the widespread use of the grid system in commercial construction, and the possibility for mullions, the matrix of panels in a hung ceiling offers an ideal structure for exploiting not only *amodal perception*, but binocular vision and other cognitive habits of perception that allow designers to alter *perceived* space. The cost of these installations represents a fraction of the cost when compared to structural changes and building code implications. Considering their effectiveness and rapid deployment, this visual technology has the potential to change buildings that otherwise have no alternatives to resolve the implications of their enclosed interiors.

At the same time, the next generation of biophilic illusions is already underway. While LED lighting systems have begun to understand the wellness implications of the color temperature of light, no one yet has attempted to marry these traits to visual content.

Circadian illusions will soon be able to mimic the properties of light that orchestrate photopic (day) vision, which is absorbed by the chromophores (chemicals that absorb light) in the cones of the eye (blue, green, or red opsins), as well as stimulate the inner retinal sensors (the melanopsin photoreceptors) that regulate the circadian cycle or the non-visual, biological effects of light.

These new circadian biophilic illusions will be dynamic architectural features like a real skylight or window. They will hold our attention for restorative purposes in the subtle and organic way both masterpiece art and nature effortlessly do. In addition, they will be visual and spatial tapestries that mimic the natural oscillations in light intensity and frequency that our neurophysiology recognizes when connected to the outdoors. This technology will enable older structures that are likely to remain occupied for decades to come to reduce their negative impact on the people they serve during the long transition to a new, fully developed biophilic architecture.

### **The Healing Sky: A Universal Experience**

The sky is humanity's most universal experience of nature. As our modern lives have kept us indoors for longer periods, it is only natural that our environments maintain this life-affirming bond. While building designs adapt to this fundamental truth in the years to come, we are left with billions of square feet of inhabitable interior spaces that are not sustainable for long-term human occupancy.

In the meantime, in view of the research, the available technology and the prevailing urban landscape, biophilic illusions can bridge the gap and create restorative environments in a cost-effective way. Open skies belong inside because no matter who we are or where we live, everyone in every culture has experienced lying on their back

looking up into cloud floating across a blue canopy. Humanity's generational experience with natural environments, particularly an open sky, across time and space remains unchanged—we're all nourished by a sense of inner peace, spatial unboundedness, and peak sensory wellness that it evokes—the hallmarks of humankind's biophilic response.

Even our bodies are attuned to the blue of the sky. It is no accident that our eyes and mind register the coolness of blue as distant space. (This is a fundamental principle behind "Impressionism" and bright red stoplights.) As a matter of fact, "blue sky" is well-recognized as a symbol for freedom and infinite possibilities.

Furthermore, the clouds that inhabit the sky occur in patterns and these patterns are actually exquisite visual expressions of the physical laws of nature that govern fluid dynamics. (We can see these same patterns repeated in the sand at the seashore, the bottom of streams or even in the large-scale erosion of patterns on Mars.) In short, the sky is not only beautiful but also a place where the workings of nature are easily accessed by all of us.

And it's from this colossal visual display of nature's forces that we can also reflect on the scale and meaning of man-made architecture and interior design. The psycho-physiological relief the sky provides outdoors can be astutely leveraged indoors. Our innate, genetic-based need to affiliate with nature, our biophilia, is most apparent in our emotional and awe-inspiring spatial relationship with views of nature and the majesty of open skies.

For more information of how Sky Factory's *Open Skies Image Technology* can create restorative environments in your project or building, please contact us at:

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