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Design vocabulary and schemas for biophilic experiences in cold climate schools

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ABSTRACT

This research explores a design approach for biophilic experiences applied to children's learning environments in cold climates. The primary research gaps addressed are the confusion among principles, experiences and architectural characteristics in biophilic design literature; the lack of common terminology for referencing spatial patterns that induce biophilic responses; and limited design methods and generative approaches for designers due to the focus on empirical validation and broad theoretical generalisations. A visual biophilic design vocabulary, including spatial enclosure and adjacencies, is developed for experiences of abiotic and biotic nature. A framework is proposed for biophilic design schemas. In the context of renovating primary schools in Quebec, Canada, 38 schemas for cold climates are developed within this framework. Using these tools in an architectural design studio course showed that this common graphic language integrates experiences of nature in design processes, enabling researchers and architects to describe biophilic spaces with shared terms and logic.

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Architectural design; design tools; biophilia; learning environments; cold climate; nature experiences

Introduction

The generative capability of architectural vocabularies and patterns plays a key role in the design process. The organisation of textual and visual elements can enhance idea generation and creativity, facilitate collaboration and structure thinking (Alexander, Ishikawa, and Silverstein 1977; Gstach and Kirschbaum 2016). Patterns further help designers to communicate rich and complete architectural views that highlight the valuable aspects of the inhabited spaces (LaVine 1988). This research explores an architectural vocabulary and design schemas that focus on biophilic experiences.

Biophilia, meaning love of life, refers to people's innate biological connection with nature. In the conception and production of biophilic buildings and places, published literature encourages the integration of multiple natural elements and processes in architecture (Browning, Ryan, and Clancy 2014; Kellert, Heerwagen, and Mador 2008). In children's environments, the successful design of biophilic spaces has shown the possibility to foster experiences of nature that form an integral and beneficial part of children's lives (Kahn and Kellert 2002; Louv 2005). Despite this knowledge about the importance of designing to relate architecture and nature, activities that foster biophilic design thinking (such as described in Browning and Ryan 2020) offer limited practical guidance on the spatial configurations that foster positive experiences of nature. Moreover, extreme weather and climate conditions, such as the prolonged presence of snow, reduced sunlight intensity and duration and cold outdoor temperatures represent a gap in the current biophilic design literature (Watchman, Demers, and Potvin 2020). While biophilic design has been less discussed in a winter context than during foliated periods and temperate situations, snow offers the potential for powerful sensory experiences and a rich understanding of natural processes.

The present research addresses the following questions. What forms and spatial configurations engender biophilic experiences? What nature exists inside and outside buildings? Which biophilic experiences do spaces engender? Which spatial configurations apply at the scale of the site, building and room? How can seasonality and climate inform spatial configurations and human experiences? This reflection contributes to the research project Schola.ca (2020) to help architects renovate learning environments in Quebec as most primary schools built before 1970 require renovations to ensure quality learning environments (Després et al. 2017).

Our reflections on these questions led to the development of two design tools. Firstly, we explored a biophilic design vocabulary that describes spatial enclosure and adjacencies as well as abiotic and biotic nature in architecture that may engender biophilic experiences. Secondly, we developed 38 biophilic design schemas for cold climate schools as part of this new framework. *Schema* refers to a theory or a plan depicted as a model or an outline, thus offering a general type or form. We define a biophilic design schema as the organisation of form and space in relation to abiotic nature (natural forces, such as sun, wind and snow) and biotic nature (living organisms, such as fauna and flora) that generates possibilities for positive human experiences of nature. Using these tools in school renovation and addition projects during an architectural design studio course showed their potential to facilitate communication and collaboration between researchers and designers.

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Background

Biophilic design helps people remain aware that the interconnectedness of nature and human life is grounded in complex reciprocal relationships. As Kellert (2015) remarks, 'simply inserting an object of nature into a human built environment, if unrelated or at variance with other more dominant characteristics of the setting, exerts little positive impact on the health and performance of the people who occupy these spaces'. Heerwagen and Gregory (2008, 228) consider biophilia 'as key to creating places imbued with positive emotional experiences – enjoyment, pleasure, interest, fascination and wonder – that are the precursors of human attachment to and caring for place'. Nature connectedness diverges from simple nature exposure in that it includes the emotional affinity people have in nature or towards nature (Mayer and McPherson Frantz 2004). Similarly, Clayton et al. (2017) argue that experiences of nature must be understood as a diverse and complex process including social and cultural contexts. Thus decades after Wilson (1984) theorised biophilia as people's innate affiliation with life and lifelike processes, the design community continues to explore the application of biophilic thinking (Beatley 2016; Browning, Ryan, and Clancy 2014; Kaplan, Kaplan, and Ryan 1998; Kellert, Heerwagen, and Mador 2008). It is even suggested that 'Biophilic, in its emphasis on both the natural world and living things (bio) and the connections with and love of nature (philia), captures more squarely what cities and city planning and design need today' (Beatley 2016, xvi).

For decades, researchers and designers have been working to define aspects of the built environment that enhance the affiliative experience of nature. However, few principles in the biophilic design literature provide spatial guidance to designers. For instance, including plants in architecture and constructed landscapes is a recurring principle (Kellert 2018). Yet recommendations concerning their spatial layout, diversity and quantity are omitted, contradictory or incomplete, even in experimental studies investigating their effects on people (Bringslimark, Hartig, and Patil 2009). When architectural variables are included, studies often describe built and natural elements in various terms, rendering the detailed comparison of study results too complex or imprecise to be useful for designers. For example, Kellert's (2018) description of views focuses on the elements in the field of view, offering architects no guidance as to window characteristics of a space. To create a visual connection with outdoor nature, Browning, Ryan, and Clancy (2014, 25) recommend to 'Design spatial layouts and furnishings to uphold desired view lines and avoid impeding the visual access when in a seated position.' Yet Bloomer (2008) questions the potential engagement with outdoor nature when viewed through large expanses of glass and discusses the importance of the ornamented view window to enrich biophilic experiences. Thus, there is a need for a common way of describing spaces that foster biophilic experiences to better compare future experimental studies.

Authors of biophilic design literature group their strategies, patterns, or principles in categories with no clear definition or presentation of how these categories were determined. They omit to describe how the elements within a category relate to each other and how they can be combined with elements from other categories. Kellert (2008) regrouped 72 *biophilic design attributes* in six categories (called *biophilic design elements*): environmental features, natural shapes and forms, natural patterns and processes, light and space, place-based relationships and evolved human-nature relationships. In later work (Kellert and Calabrese 2015), only 24 attributes of biophilic design are identified and organised into three experiences: direct experience of nature, indirect experience of nature and experience of space and place. Browning and Ryan (2020) propose 15 patterns of biophilic design based on the 14 patterns in previous work (Browning, Ryan, and Clancy 2014), which they group in three categories: nature in the space, natural analogues and nature of the space. The absence of a 'map' or of a 'weighting' of biophilic design strategies suggests that architects are on their own to select biophilic strategies with little guidance on what would be most effective or how strategies might combine to create larger significant patterns, either of 'bio' (such as eco-functional landscapes) or 'philia' (such as developing a lifelong connection to nature). A clear organisation of the knowledge would highlight the interconnectedness of the biophilic design strategies.

Despite the lack of organisation of design elements to foster experiences of nature, architectural patterns have been explored with other aims. Design patterns are 'the way in which specific architectural form and idea is generalised so that it may be communicated to and explored by other architects' (LaVine 1988). Despite being criticised and misunderstood (Dovey 1990; Salingaros 2000), design patterns are a powerful tool to understand and control complex processes. Alexander, Ishikawa, and Silverstein (1977) discuss the relationships between form and events, primarily focused on social relationships, but also on natural events. Mazria (1979) uses an expanded format of Alexander's patterns to consider interactions among climate, site, building materials and sun. Thiis-Evensen (1989) focuses on the phenomenological experiences and attendant meanings associated with primary archetypal forms and elements. Kaplan, Kaplan, and Ryan (1998) consider the physical aspects of natural settings and human perceptions. At the core of DeKay and Brown's (2014) work is the relationship between form and energy use based on environmental forces. DeKay and Brager (forthcoming) consider the subjective experiences of nature and natural forces within and around buildings as engendered by spatial patterns and associated distributions of environmental conditions. With human experience as the starting point, many of their schemas also intersect with building performance, social rituals and cultural narratives about sustainable design and nature itself. To begin addressing the current gaps in biophilic design, the authors propose, given the knowledge available in design patterns, biophilic design schemas that focus on the relationship among human experience, site and environmental forces and form and space, particularly in cold climate schools.

Learning environments are particularly interesting in terms of biophilic architecture. Children spend over a third of their day at school and daily opportunities to experience nature have been shown to positively impact their well-being (Browning and Ryan 2020; Kahn and Kellert 2002). Given the numerous reviews and empirical studies examining the relationships between nature and well-being in children's environments (such as Chawla 2015; Watchman, Demers, and Potvin 2020), this paper explores design methods and generative approaches to

describe and organise forms and spatial configurations that may foster experiences of nature.

Methods

The research and development framework examining the forms and spatial configurations that engender biophilic experiences included three concurrent steps:

- An exploration of a biophilic design vocabulary to provide a common way of describing architectural elements and spaces
- The development of an ensemble of biophilic design schemas, applicable in cold climate school architecture
- An architectural design studio course using the biophilic design vocabulary and schemas in simulated school renovation and addition projects.

The understanding gained from each activity in terms of biophilic experiences and the spatial configurations that may generate them was used to refine and further inform the other activities.

Exploring a vocabulary

We developed a vocabulary of biophilic design to clarify and facilitate the communication of design intentions during the design process and to better compare future experimental studies. Design activities generally use visual modes of representation, such as drawings and models. As Schön (1988) remarks, designers often have difficulty putting their knowledge and understandings into words. Both textual and visual forms of communication were combined in the biophilic design vocabulary since 'many characteristics of design cannot easily be expressed in any absolute terms without reference to examples and variations from them' (Eckert and Stacey 2000). The aim was not to develop all the spatial configurations that may foster experiences of nature. Instead, the actual experience of nature could emerge with the creative design process (Demers and Potvin 2017). Thus, this research aimed to provide an ensemble of matrices, strategies and schemas that architects can use to generate nature experiences while considering their project's variables.

While notions of spatial enclosure and adjacency are often used to describe architecture, this research expands on these themes to include how they create a connection or separation between people and abiotic or biotic nature. Norberg-Schulz (1965, 113) introduces the concepts of *connector* (direct physical connection), *filter* (controlled indirect connection), *switch* (regulating connector) and *barrier* (separating element) to analyse the possible conditions of physical control for environmental forces (e.g. cold, noise, humidity or light) entering buildings. To complement these design strategies, Grondzik and Kwok (2015, 194) propose a *transformer* to 'convert an environmental force (such as solar radiation) directly into a different and desirable energy form (such as electricity).' Meanwhile, Unwin (2007) differentiates seven types of control doors can offer: *switch, filter, guarding, testing, lock, valve* and *trap*. These strategies highlight the presence of people as a means of distinguishing relations between indoor and outdoor spaces.

The application of the vocabulary components was assessed by representing and analysing the opportunities for biophilic experiences in a series of school renovation and addition projects with semi-enclosed spaces in a cold climate. In its development, the biophilic design vocabulary embraced the notion that 'a design vocabulary may undergo important aesthetic and conceptual transformation and growth through the activities of design practitioners and other participants immersed in the vocabulary' (Liddament 1996, 303). Thus, it offers a framework that could facilitate the collaboration among different researchers.

Developing design schemas

We generated a system of biophilic design schemas to enhance formal and spatial guidance while clearly organising the biophilic design knowledge. Drawing on the organisation of design elements in the theoretical models discussed above (Alexander, Ishikawa, and Silverstein 1977; Mazria 1979; Thiis-Evensen 1989; Kaplan, Kaplan, and Ryan 1998; DeKay and Brown 2014; DeKay and Brager forthcoming), this research builds on the knowledge of architectural patterns by embracing a reflection on biotic nature, winter environments, and school settings. The structure of the biophilic design schemas addresses the six lower levels of scale and complexity used by DeKay and Brown (2014): from materials (level 1) to whole buildings / sites (level 6). In this system of increasing complexity, less complex design schemas help build larger, more complex schemas. A higher-level design schema is both dependent on and helps to organise multiple lower-level schemas.

This research presents a bias towards the cold-humid climate typical in Quebec, Canada, to better understand the possible influences of seasonality and cold climates on people's experience of nature. Advocating for architectural forms that directly express climatic realities in winter cities, Pressman (1995, 7) writes that 'this is needed more than anything else at the present time, since an idealised imagery from warmer places has created a dreamlike disconnection from the realities of winter.'

Application in a design studio course

The architectural studio offers an ideal opportunity to investigate biophilic design schemas as generators of forms and spatial configurations. Seven teams of two fourth-year undergraduate architecture students explored biophilic design in a school renovation and addition project at seven different locations in Quebec, Canada. The five-year Bachelor of Architecture programme at the University of Tennessee, Knoxville includes an Integration Design Studio and a corresponding applied workshop/seminar, which combines principles of sustainable design during an entire semester. Students were introduced to biophilic design by reading *14 Patterns of Biophilic Design* (Browning, Ryan, and Clancy 2014). During the semester, they received a working list of 20 biophilic design schemas, each with a one-sentence summary. Later in the semester, a different pair of schemas developed in this research was given to each of the seven teams for further exploration in their respective studio projects. Each team was tasked with improving biophilic experiences in a primary school in Quebec while adding six classrooms

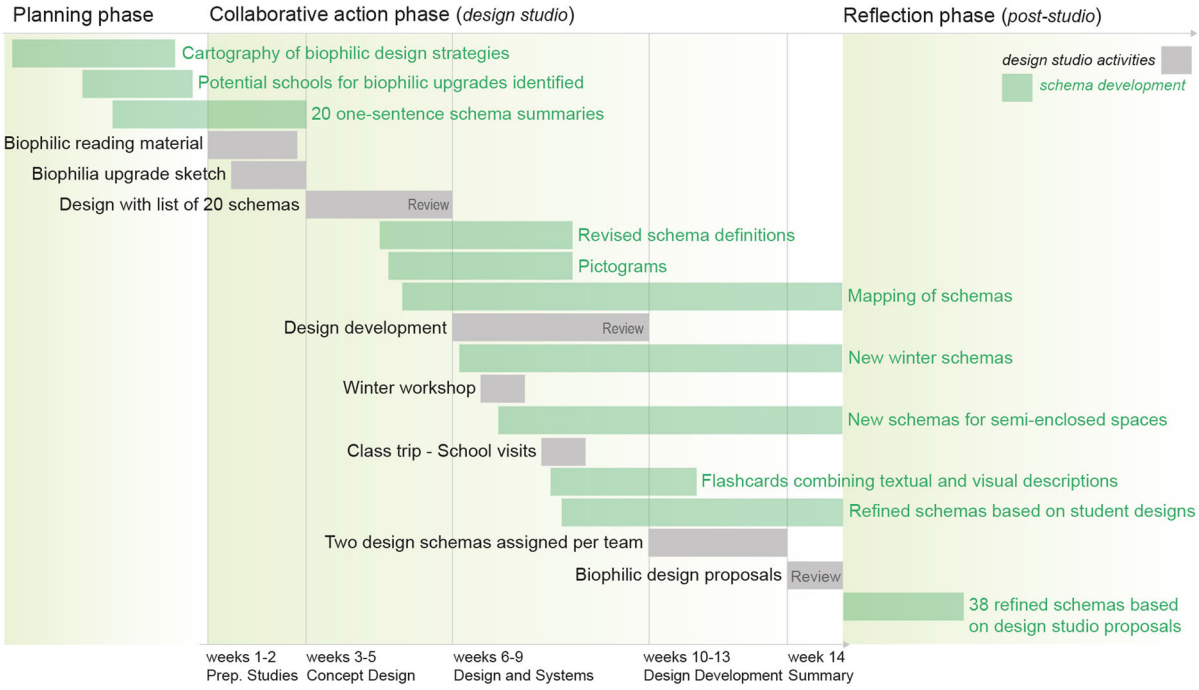

Figure 1. Design studio course activities in relation to the development of the biophilic design schemas.

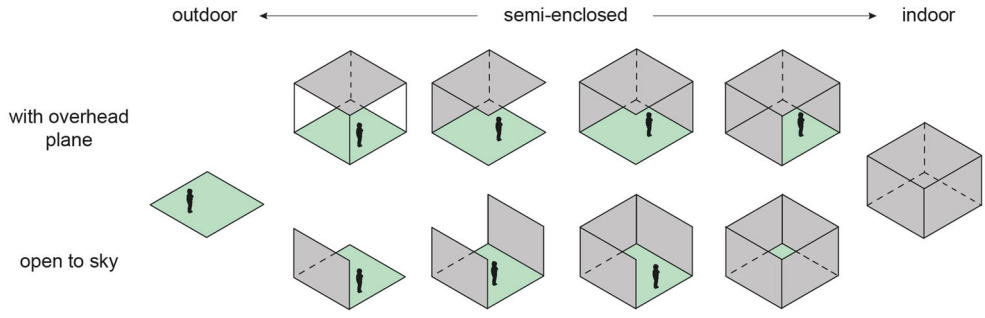

Figure 2. Degrees of spatial enclosure: vertical and horizontal interfaces.

and two specialised spaces (music, art, library or cafeteria) based on the school's needs. Figure 1 illustrates the alignment of the development of the biophilic design schemas and the activities in the design studio course. Employing the biophilic design schemas in simulated school renovation and addition projects for real school buildings enabled the ideas behind the generalisable schemas to become manifest and represented in a series of projects.

Design vocabulary results

The proposed biophilic design vocabulary communicates physical/spatial order and its link to potential occupant experiences. The vocabulary focuses on four themes: spatial enclosure, spatial adjacency, abiotic nature and biotic nature.

Spatial enclosure

Spatial enclosure can foster or hinder the dialogue that occurs among indoor and outdoor spaces. The development of a vocabulary for biophilic architecture aims to go beyond a simplistic inside-outside spatial dichotomy. Rather than focusing on elements of the building envelope that connect or separate indoor and outdoor spaces, such as windows, doors and skylights, the authors offer a new perspective on the types of connections that could foster biophilic experiences by analysing spaces that are neither fully indoors nor outdoors. This 'in-between' space-type offers multiple formal expressions, such as arcades, balconies, porches, sunspaces and courtyards. Multiple terms also exist to describe the spaces that share characteristics of indoor and outdoor spaces: in-between, transitional, interstitial, semi-enclosed, etc. Given that the terms 'in-between' and 'transitional' evoke spatial adjacencies between indoor and outdoor spaces, we selected the term 'semi-enclosed'. To focus on the biophilic experiences that spatial enclosure may generate, we abstract space types by representing the number and placement of their vertical and horizontal components (Figure 2). Their organisation along a spectrum of outdoor, semi-enclosed and indoor space types also distinguishes spaces with overhead planes from those that open to the sky.

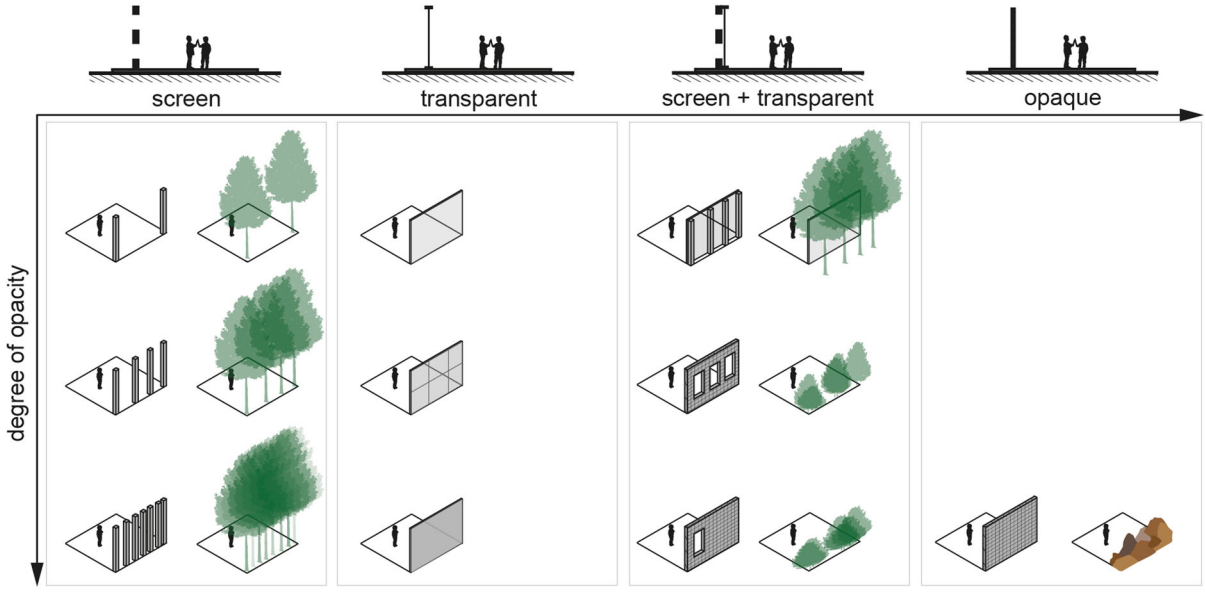

Figure 3. Representation of vertical built or natural components organised by degree of opacity.

The physical interface that separates or connects indoor, semi-enclosed and outdoor spaces is important for biophilic experiences because even the presence of glass reduces the sensory engagement with elements in the sensory field (Bloomer 2008). In the biophilic design vocabulary, we abstracted the variety of building envelope configurations and organised them by increasing degrees of opacity, from screens, to transparent surfaces, to opaque surfaces (Figure 3). Designers can differentiate these vertical and horizontal components with built elements, such as columns, transparent or translucent glazing and brick walls, or with biotic elements, such as trees, hedges and vines.

Adjacency

An experience of weather conditions and living organisms is situated in a space. In describing and analysing biophilic architecture, the context of the experience is defined by the ways in which spaces create a sense of enclosure (greater feeling of interiority) or exposure (more connection with outside). In the vocabulary, we consider the horizontal and vertical adjacencies of indoor, semi-enclosed and outdoor spaces. Figure 4 shows three *horizontal* (lateral) combinations of these space types. These formal tactics of spatial configuration may engender different experiences based on their context and adjacencies with other spaces. *Alignment* juxtaposes a repetition of the same sequence. This alignment of identical space types creates a continuity throughout the ensemble. *Interposition* shares certain similarities with an alignment, however one of the sequences is slid laterally. This offers a higher diversity of semi-enclosed spaces, now partially enclosed laterally. *Containment* radially repeats a sequence, creating identical transitions from the centre to the periphery. This renders the central space distinct from those surrounding it, while confining it to a restricted location. The relationship of a space to the surface of the earth also modifies the experiential possibilities. Spaces with the same spatial enclosure can give rise to various experiences depending on their height above ground, their immediate relation to the ground or their depth below ground (Figure 5). Thus, the adjacency of a space to the ground can generate different experiences of the sky, horizon and earth.

Abiotic and biotic nature

The nature of building envelope components and, in some cases, their operation, can be understood as strategies for regulating the degree of connection or separation from natural forces and living organisms. The strategic regulation takes the form of six types: *connect*, *filter*, *block*, *convey*, *store* and *transform*. Complementing previously mentioned types (Grondzik and Kwok 2015; Norberg-Schulz 1965; Unwin 2007), we consider *convey* as a design strategy that moves or carries a natural element or organism to another location. The *store* strategy keeps a natural element for later use. We apply these strategies to a selection of natural forces: sun, light, water (both rain and snow), wind and air (including characteristics of sound, smell, temperature and humidity). A matrix summarises the design strategies regulating natural forces and living organisms (Figure 6). This matrix allows one to consider visual, thermal, auditory and olfactory experiences of abiotic and biotic nature, rather than discussing nature solely in terms of view.

The concept of *switch* offers a unique opportunity to modulate different design strategies in time (Figure 7). We propose three types of switches: *fixed* (e.g. exterior shading devices that connect, filter or block based on sun movements), *operable* (e.g. windows, doors, movable shading) and *self-transformable* (e.g. deciduous vegetation, phase-changing materials). While mechanical switches often exist in buildings, the biophilic design vocabulary elucidates spatial configurations that may affect experiences of nature.

Although one cannot diagram nor guarantee the exact experience of space, one can set the conditions for potential biophilic experiences to arise. The combination of natural forces (Figure 6) and different types of horizontal and vertical components

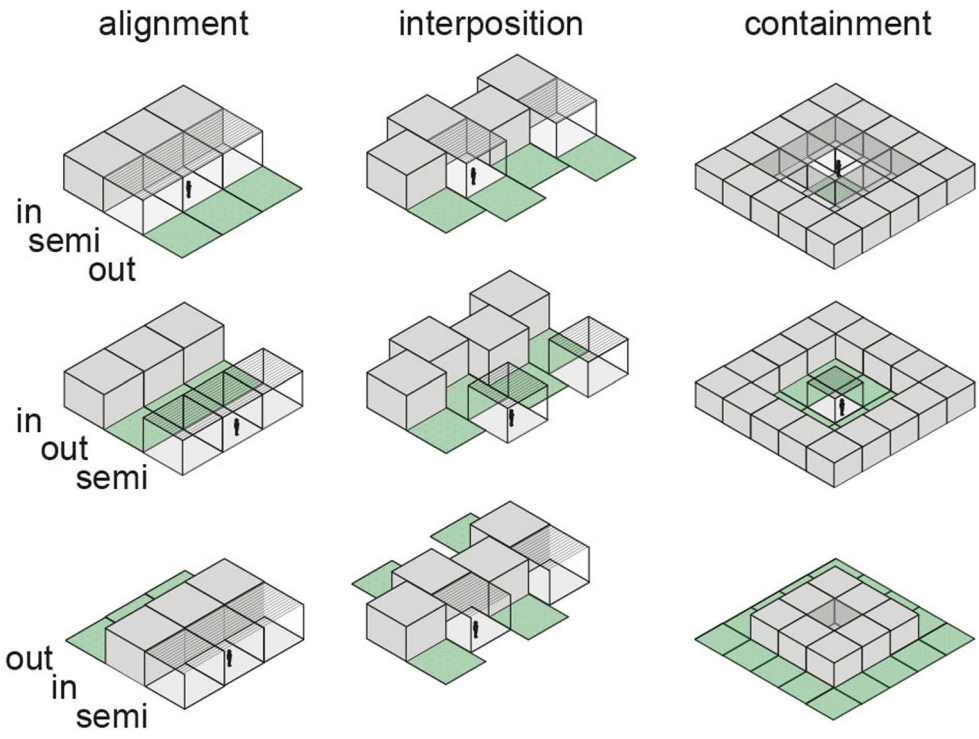

Figure 4. Possible spatial adjacencies including indoor, semi-enclosed and outdoor spaces.

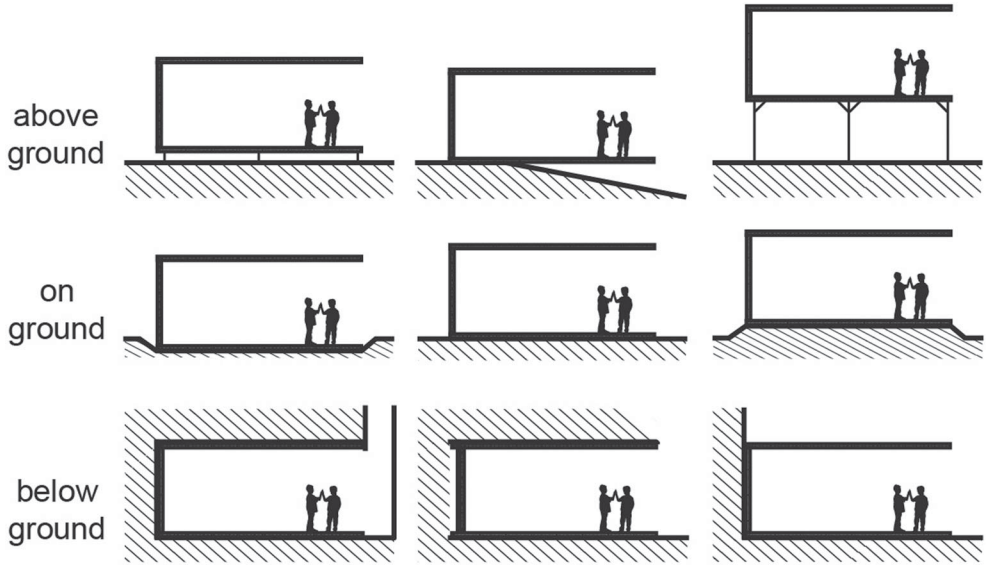

Figure 5. Possible adjacencies to the ground for rooms with the same spatial enclosure.

(Figure 3) shows how each component renders manifest the design strategies. Figure 8 illustrates the modulation of a selection of natural forces (sun, light, rain, snow, wind and air) for occupants in three abstracted scenarios: in an exposed setting, under a horizontal enclosure and adjacent to a vertical enclosure. We further detail the horizontal and vertical enclosure scenarios to represent the distinctness of a screen, a transparent or an opaque component.

The characteristics of biotic nature change seasonally, particularly in a mixed climate context. The colours, growth and density of foliage make visible the cyclic processes of nature. They attract animal activities and offer bioclimatic opportunities to seasonally shade and cool built environments. During winter, green vegetation, such as evergreens, may only punctuate snow-covered landscapes. Differentiating *green* and *white* landscapes expands the range of experiential possibilities linked with biotic nature (Figure 9). It further accentuates how the presence of water, in all its phase states, transforms the appearance of vegetation. While incomplete, this seasonal mapping approach highlights the importance of adapting the biophilic design process to its local seasonal environment.

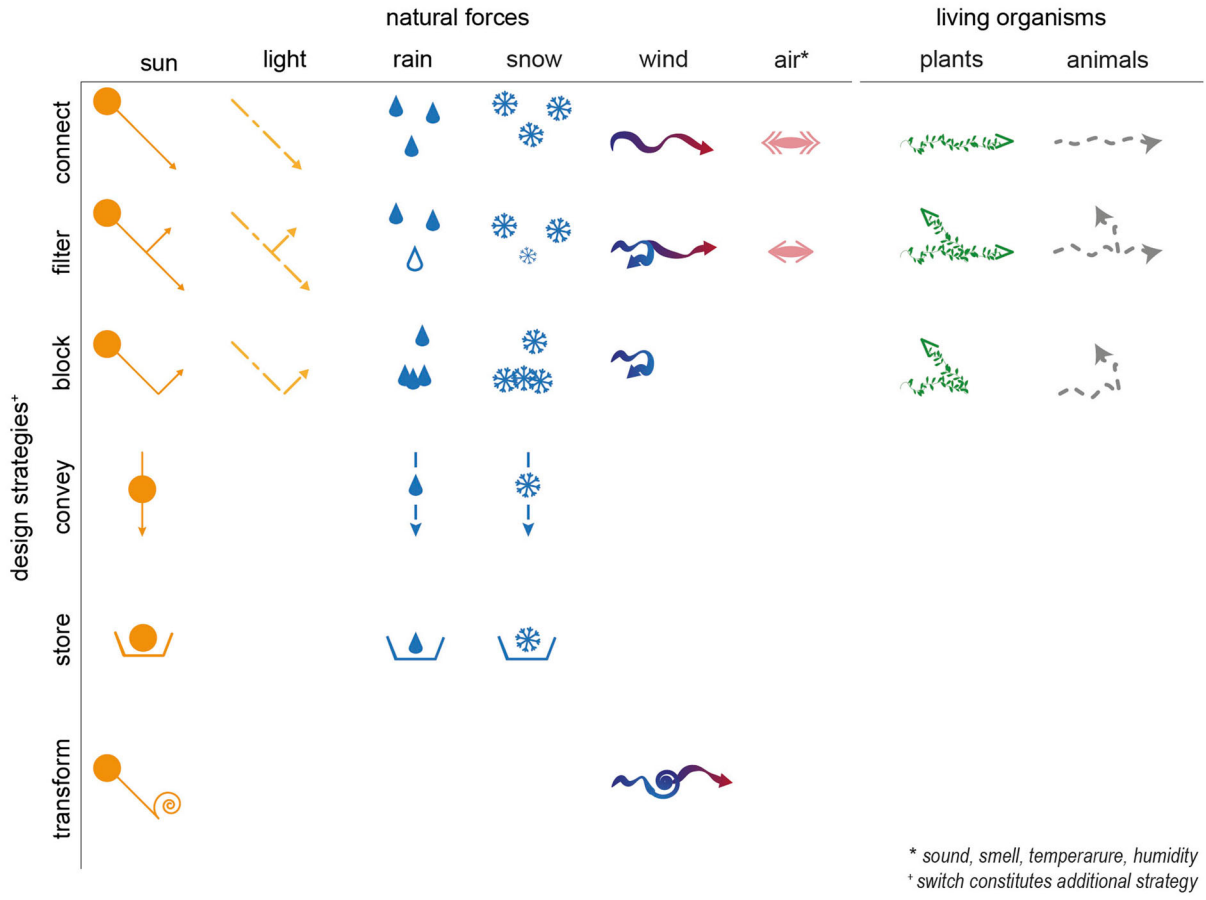

Figure 6. Design strategies for regulating natural forces and living organisms.

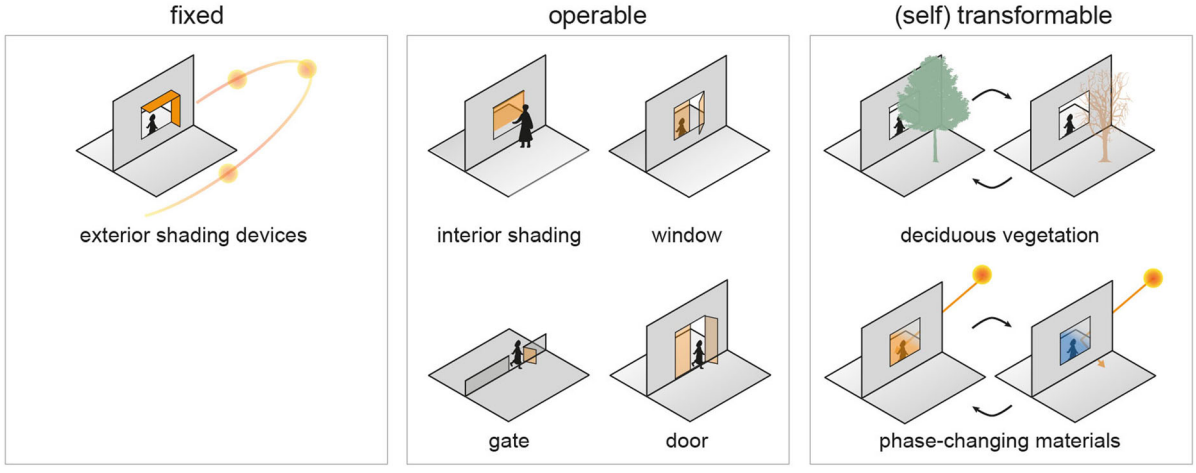

Figure 7. Types of built and biotic switches.

Applications of the biophilic design vocabulary

The application of the vocabulary components was examined by representing and analysing the opportunities for biophilic experiences in a series of school renovation projects with semi-enclosed spaces. The four main themes that form the biophilic design vocabulary (spatial enclosure, spatial adjacency, abiotic nature and biotic nature) enable the analysis of design precedents and new proposals for configurations of conditions and space that encourage experiences of nature. Each individual theme may inform architects about biophilic opportunities and challenges; collectively, they can be summarised in a single drawing. The three examples included in Figure 10 showcase some spatial configurations that are intended to engender occupant biophilic experiences in school settings in Quebec.

We deem the four themes of the vocabulary sufficient to enable the development of an affiliation with nature by means of exploring complementary layers of spatial configuration that mediate nature and therefore contribute to biophilic

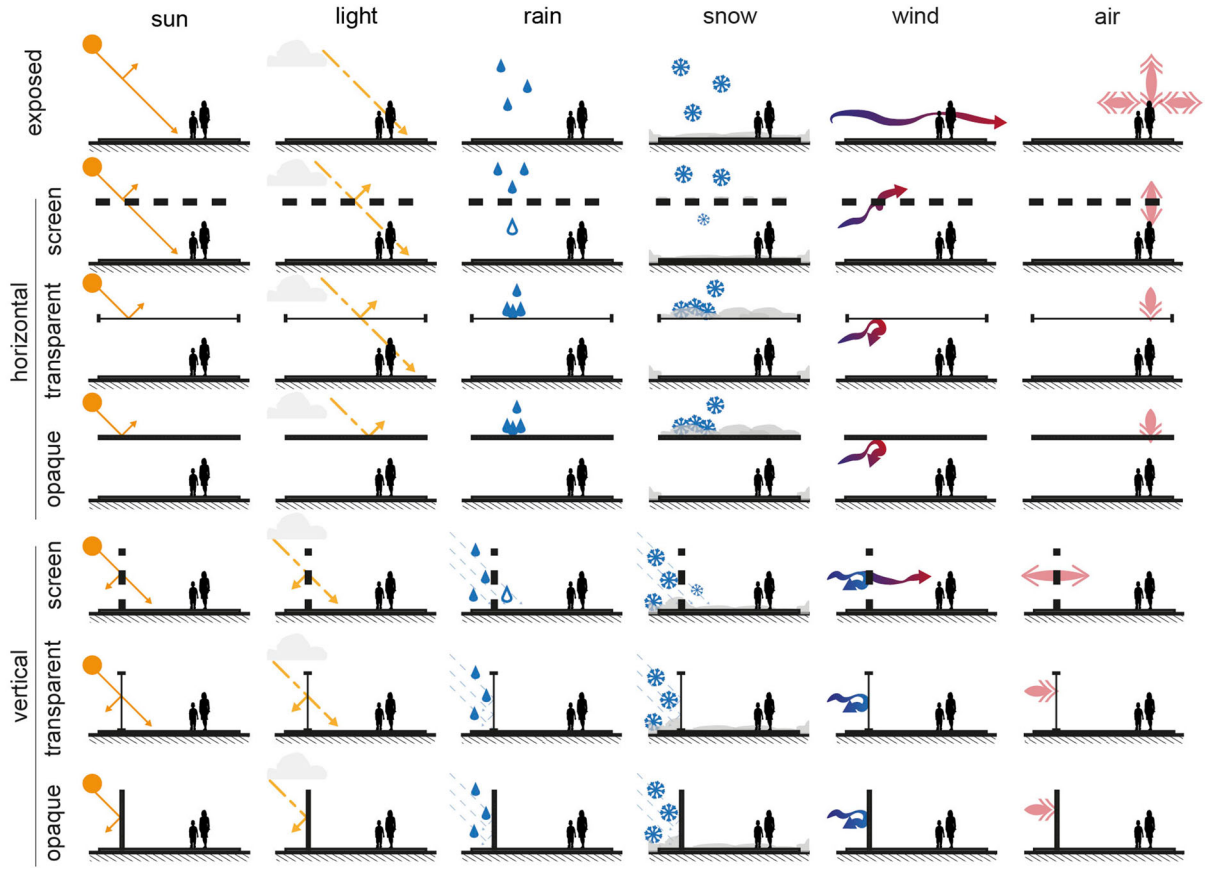

Figure 8. Modulation of natural forces by horizontal or vertical components, the catalytic conditions for experience.

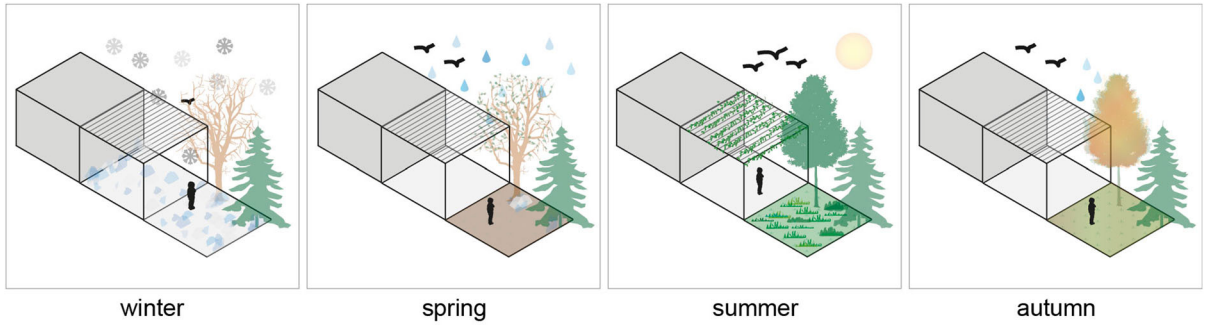

Figure 9. Experiential possibilities of seasonally changing biotic and abiotic nature.

experiences. The authors acknowledge that further themes could be explored to develop a more detailed language of biophilic architecture. For instance, the human alliance with biotic nature to provide for human purpose, such as growing food, providing shade and cleaning wastewater could be translated to architectural design strategies. The vocabulary aimed not to develop all the spatial configurations that may foster experiences of nature, but to provide an ensemble of matrices that can be used to generate and describe them. Thus, the biophilic design vocabulary offers a framework to facilitate the collaboration of multiple practitioners and researchers.

Biophilic design schemas results

To enhance formal and spatial guidance while clearly organising biophilic design knowledge, we generated a system of biophilic design schemas. These schemas organise forms and spaces with abiotic and biotic nature to generate experiences of nature. Three levels of detail exist for each schema: a concise pictogram in the schema map, a flashcard and an extended two-page format.

Pictograms in the schema map

Drawing on pattern thinking to communicate and organise the biophilic design literature, the structure proposed for the biophilic design schemas relies on a spectrum of building scales (Figure 11, rows) and on a spectrum of insideness and outsideness (Figure 11, columns). The scalar continuity indicates how schemas are related to each other across a range of scales and at a same scale while also organising schemas that typically inform indoor, semi-enclosed and outdoor spaces. There are 38 new

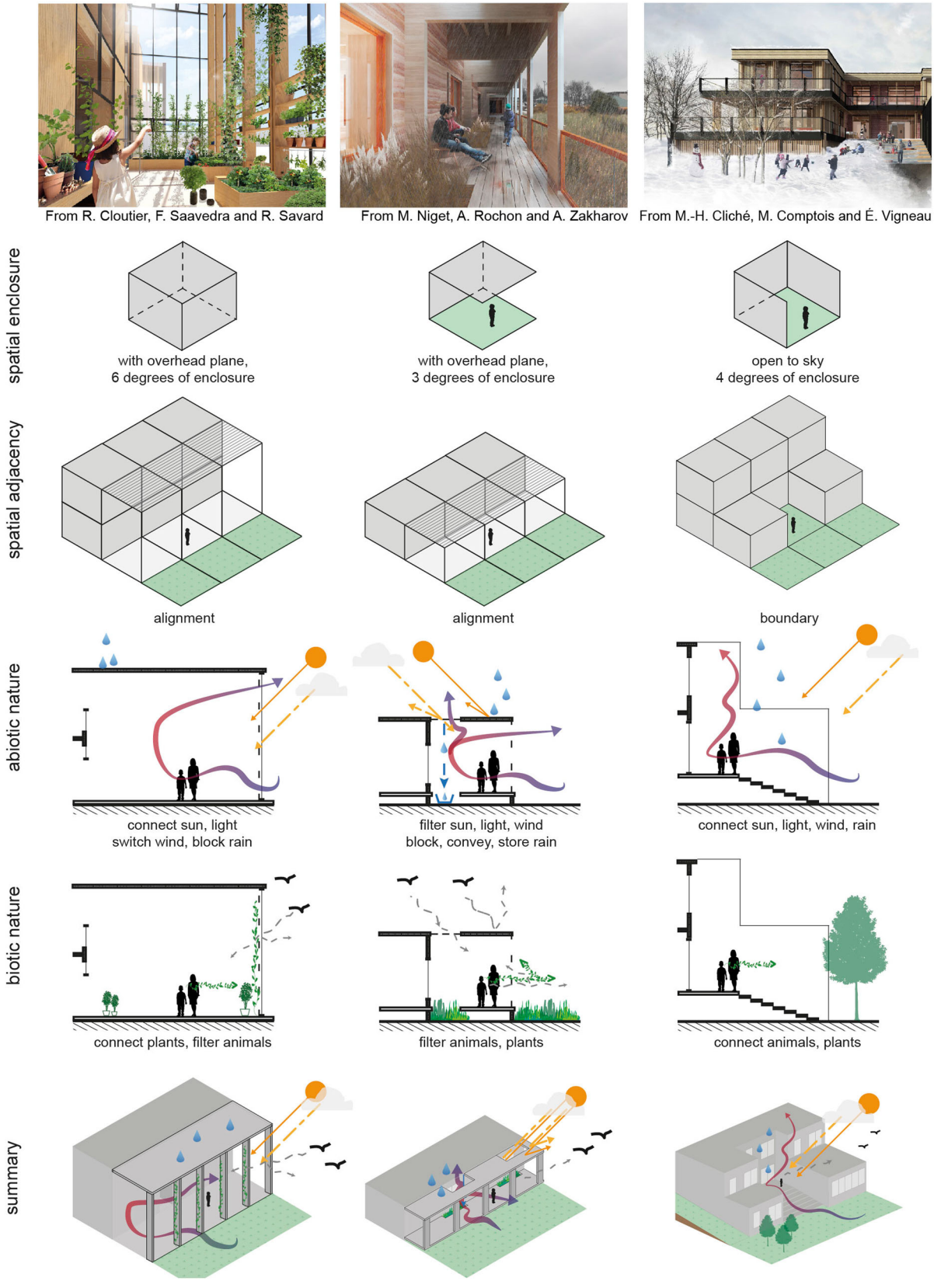

Figure 10. Biophilic design vocabulary employed for project analysis.

schema ideas shown in the schema map. The biophilic-oriented schemas were developed by reflecting on situations that could apply to children in school settings and offer winter experiences of nature. These complement the schemas being developed by DeKay and Brager (forthcoming), some of which are included in Figure 11.

Each image in the schema map represents a different design schema architects can employ. In principle, at least two

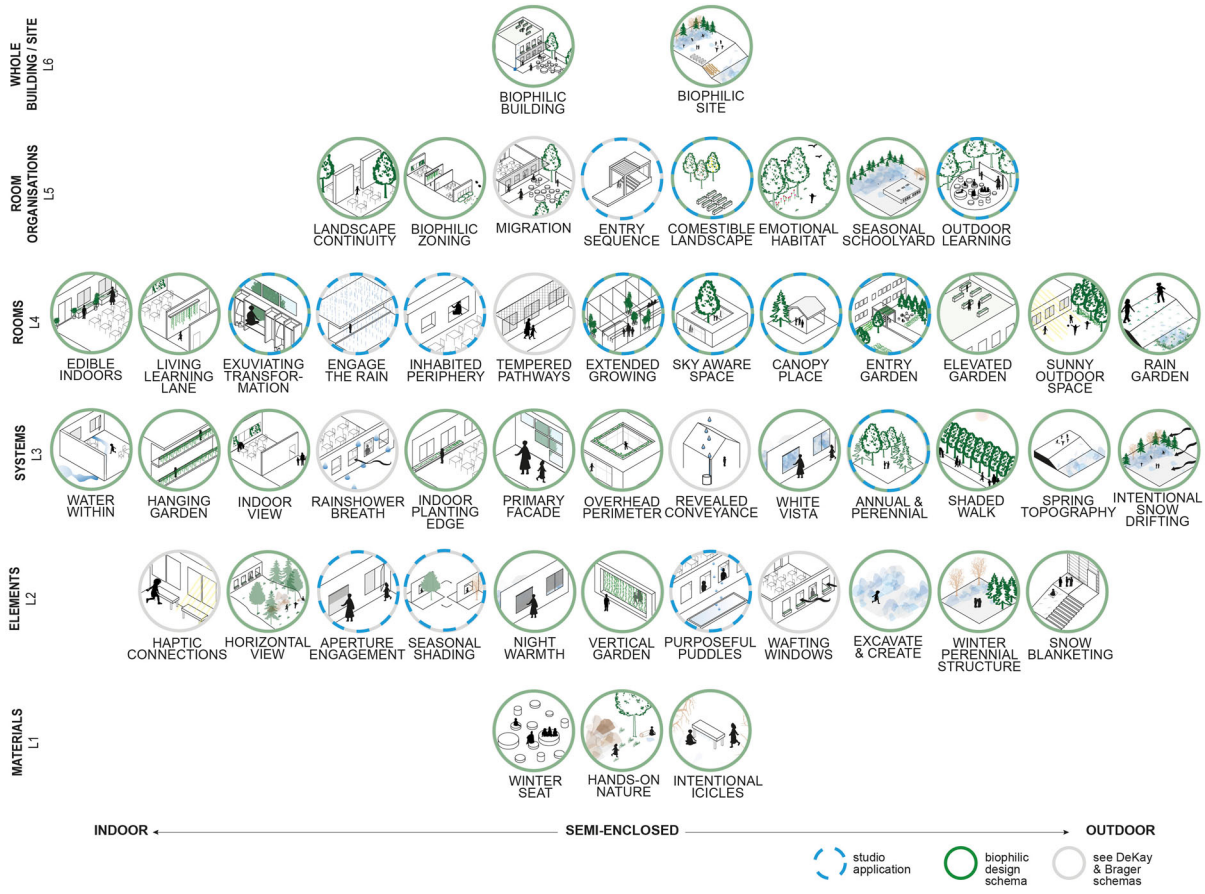

Figure 11. Biophilic schema map for cold climate schools.

lower-level schemas compose each schema above it in scale and complexity, yet a schema does not have to use all the lower-level schemas. An excerpt of the system is presented in Figure 12 for CANOPY PLACE and its related schemas of higher and lower complexity. In this example, the schemas OVERHEAD PERIMETER and WHITE VISTA at the *systems* scale compose the CANOPY PLACE schema at the *rooms* scale. The question mark indicated in certain bubbles acknowledges the importance of continued research and would benefit from contributions from other fields of inquiry to complete other design scales. Hence, extended research to map and connect all the biophilic design schemas presented in Figure 11 could generate additional schemas while further communicating their interrelationships.

Schema flash cards

Each schema is described with a brief, one-sentence summary. It identifies typical emotions and experiences that could arise, the abiotic and biotic nature present and the general spatial organisation. Table 1 organises by level of complexity one-sentence experiential summaries for 38 biophilic design schemas. A pictogram accompanies each sentence to combine both written and graphic communication of the spatial configuration. Thus, in their most concise form, the schemas become like flash cards, as illustrated by the eight examples in Figure 13 which combine the pictogram used in the biophilic schema map (Figure 11) and the one-sentence summary (Table 1). This enables the schemas to become tangible, shared resources during the design process.

The experience of nature anticipated for each schema is further detailed in a descriptive paragraph. It focuses on what the spaces feel, look, smell and sound like based on sensing the abiotic and biotic nature. Figure 14 offers three examples of experiential summaries with illustrations evoking the experience of the schema. Design proposals from a studio course taught by some of the authors at Université Laval, Canada, are used to represent inhabited school settings. Neither too complex nor too abstract, the examples aim to be understandable without a detailed explanation.

Extended two-page schema

The strategy to present the content of the biophilic design schemas rests on the idea of helping designers (1) understand the essence of the schemas, (2) diagnose the biophilic experiences in existing settings and (3) design new settings that foster an experience of nature. As developed in this work, the detailed description of a schema that fulfils these three aims is summarised within two pages. Figure 15 illustrates the anatomy of a biophilic design schema, which is composed of the biophilic design vocabulary and previously described figures.

The first portion of the schema is descriptive to help architects understand the biophilic design intention. It includes three

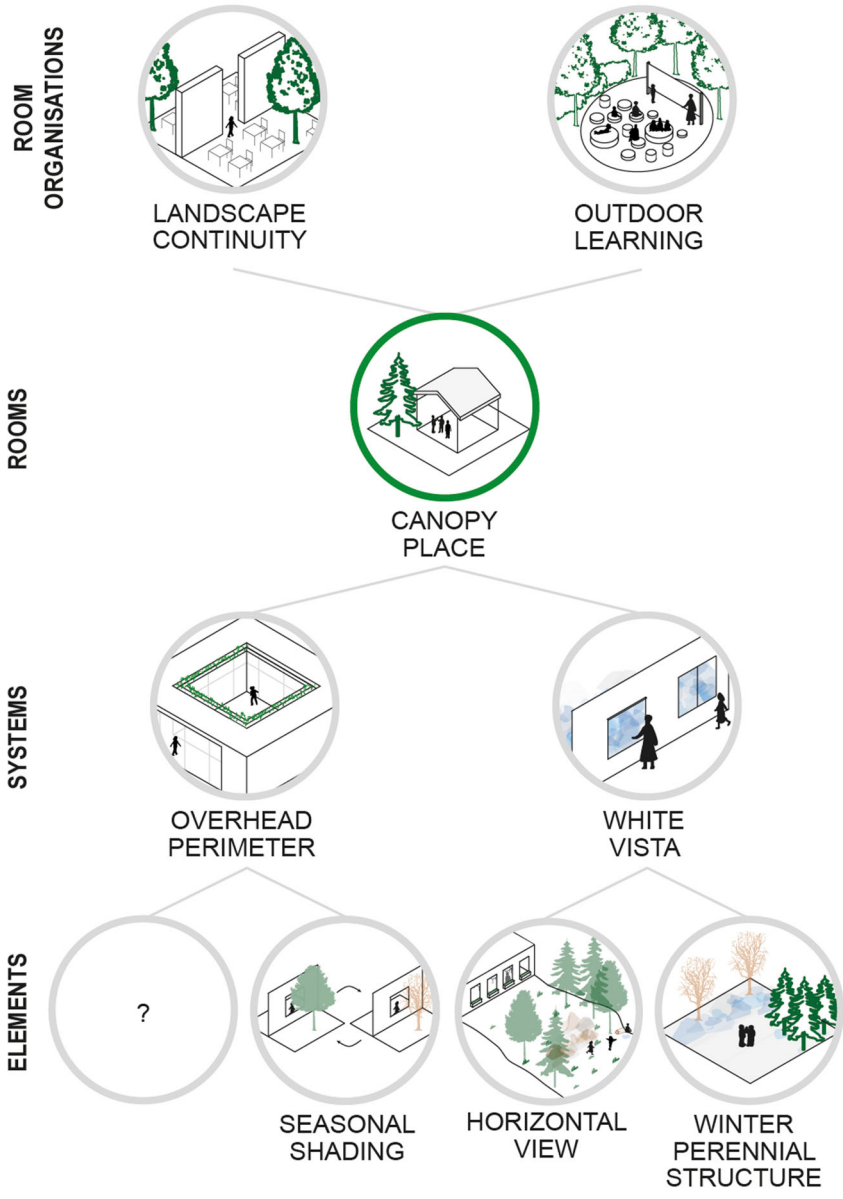

Figure 12. CANOPY PLACE and related schemas of higher and lower complexity.

elements: a header sentence, a narrative explanation and an image of a precedent. As described above, the header sentence summarises the schema in one sentence (Table 1 and Figure 13). The narrative explanation and architectural precedent provide a longer description of the experience of nature involved (Figure 14).

The second portion of the schema serves to diagnose a space in terms of the possible biophilic experiences it may generate for occupants. The evaluation covers relevant elements of the biophilic design vocabulary and discusses how the schema in question combines them.

The third portion of the schema frames the exploration of design solutions. It contains visual examples of spatial resolutions that describe generalised solutions to help during the design process. It provides specific guidelines for architects to summarise the fundamental design decisions that generate the schema. Additionally, research questions that could further contribute to the understanding and development of the schema are included. A detailed example of the schema CANOPY PLACE is presented in Figures 16 and 17.

Application of biophilic design schemas in studio projects

Seven design studio projects developed by pairs of fourth-year undergraduate architecture students revealed the ways the biophilic design schemas can contribute to the design process. Each team designed an addition and renovation to a Quebec-based primary school. Using the design schemas in the studio helped clarify the intended experiences and the refinement of their wording (as shown in Figure 1). The following sections reflect on the role of the schemas in the studio, based on observations during supervision meetings and project reviews.

Thinking about biophilic experiences

The semester began with a biophilic reading (Browning, Ryan, and Clancy 2014), however discussions about this material did

Table 1. One-sentence experiential summary for the biophilic schemas.

Level of Complexity	Biophilic schema	Experiential summary
L6 Whole Building / Site	BIOPHILIC BUILDING	brings weather and living organisms into daily life to support our innate love and affiliation.
	BIOPHILIC SITE	inspires engagement with and immersion in authentic living landscapes.
L5 Room Organisations	LANDSCAPE CONTINUITY	instigates frequent interactions with nature by spatially linking inside and outside activities.
	BIOPHILIC ZONING	organises rooms and gardens to fit activities with correlated biotic and microclimatic experiences.
	COMESTIBLE LANDSCAPE	nourishes children's sense of smell, touch and taste through on-site food production, preparation and consumption.
	EMOTIONAL HABITAT	develops empathy and attachment for wild and domestic animals by providing shelter and food consistently.
	SEASONAL SCHOOLGROUND	allies with rhythmic conditions to support playfulness throughout the day and year.
	OUTDOOR LEARNING	modulates weather exposure to encourage a variety of open-air engaged education.
L4 Rooms	EDIBLE INDOORS	introduces children to gardening joys by nurturing and harvesting food plants.
	LIVING-LEARNING LANE	fosters an understanding of lifecycles by incorporating growing organisms in sheltered circulation spaces.
	EXUVIATING TRANSFORMATION	celebrates the regular transition from outerwear to indoor clothing in algid climates.
	EXTENDED GROWING	keeps occupants in contact with green life and sunlight during cold months.
	SKY AWARE SPACE	directs attention towards the dynamics of the atmosphere and its life.
	CANOPY PLACE	encloses overhead, creating a refuge with a view or garden connection
	ENTRY GARDEN	welcomes with seasonally changing microclimates, colours and plantings.
	ELEVATED GARDEN	extends planting areas to roofs and fosters wildlife habitat.
	SUNNY OUTDOOR SPACE	creates a warm enclave, encouraging longer alfresco activity enjoyment.
	RAIN GARDEN	recalls pluvious conditions by directing runoff to infiltration zones populated with moisture-loving plants.
L3 Systems	WATER WITHIN	creates inside aquatic experiences through controlled flows.
	HANGING GARDEN	enables plants to grow at unexpected altitudes and makes the invisible wind manifest.
	INDOOR VIEW	bridges spatial boundaries via layers of frames and transparency degrees.
	INDOOR PLANTING EDGE	animates the room periphery with verdancy and productivity.
	PRIMARY FAÇADE	zones views and nature engagement both low for children and higher for adults.
	OVERHEAD PERIMETER	enhances sky experience by providing transitions at the roof edges and exterior wall tops.
	WHITE VISTA	celebrates snow-covered surface landscapes with hiemal compositions.
	ANNUAL & PERENNIAL	diversifies flora for year-round flourishing and provides verdure when annuals are gone.
	SHADED WALK	illustrates solar patterns by modulating warmth and shadows.
	SPRING TOPOGRAPHY	directs melting snow towards retention zones to enhance drier play surfaces.
	INTENTIONAL SNOW DRIFTING	responds to winter wind with site organisation that generates snowbank shapes for play and aesthetics.
L2 Elements	HORIZONTAL VIEW	arranges view corridors at children's height.
	NIGHT WARMTH	blankets the apertures to conserve stored heat for morning.
	VERTICAL GARDEN	can filter light, offer scent and provide dramatic contrast with ground vegetation.
	EXCAVATE AND CREATE	relocates snow from pathways to sculpt play structures and site microclimates.
	WINTER PERENNIAL STRUCTURE	retains deciduous and evergreen patterns to bring awareness to seasonal cycles and provide for brumal biophilia.
	SNOW BLANKETING	creates active winter play structures with built and landscape features on which snow falls.
L1 Materials	WINTER SEAT	warms the body in carefully located sheltered niches.
	HANDS-ON NATURE	encourages child development and learning by touching and manipulating life outdoors.
	INTENTIONAL ICICLES	safely form to demonstrate water phases in time, bringing visual enjoyment.

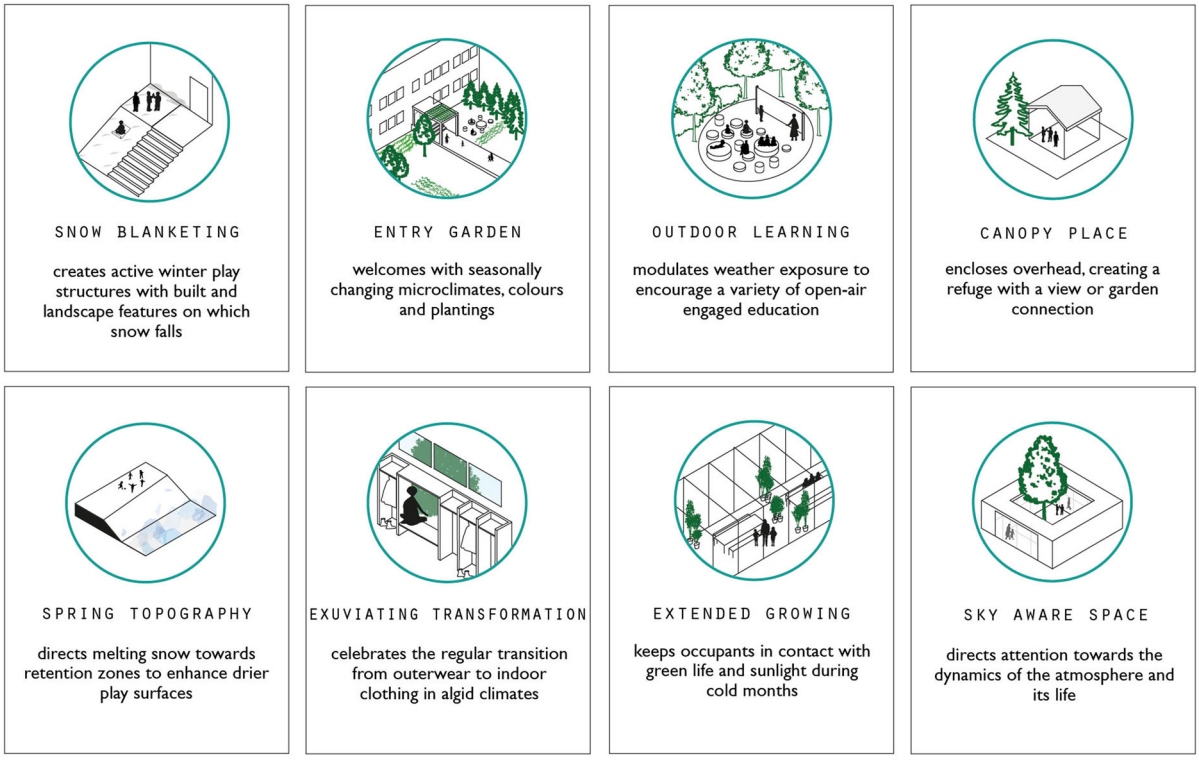

Figure 13. Pictogram and one-sentence summary for selected biophilic design schemas.

From R. Cloutier, F. Saavedra and R. Savard

SKY AWARE SPACE

This schema can inspire a sense of awe and wonder by connecting people to the drama of the daily and seasonally changing colours and motifs of the sky. It fosters an understanding of cloud and sun movement patterns, sometimes indicated by changing areas of shadow. This schema is fundamentally about connecting people to the sky by creating a space where the sky is the 'roof'. Ideally, people have a direct, unobstructed view of the sky, although roof glazing may prolong space use during rainy or cold periods. When open to the falling rain and snow, precipitation accumulations create opportunities for stimulating haptic connections. As weather conditions change, the snow on the ground reflects light differently, absorbs more or less sound and is coloured in various shades of white. Including tall or vertically growing vegetation further raises the view to the sky. Spaces enclosed on all sides may most effectively bring awareness to the rhythms of overhead nature. Spaces open on one side allow one to experience the gradients and changes from horizon to zenith.

From M. Niget, A. Rochon and A. Zakharov

CANOPY PLACE

This schema can engender a sense of shelter and refuge while linking its occupants to direct nature experiences. The canopy mediates two archetypal relationships, one to the sky and the other, to the earth. At its most essential a CANOPY PLACE takes the form of a pavilion moderating the natural forces from above, always isolating to some degree, while fundamentally connecting occupants to the horizon and to the grounded green layer of nature. In all its forms requiring a roof, it visibly expresses the human relationship with gravity by the means used to resist it. Meanwhile, the CANOPY PLACE, to achieve its horizontal biophilic connections may also block or moderate nature's forces by employing vertical enclosure. Particularly in cold climates, adjacencies to indoor rooms, sunny orientation and wind control are key to disposing conditions that allow expanded daily and seasonal occupation and therefore the enjoyment of the site's life.

From M.-H. Cliché, M. Comptois and É. Vigneau

ENTRY GARDEN

In building forecourts people both approach a building and linger where they can interact with vegetation and socialise. A WINTER PERENNIAL STRUCTURE maintains the sense of aliveness throughout the year. Pathways and benches seasonally occupy the shadows or the sunlight. The planting plan fosters a dialogue with nature and offers multiple ecological benefits. The entry garden acts as a climate modulating domain, offering warmth in winter and shade in the summer as needed. In warm months, living and built structures reduce heat levels by blocking the sun, thus reducing ground-level temperatures. In cold months, its orientation towards the sun and the presence of heat-retaining surfaces prolong the enjoyment of the outdoor environment. The spatial configuration and degree of enclosure of the entrance shelter people from the cold winter winds.

Figure 14. Examples of schema descriptions summarising the intended experiences of nature.

not help students to include biophilic design principles in their design projects. The list of 20 schemas and a different pair of specific schemas given to each team were used to further develop particular spaces in their projects with biophilic experiences in mind. The schemas became helpful to 'name' the design concepts and experiences, facilitating communication among students and with the instructors. The biophilic design schema INHABITED PERIPHERY encouraged a pair of students to link distinct indoor and outdoor conditions by treating the building envelope as an occupiable edge (Figure 18). The team created zones adjacent to classrooms on the three floors of the school. This schema complements CANOPY PLACE by extending the use of these zones to the heating season. By manipulating shading devices and window openings, students and staff can modulate their experiences of nature throughout the day and seasons. This inhabitation of the building edge expands the use of classroom spaces and incorporates living organisms, such as growing plants, as tangible components of the educational curriculum.

Perhaps because their previous studios were oriented towards formal compositions and other issues, students initially expressed some difficulty in thinking about biophilic

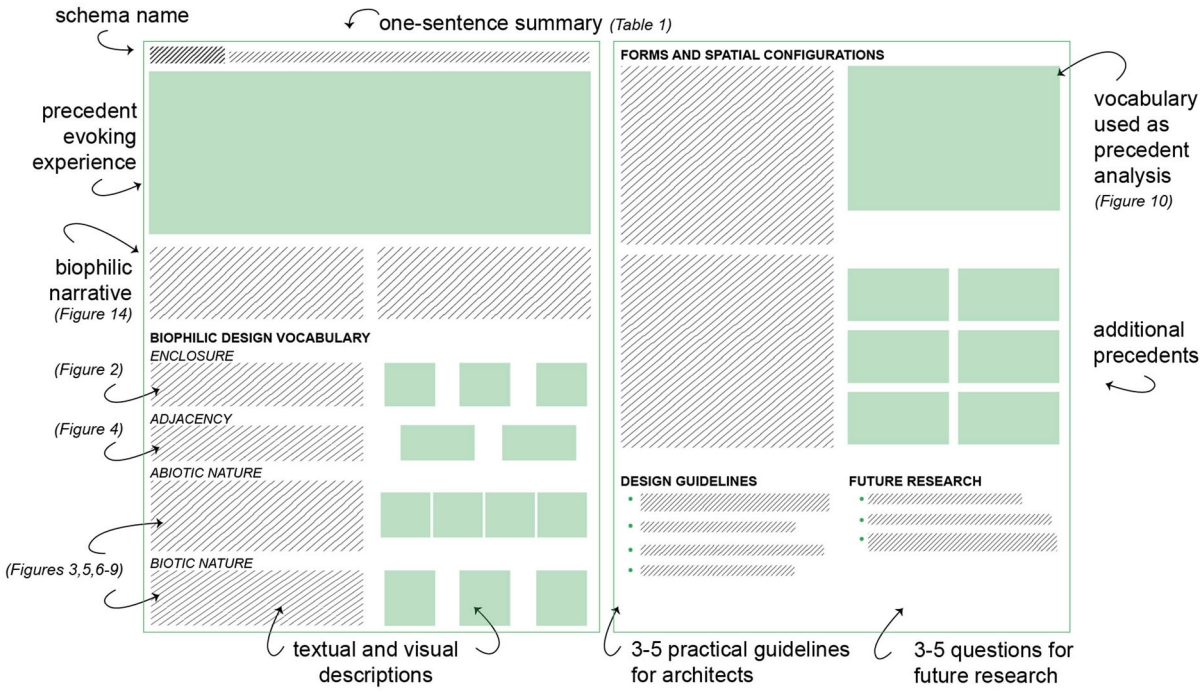

Figure 15. Anatomy of a biophilic design schema.

experiences. To them, it was unfamiliar territory. Thus, as the school projects developed during the semester, the biophilic design schemas were used in different ways. While they initially helped to describe and understand the multi-scalar and multi-sensory aspects of biophilic design, they became tools informing how architecture could manipulate natural forces and living organisms to engender experiences of nature.

Remembering, 'No bio, no biophilia'

Students were asked to explore and incorporate living organisms throughout the design process. Even with constant reminders of 'no bio, no biophilia', including vegetation in the weekly representations of the project was challenging for them. Offering schemas that describe an experience of vegetation transformed the use of plants into generators of spatial configurations.

The architectural translation of the biophilic design schema EXTENDED GROWING inspired one team to place winter gardens in the school addition. The schema creates settings that nurture plant growth and contact with sunlight during colder months. In the students' design, winter gardens adjacent to classrooms encourage learning activities to flow into these collaborative and lively spaces (Figure 19). The team further identified a variety of surfaces to support plant growth and encourage children to interact with them. A direct access from the winter garden to an outdoor garden enables an easy transportation of plants when seasons change. Additionally, gardening on the roof was developed to optimise plant growth and food production. While integrating vegetation in the project to foster an awareness and understanding of plant cycles, daylight and solar heating analyses informed the shape and position of glazing surfaces. Overall, this combination of summer and winter gardens aims to create moments of discovery for children's sense of touch, smell and taste.

Detailing indoor, semi-enclosed and outdoor spaces

The biophilic design schemas provided tangible descriptions of spatial configurations for semi-enclosed and outdoor spaces. The architecture students were encouraged to develop balanced designs that included outdoor spaces with a similar level of detail as indoor spaces (Figure 20). While indoor learning spaces where relatively easy for them to define and detail, designing semi-enclosed and outdoor rooms required significantly more effort throughout the semester. The schemas positively contributed to their design solutions.

Overall, these explorations of biophilic design schemas in the architectural studio show their potential to provide practical guidance during the design process to foster experiences of nature at multiple building scales while facilitating communication and collaboration in the design teams.

Discussion

This research describes and illustrates a new vocabulary for experiential biophilic design aiming to enrich considerations of nature in the design process. It combines selected aspects of biophilic design strategies and the logic of a visual design language to initiate a new critical knowledge base about biophilic experiences in terms of spatial enclosure, adjacency, abiotic nature and biotic nature. Such knowledge will allow for a shift in focus towards the subjective experiences of nature and the organised relationships that exist among biophilic design elements.

The strength of the biophilic design schemas rests in their organisation across scales and among indoor, semi-enclosed and outdoor spaces. In the biophilic design patterns or strategies proposed by Kellert, Heerwagen, and Mador (2008), Kellert and Calabrese (2015) and Browning, Ryan, and Clancy (2014), the

CANOPY PLACE encloses overhead, creating a refuge with a connection to a garden or view.

Exterior Walkway Adjacent to Classrooms. From M. Niget, A. Rochon and A. Zakharov

This schema can engender a sense of shelter and refuge while linking its occupants to direct nature experiences. The canopy mediates two archetypal relationships, one to the sky and the other, to the earth. At its most essential a CANOPY PLACE takes the form of a pavilion moderating the natural forces from above, always isolating to some degree, while fundamentally connecting occupants to the horizon and to the grounded green layer of nature. In all its forms requiring a roof, it visibly expresses the human relationship with gravity by the means used to resist it. Meanwhile, the CANOPY PLACE, to achieve its horizontal biophilic connections may also block or moderate nature's forces by employing vertical enclosure. Particularly in cold climates, adjacencies to indoor rooms, sunny orientation and wind control are key to disposing conditions that allow expanded daily and seasonal occupation and therefore the enjoyment of the site's life.

BIOPHILIC DESIGN VOCABULARY

ENCLOSURE

A CANOPY PLACE minimally includes a layer of overhead enclosure. Vertical components may be employed depending on the structural design, the degree of spatial adjacency or to modify their season of usability.

ADJACENCY

Locate a CANOPY PLACE adjacent to the building to encourage people to take inside activities to these sheltered areas. To increase the sensation of refuge, locate a CANOPY PLACE independent from buildings. Adjacent vegetation can further increase the experience of biotic nature.

ABIOTIC NATURE

COOLING SEASON STRATEGIES

The core strategies for a CANOPY PLACE are to block rain from entering the spaces and to minimise solar gains while enabling viewing out.

HEATING SEASON STRATEGIES

To extend the use of a CANOPY PLACE in colder months, incorporate "switches" to collect sun, and block wind and air. Ensure views out are maintained.

BIOTIC NATURE

From nearby ground surfaces to vertical structures in the distant field of view, a pleasant prospect engages the imagination. Including vegetative elements on the canopy itself can further contribute to the sense of refuge.

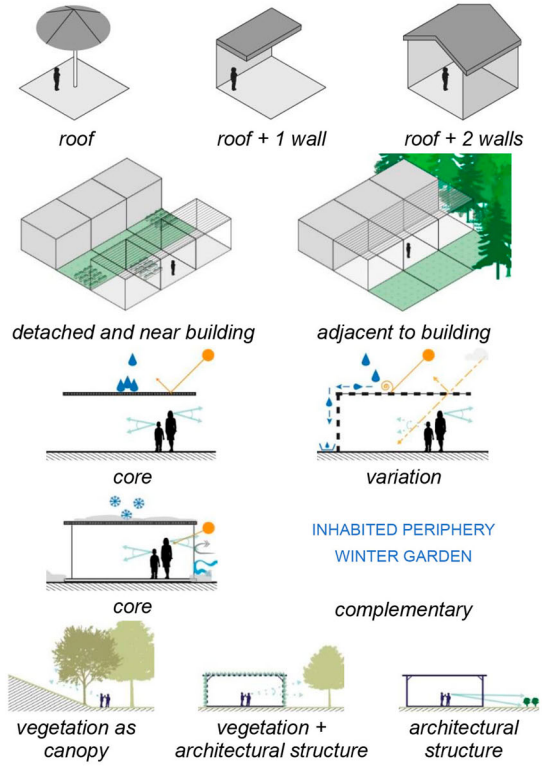

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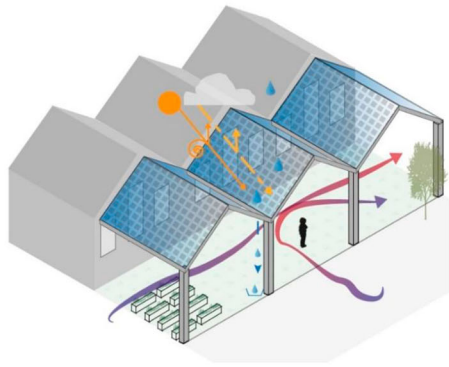
Figure 16. CANOPY PLACE schema, page 1.

absence of a map or a description of how the strategies relate to each other offers architects little guidance on what would be most effective or how strategies might combine to create larger significant patterns. Unlike the disconnected biophilic design strategies or principles often present in the literature, this framework provides a structure and understanding of the interrelatedness of the information. Similar to but more structured than the linkages in *A Pattern Language* (Alexander, Ishikawa, and Silverstein 1977), this organisation communicates that integrating biophilic design schemas in a design project cannot focus on a single element or space. To make a place more coherent, designers are challenged to consider at each scale the

FORMS AND SPATIAL CONFIGURATIONS

An example of a CANOPY PLACE can be found in the Westborough Primary School in the United Kingdom designed by Cottrell & Vermeulen Architecture Ltd. During a renovation project to increase the energy efficiency of the school, a semi-enclosed space was created adjacent to the classrooms.

The inclined canopy surfaces alternate between north-facing translucent panels that filter light and a south-facing grid of solar panels. In proximity to the brick wall of the school that stores and radiates heat back into the CANOPY PLACE, this semi-enclosed space is open to the breezes and views of the schoolyard. Under portions of the canopy system, a comestible landscape emerges with the presence of vegetable gardens.



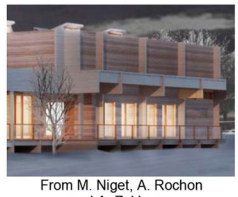
This selection of design precedents illustrates various spatial configurations of a CANOPY PLACE. The horizontal and vertical components employed reflect different strategies to connect, filter, block or switch abiotic forces.

The precedents are organised top-to-bottom based on their suggested sense of refuge, of protection from the sun and the rain. The adjacency of a CANOPY PLACE to a building edge and the size of the space created by the canopy can influence the sense of refuge. The opacity of the canopy further affects the protection from the rain and snow, while maintaining a visual relation with the sky.

The left-to-right organisation reflects on the experience of sensory variations throughout the day and the seasons. The spaces in the column on the right suggest more variability in sensory experiences because they are more permeable and transparent than the spaces on their left with a similar degree of shelter. Canopies constructed of permeable materials may offer more fluctuations of sun and shade and exposure to the rain than opaque structures.

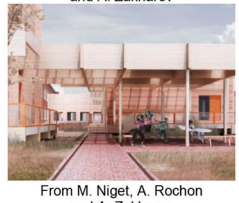
Experience of sensory variations →

← Sense of shelter, refuge



From M. Niget, A. Rochon and A. Zakharov

From J. Guillemette, M. Bazeniet and S. Laprise



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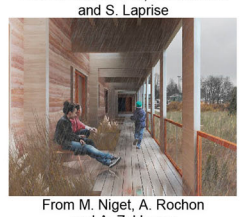

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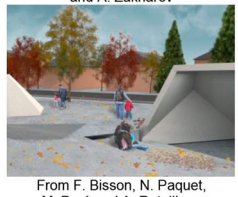

From F. Bisson, N. Paquet, M. Paré and A. Rotailleau

From R. Cloutier, F. Saavedra and R. Savard

DESIGN GUIDELINES

- In essence, a CANOPY PLACE takes the form of a pavilion moderating the natural forces from above to create a sense of refuge, of shelter.
- Its overhead structure is high enough to allow the winter sun to penetrate and heat the floor, yet low enough to block the high summer sun.
- Ideally, a CANOPY PLACE opens to a garden or other pleasant prospect.
- In cold climates, adjacencies to indoor rooms, sunny orientation and wind control are key to expand daily and seasonal occupation.

FUTURE RESEARCH

- Do naturally occurring shelters affect children's sense of refuge differently than shelters they actively shape or construct?
- How does the degree of softness, suppleness of the canopy contribute to the expression and experience of air movements?
- To what extent does a vegetative canopy foster a sense of relaxation?
- Do canopy edges low enough for people to touch heighten the sense of protection in the space?

2

Figure 17. CANOPY PLACE schema, page 2.

larger context of a schema and concomitantly its constituent elements. When applied in the design studio course, the schema system provided guidance at multiple building scales to foster experiences of nature in both warm and cool seasons.

Student explorations in an architectural studio revealed the potential of the biophilic schemas in the design process. The schemas helped to generate school additions beyond formal, functional, technical and aesthetic considerations to embrace potential biophilic experiences for the occupants. Design schemas relating to vegetation made living organisms integral to the design, rather than ornamental additions. Being able to name and describe the indoor, semi-enclosed and

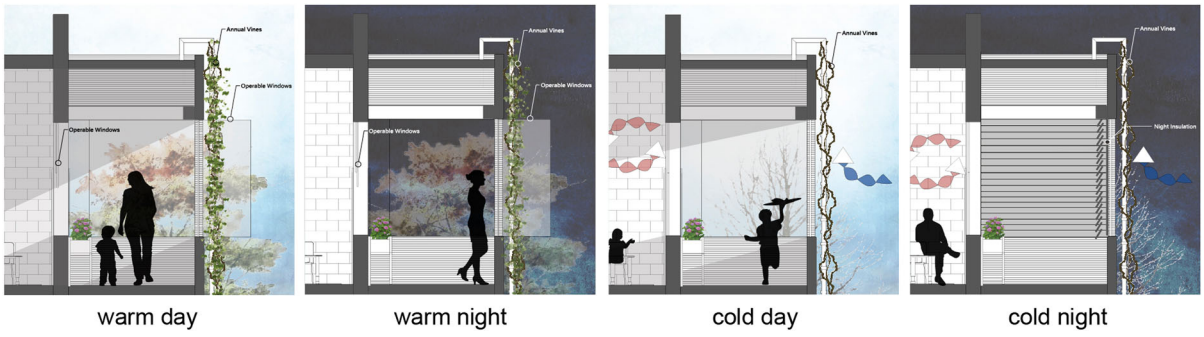

Figure 18. Studio exploration of an INHABITED PERIPHERY. From A. Brotzman and M. Hooper.

Figure 19. Studio exploration of EXTENDED GROWING. From H. Dennis and I. West.

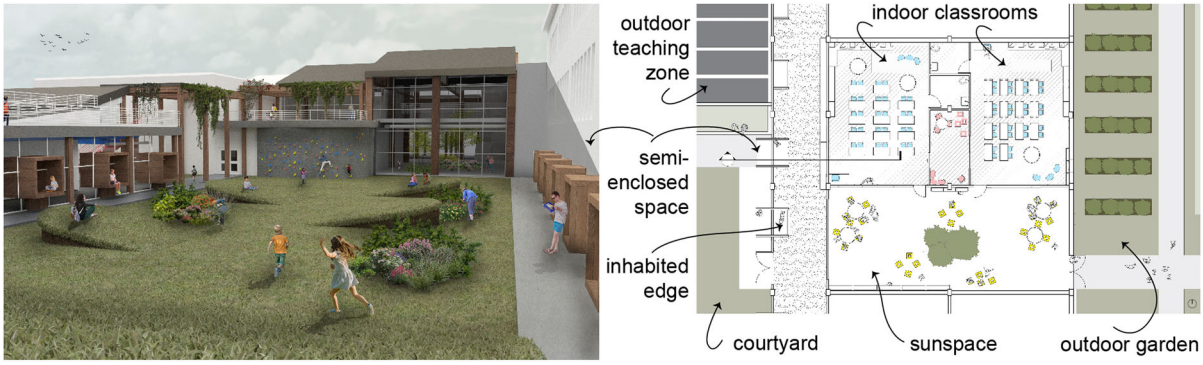

Figure 20. Detailed indoor, semi-enclosed and outdoor learning spaces. From H. Dennis and I. West.

outdoor spaces during the design process facilitated communication in the team of students, with studio instructors, lay people and with critics unfamiliar with the work. Using the design schemas in the studio clarified the intended experiences and further improved the formulation of the spatial recommendations. Finally, the biophilic schemas generated a positive learning experience for participating students. In the discussions at the end of the semester, one student expressed that the schemas provided 'an intention for each of our teams that reflected the ideas that we were trying to develop, but had difficulty to formulate into words.' Another student mentioned the desire to continue including biophilic design principles in future projects: 'I want to seek the connections and interactions of humans and nature cultured by my architecture.'

The biophilic design vocabulary and system of design schemas offer a framework for further research. Such an integrated framework makes it easier for multiple researchers to collaborate and to contribute schemas they observe or use in their respective work. This open-ended framework allows the addition of new schemas and the revision of existing ones as new research emerges. The approach articulated in the paper emphasises the architectural elements that may give rise to spatial experiences and experiences of nature. This framework could be expanded to include a broader understanding of architectural and biophilic experiences grounded in socio-cultural traditions. On one hand, the biophilic design vocabulary and schemas emerge from a typological reflection (similar to Thiis-Evensen 1989) and on the other, they acknowledge that such abstractions

are transformed by the form languages of particular socio-cultural traditions (i.e. the way of building in specific places). The design vocabulary could further serve in post-occupancy evaluations and in studies examining the outcomes of biophilic design by providing a more detailed language of spaces and variables for testing. By using shared terms, the vocabulary could help better understand and qualify the architectural and living elements that generate positive experiences of nature.

Conclusion

In exploring the forms and spatial configurations that engender biophilic experiences, two design tools have been developed: a *biophilic design vocabulary* and an ensemble of *biophilic design schemas*. The outcome of this exercise suggests that design methods and generative approaches, such as the biophilic design vocabulary and schemas, can help to address current gaps (lack of common terminology, of consideration for winter and of guidance on spatial configurations fostering biophilic experiences) in the biophilic design literature.

The applications of the biophilic vocabulary explored in this paper focus on school settings in a cold climate. They illustrate the impact of climate on the availability and variability of natural elements and processes. Focusing on primary school activities highlights children's experiences of nature when school staff control the opportunities to adapt the building or to migrate between spaces. We believe the themes and organisation of the design vocabulary could be transferable to multiple projects. Studying different building programmes and climate contexts could lead to new and overlapping vocabulary themes and schemas.

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References

Alexander, Christopher, Sara Ishikawa, and Murray Silverstein. 1977. *A Pattern Language: Towns, Buildings, Construction*. New York: Oxford University Press.

Beatley, Timothy. 2016. *Handbook of Biophilic City Planning and Design*. Washington, DC: Island Press.

Bloomer, Kent. 2008. "Picture Window: The Problem of View Nature Through Glass." In *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*, edited by Stephen R. Kellert, Judith Heerwagen, and Martin Mador, 253–261. Hoboken: Wiley.

Bringslimark, Tina, Terry Hartig, and Grete G. Patil. 2009. "The Psychological Benefits of Indoor Plants: A Critical Review of the Experimental Literature." *Journal of Environmental Psychology* 29 (4): 422–433. doi:10.1016/j.jenvp.2009.05.001.

Browning, William D., and Catherine O. Ryan. 2020. *Nature Inside: A Biophilic Design Guide*. RIBA Publishing. doi:10.4324/9781003033011.

Browning, William D., Catherine O. Ryan, and Joseph O. Clancy. 2014. *14 Patterns of Biophilic Design: Improving Health & Well-Being in the Built Environment*. New York: Terrapin Bright Green.

Chawla, Louise. 2015. "Benefits of Nature Contact for Children." *Journal of Planning Literature* 30 (4): 433–452. doi:10.1177/0885412215595441.

Clayton, Susan, Agathe Colléony, Pauline Conversy, Étienne Maclouf, Léo Martin, Ana-Cristina Torres, Minh-Xuan Truong, and Anne-Caroline Prévot. 2017. "Transformation of Experience: Toward a New Relationship with Nature: New Experiences of Nature." *Conservation Letters* 10 (5): 645–651. doi:10.1111/conl.12337.

DeKay, Mark, and Gail Brager. Forthcoming. *Feeling Form: Experiential Design Schemas*. Washington, DC: Island Press.

DeKay, Mark, and G. Z. Brown. 2014. *Sun, Wind and Light: Architectural Design Strategies*. 3rd ed. Hoboken: Wiley.

Demers, Claude M. H., and André Potvin. 2017. "Erosion in Architecture: A Tactile Design Process Fostering Biophilia." *Architectural Science Review* 60 (4): 325–342. doi:10.1080/00038628.2017.1336982.

Després, Carole, Andrée-Anne Larivière-Lajoie, Sandrine Tremblay-Lemieux, Marianne Legault, and Denise Piché. 2017. "Healthy Schools - Healthy Lifestyles: A Literature Review on the Built Environment Contribution." In *Health and Wellbeing for Interior Architecture*, edited by Dan Kopec, 123–136. New York: Routledge, Taylor and Francis Ltd.

Dovey, Kimberly. 1990. "The Pattern Language and Its Enemies." *Design Studies* 11 (1): 3–9.

Eckert, Claudia, and Martin Stacey. 2000. "Sources of Inspiration: A Language of Design." *Design Studies* 21 (5): 523–538. doi:10.1016/S0142-694X(00)00022-3.

Grondzik, Walter T., and Alison G. Kwok. 2015. *Mechanical and Electrical Equipment for Buildings*. 12th ed. Hoboken: Wiley.

Gstach, Doris, and Marc Kirschbaum. 2016. "Language as Design Tool: An Empirical and Design Perspective in the Field of Architecture and Planning." *Architectural Science Review* 59 (6): 465–473. doi:10.1080/00038628.2016.1214809.

Heerwagen, Judith, and Bert Gregory. 2008. "Biophilia and Sensory Aesthetics." In *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*, edited by Stephen R. Kellert, Judith Heerwagen, and Martin Mador, 227–241. Hoboken: Wiley.

Kahn, Peter H., and Stephen R. Kellert, eds. 2002. *Children and Nature: Psychological, Sociocultural and Evolutionary Investigations*. Cambridge: The MIT Press.

Kaplan, Rachel, Stephen Kaplan, and Robert L. Ryan. 1998. *With People in Mind: Design and Management of Everyday Nature*. Washington, DC: Island Press.

Kellert, Stephen R. 2008. "Dimensions, Elements, and Attributes of Biophilic Design." In *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*, edited by Stephen R. Kellert, Judith Heerwagen, and Martin Mador, 3–19. Hoboken: Wiley.

Kellert, Stephen R. 2015. 'What is and is not biophilic design?' *Metropolis*, October 26. http://www.metropolismag.com/architecture/what-is-and-is-not-biophilic-design/.

Kellert, Stephen R. 2018. *Nature by Design: The Practice of Biophilic Design*. New Haven: Yale University Press.

Kellert, Stephen R., and Elizabeth F. Calabrese. 2015. *The Practice of Biophilic Design*. https://www.biophilic-design.com.

Kellert, Stephen R, Judith Heerwagen, and Martin Mador. 2008. *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*. Hoboken: Wiley.

LaVine, Lance. 1988. 'Patterns, Purpose, and the Design of Energy Conscious Architecture.' Paper presented at the Society of Building Science Educators (SBSE) Summer Retreat.

Liddament, Terry. 1996. "The Metamorphosis of the Design Vocabulary." *Design Studies* 17 (3): 303–318. doi:10.1016/0142-694X(96)00003-8.

Louv, Richard. 2005. *Last Child in the Woods*. Chapel Hill: Algonquin Books.

Mayer, F. Stephan, and Cynthia McPherson Frantz. 2004. "'The Connectedness to Nature Scale: A Measure of Individuals' Feeling in Community with Nature.'." *Journal of Environmental Psychology* 24 (4): 503–515. doi:10.1016/j.jenvp.2004.10.001.

Mazria, Edward. 1979. *The Passive Solar Energy Book*. Emmaus: Rodale Press.

Norberg-Schulz, Christian. 1965. *Intentions in Architecture*. Cambridge: The MIT Press.

Pressman, Norman. 1995. *Northern Cityscape: Linking Design to Climate*. Yellowknife: Winter Cities Association.

Salingaros, Nikos A. 2000. "The Structure of Pattern Languages." *Architectural Research Quarterly* 4 (2): 149–162. doi:10.1017/S1359135500002591.

Schola. 2020. 'Schola.ca - Plateforme d'expertise en architecture scolaire'. https://schola.ca/.

Schön, Donald A. 1988. "Designing: Rules, Types and Worlds." *Design Studies* 9 (3): 181–190.

Thiis-Evensen, Thomas. 1989. *Archetypes in Architecture*. Oxford: Oxford University Press.

Unwin, Simon. 2007. *Doorway*. New York: Routledge.

Watchman, Mélanie, Claude M. H. Demers, and André Potvin. 2020. "Biophilic School Architecture in Cold Climates." *Indoor and Built Environment. Advance Online Publication*, doi:10.1177/1420326X20908308.

Wilson, Edward O. 1984. *Biophilia*. Cambridge: Harvard University Press.