



Article

Outcomes of Biophilic Design for Schools

William Browning and Jim Determan

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Article Outcomes of Biophilic Design for Schools

William Browning ¹,*¹ and Jim Determan ²,*

- ¹ Terrapin Bright Green, 250 W 57th St., 17 FL, New York, NY 10107, USA
- ² Craig Gaulden Davis Architecture, 2002 Clipper Park Rd., Ste 201, Baltimore, MD 21211, USA
- * Correspondence: bill@terrapinbg.com (W.B.); jdeterman@cgdarch.com (J.D.); Tel.: +1-(646)-460-8400 (W.B.); +1-(410)-237-7115C (J.D.)

Abstract: Biophilia is the theory that humans are innately connected to nature. As a basis for forming built space, biophilic design has been proven to reduce stress, improve cognition and enhance mood it makes us happier. In the last 20 years, research in learning spaces has shown an association between biophilic design and student mood, calmness and improved standardized test scores. In 2019, a group of architects, scientists and educators led an experiment involving 6th-grade Math students at the Green Street Academy, which found that student stress was significantly reduced and learning significantly improved in a classroom enriched with biophilic strategies. The architects applied these strategies to the design of Bethel Hanberry Elementary School, and after a year of occupancy, an independent assessment found positive perceptions of the biophilic design, fewer behavior referrals, better teacher retention, lower absenteeism and improved test scores. In both a controlled research experiment and real-world application, the design of learning space, using biophilic strategies, has a significant impact.

Keywords: biophilia; biophilic design; learning rate; school design; stress reduction

1. Introduction

Biophilia is the innate human connection to nature. The word was coined by the social psychologist Erich Fromm from the Greek words for life and love [1]. The most common definition comes from biologist Edward O. Wilson [2]. However, the history of designing for a connection with nature can be traced back millennia.

Research on how experiences of nature impact people looks at both psychological and physiological responses. It involves many fields of science, including environmental psychology, post-occupancy evaluation and neuroscience. Measurements can include heart rate, blood pressure, stress hormones, recovery time, fMRI imaging, eye tracking, cognitive performance and emotional responses.

The difference between experiencing a biophilic setting versus a non-biophilic setting can be measured through lower blood pressure, heart rate, and stress hormones, like cortisol, as well as through improvements in emotional state and short-term memory [3,4].

Being out in nature and even briefly viewing an image of a natural landscape can lead to experiencing a state called soft fascination. People are aware of their surroundings, but the brain is relaxed. This experience is part of Attention Restoration Theory [5]. When viewing nature, the prefrontal cortex of the brain quiets down and expends less energy; subsequently, when returning to focus on a task, there is improved cognitive capacity [6].

There are 15 different experiences of nature (with supporting scientific evidence of positive health impacts) that can be translated into experiences of the built environment. These experiences can be characterized into a pattern language for biophilic design [7]. These patterns fall into three broad categories: Nature in Space, Natural Analogues, and Nature of Space.



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Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). *Nature in the Space* refers to direct experiences of nature and natural processes in the built environment. These include views of the landscape, the presence of living plants, animals, water, sunlight, breezes, and the changing seasons.

Natural Analogues refers to indirect experiences of nature in the built environment. These include collinear and biomorphic forms, natural materials, and a level of complexity and order through materials or patterns, such as fractals.

Nature of the Space refers to experiences induced by certain three-dimensional characteristics of spaces. These include distant views through a space, spaces that provide refuge and retreat, spaces that compel exploration, spaces that have an element of risk and peril, and spaces that induce awe.

Different patterns support different outcomes. A pattern might support stress reduction, enhance cognitive performance, improve mood, or stimulate prosocial behavior. Some patterns support a single outcome, while others support multiple outcomes (Figure 1). A good approach to biophilic design is to create a narrative about the outcomes that you would like to support for the users of your space, and then determine which biophilic patterns best match those needs [7].

Nature in the Space	Biophilic Pattern	Stress Reduction	Cognitive Performance	Emotion, Mood & Preference
	Visual Connection with Nature	Heart rate, Blood pressure, Parasympathetic system activity	Mental engagement, Attentiveness	Attitude, Neurological rumination, Motivation, Future discounting
	Non-Visual Connection with Nature	Blood pressure, Stress hormones	Cognitive performance, Creativity	Perceived mental health, Tranquility, Pain management
	Non-Rhythmic Sensory Stimuli	Heart rate, Systolic blood pressure, Sympathetic nervous system		Dwell time, Behavioral attention and exploration
	Thermal & Airflow Variability	Comfort	Task performance, Productivity	Preceived temporal and spatial pleasure (alliesthesia)
	Presence of Water	Overall stress, Heart rate, Blood pressure	Cognitive performance, Creativity	Positive emotion, Tranquility
Natural Analogues	Dynamic & Diffuse Light	Circadian system functioning, Visual comfort	Cognitive performance Behavioral performance	Attitude, Overall happiness
	Connection w/ Natural Systems	Overall health		Perception of environment
	Biomorphic Forms & Patterns	Stress recovery	Learning outcomes	View preference
	Material Connection with Nature	Heart rate variability, Comfort, Calming, Blood pressure, Stress hormones	Task performance, Creativity	Material preference
	Complexity & Order	Perceptual and physiological stress responses	Environmental navigation, Learning outcomes, Mental relaxation	View preference
Nature of the Space	Prospect	Overall stress, Perceived safety, Comfort		Visual interest, Fatigue, Irritation, Boredom
	Refuge	Perceived safety		Visual preference
	Mystery			Pleasure response, Visual preference
	Risk/Peril			Pleasure response
	Awe	Stress related symptoms		Pro-social behavior, Attitude, Overall happiness

15 Patterns with Positive Health Outcomes

SOURCE: Browning & Ryan (2020). Nature Inside, A Biophilic Design Guide (Toolkit F)

Figure 1. Terrapin Bright Green, 15 patterns of biophilic design and associated outcomes [7].

2. Biophilia and Schools

Early research indicated that introducing daylight into classrooms improved academic performance [8,9]. Similar outcomes were seen in daylighting office spaces, although, over time, one researcher came to the conclusion that the view out the window might be more influential than just the effect of daylight. This led to an experiment in a daylit call center for a public utility company, in which workstations were realigned 11 degrees off perpendicular to the windows, to bring views to the outside within the peripheral vision of the workers. This resulted in a 6% improvement in call-handling capacity in the call center [10].

Classroom views to nature have been positively correlated to the likelihood of high school graduation and plans to attend college [11]. Students who do not graduate from high school typically earn about USD 10 k less per year than high school graduates and about USD 36 k less than college graduates [12].

The presence of nature in the schoolyard has also been studied. Access to nature, for example, tree cover in the schoolyard, has been shown to positively impact overall cognitive development, particularly students' working memory and attention [13].

Biophilic measures in the classroom have been found to improve student mood and calmness and to increase performance in standardized tests. Increasing student test scores by a quarter of a standard deviation would yield an average increase of 5.2% of discounted GDP above what is anticipated based on current achievement. The resulting increase would more than cover the entire U.S. expenditure on public education—approximately 4% of GDP [14].

An experiment in a girl's high school in London involved adding plantings to one classroom, a photo mural of woodlands in another, and no changes in a control classroom. Students in the classroom with plants demonstrated improved cognitive performance, and the students in the classroom with the photo mural indicated a higher level of emotional wellbeing [15].

3. Hypothesis and Methods

Our hypothesis is that simple low-cost biophilic design interventions could improve academic and other outcomes in schools. This paper summarizes the results of two studies. The first focused on a single classroom at the Green Street Academy in inner-city Baltimore, Maryland. The second study, building on the lessons of the first study, was an entirely new school, Bethel-Hanberry Elementary School, which replaced an existing school in Blythewood, South Carolina.

Our methods for measurement included comparisons of pre- and post-intervention academic outcomes, surveys and interviews of students and faculty. In the Baltimore study, biometric testing of stress recovery characteristics was conducted using heart rate variability (HRV) measurements. Since the Blythewood study involved an entire school, comparisons of absenteeism, behavior and teacher retention were also made.

4. Green Street Academy

The Green Street Academy is a locally funded public charter school in Baltimore, Maryland, in the United States. The school uses a STEAM (Science, Technology, Engineering, Arts, Mathematics) curriculum. The selected location for the school was in a shuttered City of Baltimore public school building in an underserved neighborhood. The 1925-era school was renovated and redesigned by architect Jim Determan of Craig Gaulden Davis Architects. Biophilic additions included indoor koi ponds, green houses and artwork of local ecosystems.

While the classrooms are not designed with specific biophilic elements, many of the classrooms are located on the long, east-facing rear façade and have a view out to grass and distant trees. The glare from the morning sun causes teachers to lower the window blinds, which are then rarely lifted.

Determan, along with partners from Morgan State University, Terrapin Bright Green, and the Salk Institute of Biological Studies, wanted to explore whether the use of low-cost biophilic interior elements would both lower the stress and improve learning outcomes in a classroom [16]. The classroom design interventions were focused on several biophilic design patterns, in particular Visual Connection to Nature, Biomorphic Forms & Patterns, Dynamic & Diffuse Light, and Complexity & Order.

To test Determan's hypothesis, a sixth-grade math classroom was renovated with carpet tiles, window shades, a wallpaper frieze and some waveform ceiling tiles, each expressing biomorphic forms or complex fractal patterns (Figure 2).



Figure 2. Craig Gaulden Davis Architects, Green Street Academy classroom redesign concept, Baltimore, Maryland, 2018–2019. Proposed biophilic classroom incorporating four simple design interventions.

The carpet tiles made by Interface featured a strongly collinear biomorphic pattern called Prairie Grass. The wallpaper frieze around the top of the classroom was jointly designed by artists from DesignTex/Steelcase and was an abstraction of palm leaves with biomorphic curves and collinear lines. These are examples of Biomorphic Forms & Patterns.

Many objects in nature have collinear striations or patterns that are broken into segments to form nested contours like fur, wood grain or grasses in a field. Studies with rhesus monkeys indicated that (within a given image) lines running in the same direction are processed by one set of neurons in the brain, whereas, with lines running in multiple directions, more effort is needed, by multiple sets of neurons, to process the image [17]. The brain will follow curvatures and contours [18] and even connect short segments of lines to discern a longer curving pattern [19]. These pattern conditions occur frequently in nature, and our brains, it could be argued, are predisposed to easily decipher them [20].

The venetian blinds were replaced with automated fabric blinds made by Mechoshade. The blinds had silkscreened patterns of tree branch shadows, which formed a pleasing statistical fractal pattern when the blinds were lowered. Fractals are layered self-repeating mathematical patterns. Exact fractals, which are the result of the same equation replicated at various scales, like embedded fractal gaskets or the trippy Mandelbrot sets, do not occur in nature. However, when those mathematical patterns have variations, their ubiquity in nature becomes quite evident, such as with snowflakes, fern leaves, waves on a beach, flames in a fireplace, the dappled light under trees. These are statistical fractals, so common that when we see these patterns, even in human-designed objects, it is easy for the brain to process the image and measurably lower our stress level [21,22] This effect is called fractal fluency [23]. This is an example of Complexity & Order.

The auto-controlled fabric window shades lifted, once the morning glare was off the windows, to a view of a newly planted outdoor garden. This supported both Dynamic & Diffuse Light and Visual Connection to Nature (Figure 3a).

For comparison, a seventh-grade math classroom along the same hall was chosen as a control space. The only change to that classroom was the addition of carpet tiles without any biophilic references so as to match the acoustic and haptic experiences of the experimental classroom (Figure 3b).

One class in the experimental classroom and another math class held at the same time in the control classroom were used for biometric testing. Heart rate variability (HRV) is a good indicator of the ability to recover from stress (high HRV is generally considered healthy). At the beginning and end of class, three times per week, student heart rate variability levels were measured using a finger-clip HRV monitor synced with a smartphone app. Due to the difficulty in getting permissions to conduct biometric testing with school children, there are only four months of HRV data. Students in the biophilic classroom demonstrated better stress recovery characteristics than students in the control classroom (Figure 4a).



Figure 3. Cont.



Figure 3. (**a**,**b**). Craig Gaulden Davis Architects, Green Street Academy classrooms, Baltimore, Maryland, 2018–2019. Comparative classroom study sites included two Math classrooms, (**a**) the biophilic classroom and (**b**) the control classroom. Blinds are drawn to show a comparative impact to the classroom environment.

During the 2018–2019 school year, the experiment tracked academic performance in a sixth-grade mathematics class. Test scores of current students were compared to those of students in the prior year in the same classroom with the same teacher and same curriculum. Students in the biophilic classroom attained better testing scores than the students in the prior years (Figure 4b).

Previously, the walls were covered with papers displaying formulas and notes, which some teachers will use to signal how much content is being conveyed in their classroom. Salk Institute neuroscientist Thomas Albright argues that covering the walls with so much material can result in an overstimulated environment.

Getting the teacher to agree to limit the amount of material taped onto the walls in the biophilic classroom was a challenge. At first, the teacher felt that would limit the students' retention of lessons, agreeing to put up sheets temporarily and then take them down. Over time, the teacher came to realize that the students calmed down in the room, she felt calmer in the room, and that other teachers would come into the room to take a break.

The view out of the window could have been a significant factor in the outcomes. However, for most of the experiment, there were no leaves on the trees. As seen in the HRV data, in April, when the trees blossomed, there was a spike in the response, which then diminished after the bloom. This is an indication that the biophilic design elements within the room were the significant factor in the outcomes [16].



(a)



Figure 4. (a) Determan, et al. [16], Green Street Academy study results, 2018–2019. Heart rate variability (HRV). (b) Determan, et al. [16], Green Street Academy study results, 2018–2019. Test score differentials.

5. Bethel-Hanberry Elementary School

Design Application

Following the first study, the architects at Craig Gaulden Davis were excited to apply this new knowledge from the Green Street Academy Study to the design of Bethel-Hanberry Elementary School (BHES) in Blythewood, South Carolina. In this study, the entire population of students and teachers moved from an existing school into a new facility. What follows are illustrations of the biophilic applications. Students enter a tall daylit space with wood panels above and biomorphic forms dancing along the walls. Prospect helps students feel safe as they can see through the perforated risers of a blue stair out to a courtyard (Figure 5).



Figure 5. Kris Decker/Firewater Photography, Bethel-Hanberry Elementary School Entrance Lobby.

Students walk through, what appears to be, the dappled light through a tree canopy. The shadow is cast by a ceramic frit pattern on the west-facing glass along the main corridor. This has a calming effect as students walk between classes in the afternoon. (Figure 6).

Long vistas create a feeling of safety, and window seats provide refuge along the main corridor (Figure 7).

Collaborative learning spaces are tall, open, and full of daylight, with views of nature. Transparency from the classroom to the collaboration space helps students feel safe knowing what is happening outside their classroom (Figure 8).

In the library, the grand scale, biomorphic forms and panoramic views of nature produce the 15th biophilic pattern, Awe. (Figure 9) Summer Allen, in *The Science of Awe*, [24] writes "Experiencing awe often puts people in a self-transcendent state where they focus less on themselves and feel more like a part of a larger whole". When it comes to psychological effects, studies have found that awe can "increase feelings of connectedness, increase critical thinking, increase positive mood". "Multiple studies have found evidence that experiencing awe makes people more kind and generous".





Figure 6. Kris Decker/Firewater Photography, Bethel-Hanberry Elementary School, Dynamic and Diffuse Daylight.



Figure 7. Kris Decker/Firewater Photography, Bethel-Hanberry Elementary School, Prospect + Refuge.



Figure 8. Kris Decker/Firewater Photography, Bethel-Hanberry Elementary School, Collaborative Learning Space.



Figure 9. Kris Decker/Firewater Photography, Bethel-Hanberry Elementary School, Awe.

6. Assessment

After the first year of occupancy at BHES, a team from the University of South Carlina Upstate conducted surveys and interviews to assess the impact of the biophilic design elements and used school metrics to assess student behavior and performance [25].

6.1. Perceptions

The percent of survey participants who agree that biophilic design strategies have made a positive contribution to the learning environment is as follows.

Parents 95%

Students 82% Teachers 93% Administrators 100%

6.2. Absenteeism

Out of 20 elementary schools in the district, BHE is tied for having the greatest reduction in chronic absenteeism (missing 10% or more of the school year), reducing from 17.3% (last year in the old school) to 12.3% (this year in the new school). The National Center for Education Statistics reports that the national average of chronic absenteeism is 17% [26], and the SC Department of Education reported an average of 24.73% for the 2021–2022 school year.

6.3. Behavior

The Assistant Principal reports that there are fewer disciplinary problems this year as compared to last year. "There's been a decrease in the overall number of referrals and the intensity of the infractions. I think the sense of calm that's promoted throughout the building makes a difference. And I think it manifests in the behaviors that we do and do not see".

6.4. Teacher Retention

BHES experienced among the highest increases in teacher retention of the 24 elementary schools in the district. Teacher retention increased from 83.7% to 91.5%. Districtwide teacher retention was 81.9%.

6.5. Learning Outcomes

MAP (Measures of Academic Progress) testing measures student growth in Math and Language Arts/Reading and compares student growth from one year to the next. BHES MAP scores in Math indicate that growth exceeded projected growth in every grade. The Language Arts/Reading scores exceeded the projected growth for grades 2–4 and met the projected growth in grade 5.

Principal Holland describes the academic performance improvement the first year in the new school as "fantastic and highly motivating!". It is amazing that we met all and exceeded seven of eight growth projections. This is a great accomplishment, which we celebrate and are energized to continue. This is remarkable in the context of a 2023 NAEP report that scores have declined in every course nationally.

While the designers do not that claim biophilic design strategies are solely responsible for the student success described in this assessment, given the research and survey results, they believe biophilic design made a powerful contribution.

7. Discussion

Biophilic design is sometimes viewed as requiring living interventions like green walls and live animals. Green walls and live plants can both be biophilic strategies. There is evidence that live plants in a classroom can enhance cognitive performance [15]. There is evidence that animals in the classroom can have a positive effect on children [27]. Neither of the studies in this paper used these living interventions. Both relied on passive measures that were part of the space; different outcomes might be possible with other design strategies.

In both studies, academic outcomes improved, and additional benefits were measured. Inevitably, improvements in performance in a changed or new facility are attributed to the Hawthorne Effect, which is typically summarized as changes in the environment signal concern for the users, thereby, lead to gains in performance, and, therefore, the physical environment is less important than how people are managed. While datasets in changed environments will show a spike in performance in the first blush of time, after a few months, the newness wears off. Yearlong datasets overcome that effect [28], and other investigations of productivity have come to different conclusions than the Hawthorne work [29,30]. Additionally, investigation of the original Hawthorne studies indicate that they were deeply flawed and do not support their widely quoted conclusions [31,32].

While the biophilic design interventions in both studies used surfaces with biomorphic forms and statistical fractals and other design strategies, it is unclear which elements were most effective in supporting a biophilic response in the spaces. Research using gaze attention tracking tied with physiological measurements in a virtual office space indicates that this combination of measurement technologies can provide indications of which biophilic design interventions are most effective in a specific space [33]. Future research using gaze attention tracking tied with physiological measurements in real spaces could provide an indication of which interventions are most effective.

8. Conclusions

From research experiments to real-world application, we see the benefits of biophilic design in learning spaces. If minimal design interventions in the classroom can help make students happier, healthier and improve learning, and if they can improve teacher retention, reduce absenteeism and curtail bad behavior, why would we not do this in all schools? Every effort to help improve a young person's capacity to learn and enhance their social-emotional wellness will pay dividends to them as individuals and for us as a society.

Schools at the turn of the 20th century were daylit and naturally ventilated by operable windows. This typically allowed for views of trees, clouds and other outside activity. In the 1960s, the U.S. education system perpetuated the belief that views were 'distractions' and that the attention of children should be focused on activities within the classroom. Henceforth, the construction of windowless or transom-window classrooms became pervasive in practice, particularly among temporary modular structures, many of which are still in use decades later. Bringing access to daylight, views to nature and the use of biophilic elements in the classroom clearly have a measurable benefit for the learning environment [34].

David Orr, an emeritus professor of Environmental Studies at Oberlin College, says that buildings are 'crystalized pedagogy'; they inherently tell us about the belief systems that led to their design [35]. Biophilic design can be leveraged as a philosophy of education and design that helps both support improved academic performance and a greater connectedness between buildings and nature.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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