Biophilic primary schools in cold climates: Design opportunities fostering multisensory experiences and well-being

Thèse

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Résumé

Les enfants passent plus du tiers de leur journée à l'école où la plupart de leurs activités d'apprentissage se déroulent à l'intérieur. Au Québec, Canada, la plupart des écoles primaires ont atteint la fin d'un premier cycle de vie et doivent être rénovées pour assurer un environnement d'apprentissage de qualité. Ces rénovations offrent le potentiel de favoriser la réussite éducative et le bien-être des élèves et du personnel scolaire en améliorant la qualité de l'environnement visuel, thermique, olfactif et auditif. Au Québec, des variations saisonnières importantes influencent l'expérience de la nature et la relation entre les espaces intérieurs et extérieurs. Cette recherche vise à développer une approche de rénovation biophilique des écoles primaires québécoises qui tient compte de la diversité saisonnière.

Dans le contexte de la rénovation des écoles québécoises pour améliorer l'expérience et le bien-être des occupants, cette thèse s'appuie sur l'évaluation post-occupationnelle et le design informé par les données probantes (*evidence-based design*) pour caractériser les déterminants mesurables et perceptuels de l'architecture biophilique en climat froid. Cette recherche vise à (1) recenser les études sur les relations entre le design biophilique et le bien-être, avec une attention particulière pour les écoles en climats froids, (2) diagnostiquer les qualités biophiliques des bâtiments existants avant de réaliser des visites de sites, (3) évaluer les expériences biophiliques lors de visites d'écoles dans une démarche d'évaluation post-occupationnelle et (4) examiner les configurations spatiales qui engendrent des expériences biophiliques et proposer une approche de conception pour les environnements d'apprentissage des enfants.

Cette thèse développe des outils pour soutenir la réalisation de diagnostics et proposer des solutions à plusieurs échelles architecturales qui favorisent les expériences multisensorielles liées aux forces naturelles et aux organismes vivants (ex. lumière, vent, neige et végétation). Cette approche multiméthodes comprend des analyses de dessins d'architecture, des visites d'écoles et des mesures des conditions environnementales dans un échantillon d'écoles primaires québécoises. Dans une optique de recherche et développement, des analyses de précédents et des ateliers d'architecture ont permis d'étudier l'expérience multisensorielle des ambiances physiques dans des projets d'agrandissement d'écoles.

Premièrement, *l'outil diagnostique basé sur la géométrie spatiale* des bâtiments utilise les éléments mesurables des dessins d'architecture pour évaluer le design biophilique. Une combinaison des critères de certification des bâtiments, des principes de conception bioclimatique et des stratégies de design biophilique offre un moyen simple d'analyser les qualités architecturales d'une école, ce qui s'avère bénéfique aux étapes préliminaires du diagnostic et de la conception. Deuxièmement, *l'outil de représentation des expériences biophiliques* (BERT) évalue subjectivement des caractéristiques environnementales (comme le soleil, la neige et la végétation) et décrit les sensations, les sentiments, la compréhension et l'affiliation à la nature que les espaces engendrent. Utilisé lors des visites de site, il permet aux architectes de confirmer ou d'infirmer les possibilités de design identifiées à l'aide de dessins d'architecture. BERT permet d'évaluer plusieurs espaces dans un court laps de temps tout en minimisant les perturbations pour les élèves et le personnel. Cet outil diagnostique a servi lors de visites d'écoles en hiver pour indiquer où les caractéristiques environnementales pourraient être améliorées pour favoriser le bien-être des occupants. Alors que les outils diagnostiques concernent des dessins d'architecture ou des expériences *in situ,* les outils d'aide à la conception développés dans la thèse intègrent ces deux aspects pour favoriser le bien-être en milieu scolaire. Le *vocabulaire de design biophilique* illustre les possibles expériences multisensorielles d'un espace. Il classe les éléments architecturaux et les espaces selon le degré d'intériorité – extériorité et de contiguïté. Les *schémas de design biophilique* complètent le vocabulaire de design biophilique pour aider les architectes à explorer les configurations spatiales qui engendrent des expériences biophiliques dans les écoles. Les 38 schémas proposés sont organisés par échelle architecturale et type d'espace (intérieurs, semi-fermés et extérieurs). Ces outils offrent une représentation visuelle simplifiée des expériences de la nature et une organisation des stratégies de design à diverses échelles du bâtiment.

Les méthodes développées dans cette thèse aident à caractériser les opportunités et défis architecturaux pour les expériences biophiliques dans les écoles québécoises. Ces outils guident les architectes dès l'évaluation préliminaire d'un bâtiment, lors des visites de sites, à l'étape de la conception et dans l'évaluation post-occupationnelle des écoles rénovées.

Abstract

Children spend over a third of their day at school where most of their learning activities occur indoors. In the province of Quebec, Canada, most primary schools have reached the end of a first life cycle and require renovations to ensure a quality learning environment. Renovating these buildings offers the potential to foster academic success and the well-being of students and school staff by enhancing the quality of the visual, thermal, olfactory and auditory environment. In Quebec, the relationship between interior and exterior spaces is a fundamental aspect in architectural design considering the important seasonal variations that generate different experiences of nature throughout the year. This research aims to develop an approach to the biophilic redesign of learning environments in Quebec schools by taking into consideration seasonal diversity.

In the context of renovating Quebec schools to enhance occupant experiences and well-being, this thesis uses a post-occupancy evaluation and evidence-based design framework to characterise measurable and perceptual determinants of biophilic architecture in cold climates. This research aims to (1) review studies into the relationships between biophilic design and well-being, with particular consideration for schools in cold climates, (2) diagnose the biophilic qualities of existing buildings before site visits are carried out, (3) assess people's experiences of nature during building walkthroughs in post-occupancy evaluations and (4) examine the forms and spatial configurations that engender biophilic experiences and propose a design approach for children's learning environments.

This thesis develops an ensemble of architectural tools to support the realisation of diagnoses and to identify solutions at several building scales that promote multisensory experiences of natural forces and living organisms (such as light, wind, snow and vegetation). This multi-method approach includes analyses of architectural drawings, school visits and measurements of environmental conditions in a sample of primary schools in Quebec. Within a research and development framework, precedent analyses and architectural design studios offer the opportunity to investigate visual, thermal, olfactory and auditory experiences in simulated school addition projects.

Firstly, the *diagnostic tool based on spatial geometry* uses the measurable elements contained in architectural drawings to assess biophilic design. A combination of building certification criteria, bioclimatic design principles and biophilic design guidelines offers a simple means of assessing architectural qualities while considering the climatic context, which can be highly beneficial in the early diagnostic and design stages. Secondly, the *Biophilic Experience Representation Tool* (BERT) subjectively evaluates a selection of environmental features (such as sun, snow and vegetation) and describes the sensations, feelings, understanding and affiliation with nature that the settings engender. Used during site visits, it enables architects to confirm or disprove the design opportunities identified using architectural drawings. The value of using BERT lies in its ability to enable architects to evaluate multiple spaces in a short period of time while minimising disruptions for schoolchildren and staff. This diagnostic tool was used during school visits in winter to indicate where environmental features could be enhanced to foster the well-being of occupants. While the diagnostic tools focus on architectural drawings or *in situ* experiences, the design tools combine both aspects to offer a design approach that fosters experiences of nature in children's learning environments. The *biophilic design vocabulary* offers a common way of describing potential biophilic experiences. It categorises architectural elements and spaces in terms of spatial enclosure, adjacency, abiotic nature and biotic nature. The *biophilic design schemas* expand on the biophilic design vocabulary to help architects explore the spatial configurations that engender biophilic experiences in schools. Drawing on pattern thinking, the 38 schemas are organised across design scales and indoor, semi-enclosed and outdoor spaces. These design tools provide a simplified visual representation of experiences of nature and an organisation of design strategies throughout building scales in the preliminary design stages.

The diagnostic and design methods developed in this thesis help to characterise current challenges and opportunities for biophilic experiences in Quebec schools. These tools therefore provide valuable guidance from the early assessment of a building, during site visits, in the design development process and in the post-occupancy evaluation of the renovated schools.

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This thesis is a testament to the love, support and patience of my family. I share the happiness of having completed this project with you. Thank you for accompanying me on this great adventure.

Preface

This thesis is part of the project *Schola.ca: plateforme d'expertise en architecture scolaire* led by a team of researchers from *Université Laval*. The contribution of this thesis consists in examining the physical ambiances in primary schools in Quebec in terms of occupant well-being and environmental performance in order to foster experiences of nature in indoor and outdoor spaces.

This work was conducted within the *Groupe de recherche en ambiances physiques* (GRAP) under the supervision of Claude Demers and the co-supervision of André Potvin, professors at the School of Architecture at *Université Laval*. A portion of this work was conducted during a research semester with Mark DeKay, professor of architecture at the University of Tennessee, Knoxville.

Completed in the doctoral programme in architecture, this work is presented as a thesis by published works. The four scientific papers included in this thesis were written by me, Mélanie Watchman, as the first author. I researched and prepared each article and was supported by the co-authors as research advisors and proofreaders of the manuscripts.

The first article "Biophilic school architecture in cold climates" by Watchman, Demers and Potvin was published in the journal *Indoor and Built Environment* in 2021 (Volume 30, Issue 5, https://doi.org/10.1177/1420326X20908308). The second article "Biophilia in school buildings: towards a simplified assessment method based on spatial geometry" by Watchman, Demers and Potvin was published in *Architectural Engineering and Design Management* in July 2021 (https://doi.org/10.1080/17452007.2021.1956419). The third article "Towards a Biophilic Experience Representation Tool (BERT) for architectural walkthroughs: a pilot study in two Canadian primary schools" by Watchman, Demers and Potvin was published in the journal *Intelligent Buildings International* in May 2021 (https://doi.org/10.1080/17508975.2021.1925209). The fourth article "Design vocabulary and schemas for biophilic experiences in cold climate schools" by Watchman, DeKay, Demers and Potvin was published in the journal *Architectural Science Review* (https://doi.org/10.1080/00038628.2021.1927666) in May 2021.

Portions of this thesis were presented at local and international peer-reviewed conferences:

- Annual conference of the Institut Hydro-Québec en environnement, développement et société (Institut EDS), Quebec City, 27 February 2019.
- 24th Student conference of the Centre de recherche en aménagement et développement (CRAD), Quebec City, 15 March 2019.
- 72nd Society of Architectural Historians (SAH) conference, Providence, United States, 26 April 2019.
- 50th Environmental Design Research Association (EDRA) conference, Brooklyn, United States, 24 May 2019.
- 25th Student conference of the Centre de recherche en aménagement et développement (CRAD), Quebec City, 13 March 2020.
- 51st Environmental Design Research Association (EDRA) conference, Tempe, United States, 5 April 2020.
- 26th International Association of People-Environment Studies (IAPS) conference, Quebec City, 23 June 2020.

This work was also partially presented during events aimed at stakeholders from the public and private sectors concerned by the renovation of school environments in Quebec:

- *Comité régional des services de ressources matérielles*, Shannon, 8 February 2019.
- Training day of the *Fédération des commissions scolaires du Québec* (FCSQ), Laval, 21 February 2019.
- Webinar "*Les salles de classe des écoles du Québec : un portrait en 4 dimensions*" organised by Schola.ca, Quebec City, 20 March 2019.
- Conference "*Écoles vertes: bâtir mieux au service de la réussite scolaire*" organised by the *Conseil du bâtiment durable du Canada – Québec*, Montreal, 8 May 2019.
- Webinar "*Schola - Recherche et design : Rénover les écoles primaires et secondaires*", Online, 17 June 2021.

Presentations further took place in academic settings to share portions of this work with students in architecture and interior design:

- Graduate course "Ambiances physiques architecturales et urbaines", École d'architecture, Université Laval, 17 January 2019. Professor: Claude Demers.
- Undergraduate "Integration Design Studio", School of Architecture, University of Tennessee, Knoxville, 13 September 2019. Professor: Mark DeKay.
- Undergraduate course "Lumière et ambiances physiques", École d'architecture, Université Laval, 8 September 2020. Professor: Claude Demers.
- Undergraduate studio-seminar in interior design, École de design, Université de Montréal, 19 November 2020. Professor: Virginie LaSalle.

- Undergraduate course “Architecture et environnement”, École d’architecture, Université Laval, 26 November 2020. Professor: André Potvin.
- Postdoctoral seminar “Integral Design and Research”, Università Iuav di Venezia. 26 April 2021. Professor: Mark DeKay.

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General introduction

This thesis offers an architectural reflection on multisensory experiences of nature in the context of renovating primary schools in Quebec to improve the well-being and academic achievement of students. Renovating buildings to improve occupant well-being through experiences of nature is an emerging design reflection that would benefit greatly from science-based evidence to guide the effective selection and implementation of biophilic design principles. Growing research has indicated that a connection to the natural world is crucial for children's development and their well-being (Chawla, 2015; Louv, 2005). Abundant research has also shown that the quality of physical ambiances such as light, temperature, ventilation and sound affects the health and academic success of school children (Barrett et al., 2015; Bluyssen, 2017; Heschong-Mahone Group, 2003). In Quebec, the relationship between interior and exterior spaces is a fundamental aspect of architectural design given the important seasonal variations that generate different visual, thermal, olfactory and auditory conditions throughout the year. Yet current biophilic design literature (such as Browning et al., 2014; Kellert, 2018) has overlooked winter in cold climates in favour of temperate conditions which see less seasonal variability and therefore facilitate indoor and outdoor experiences of nature throughout the year. While limited sunshine, abundant precipitations and cold temperatures during winter in cold climates pose challenges to balance a building's environmental performance and the well-being of occupants, the seasonal diversity in Quebec also offers unique opportunities to foster people's experience of nature and connect buildings and natural systems.

This research develops a biophilic design approach for learning environments that considers the seasonal diversity experienced during the school year in Quebec. It integrates objective (measurable) and subjective (perceptual) determinants of biophilic architecture to identify, understand and communicate biophilic design challenges and opportunities for primary schools in cold climates. This thesis develops an ensemble of architectural diagnostic and design tools to help architects characterise visual, thermal, olfactory and auditory experiences related to natural forces and living organisms (e.g., sun, light, wind, snow, rain and vegetation) at multiple building scales (e.g., materials, rooms, building and site) throughout the school year. The research results offer design recommendations not only for school renovations, but also to promote architectural strategies that respect the needs of occupants and sustainability goals in a biophilic design framework for cold climates.

Discomfort and environmental quality issues in primary schools in Quebec

Children generally spend over a third of their day at school, where most of their learning activities occur indoors. As most of human life is lived indoors, buildings become the way nature is or is not experienced most of the time. Design that reconnects people with nature – biophilic design – provides children and adults with opportunities to live and work in healthy spaces that foster greater overall well-being. However, inadequate physical environments have been reported in numerous school buildings. In the province of Quebec, Canada, most primary schools that were built prior to 1970 require renovations to ensure a quality learning environment (Després et al., 2017). The renovation of schools should consider the impacts on occupants of physical ambiances such as light, temperature, ventilation and sounds, because they can increase well-being and academic success (Barrett et al., 2015; Bluyssen, 2017; Heschong-Mahone Group, 2003). Addressing these issues can also help school buildings attain environmental sustainability by maximising the use of natural resources available outside the building to create comfortable indoor settings. Although bioclimatic design is not always biophilic, it can contribute to people's experience of natural elements (such as daylight and thermal variability). Relying on resources in the surrounding environment can not only improve the environmental performance of a building and occupant comfort, it may also enhance designers', and ultimately occupants', awareness and appreciation of natural elements and processes.

The inadequate visual, thermal, olfactory and auditory conditions of school spaces often represent obstacles to activities with students in the different types of school buildings in the province. In a study of 1036 staff members in 195 school buildings throughout the province of Quebec, issues concerning the physical ambiances represent the most commonly reported complaints, along with the size of the rooms, sharing of space and clutter (Schola, 2018). Among sources of discomfort related to the physical ambiances, the most frequent issues concern excessive indoor or outdoor noise levels, inadequate natural ventilation, not enough daylight and temperature extremes (Figure 1). The monitoring of light levels, temperatures, carbon dioxide concentrations and noise levels in a sample of schools in the province of

Quebec highlights similar concerns, especially for in-school childcare spaces which are often relegated to basements (GRAP 2015). The duration and diversity of the occupancy of these spaces represent a possible explanation for some of these sources of discomfort.

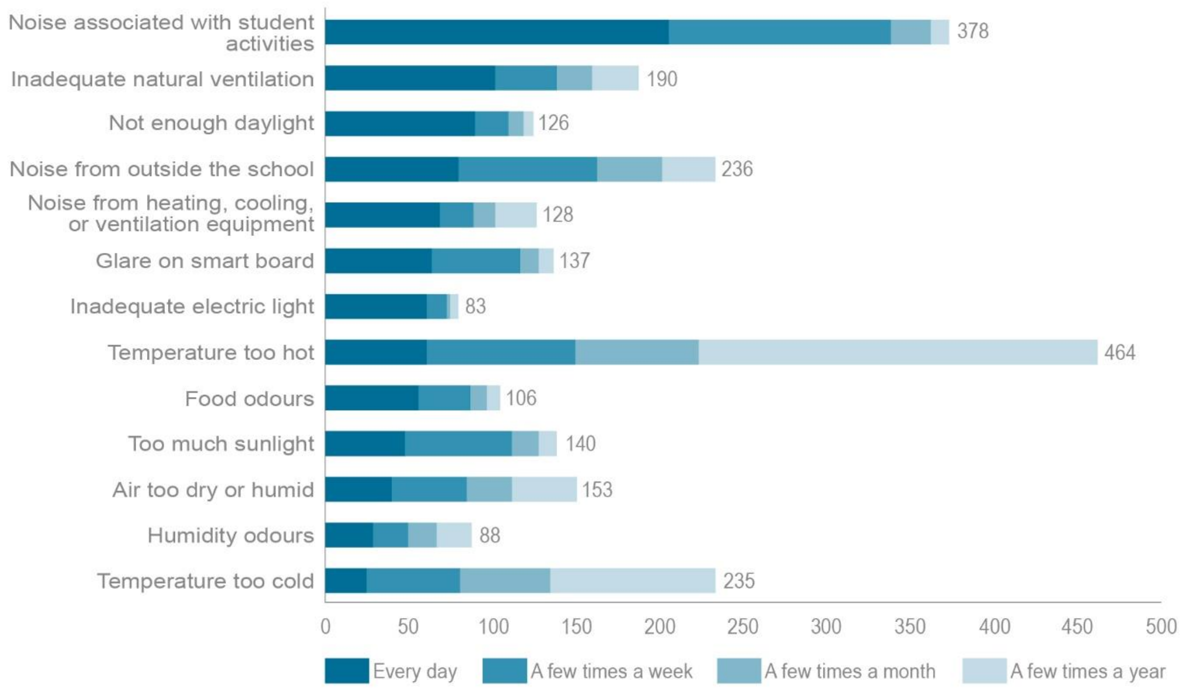

Figure 1. Sources of discomfort encountered by school staff during the last school year (n=647). Data source: Survey Renseignez-nous!, Schola (2018).

In schools constructed in the first half of the 20th century, the design of the classroom as the central learning space that occupies the largest floor area in the building was widespread. These spaces were typically used for a few hours in the morning and in the afternoon, as children returned home for lunch and after school. These inoccupancy periods helped regulate indoor temperatures and air quality via natural ventilation. Acoustic conflicts were also minimised, as the school spaces were simultaneously used for the same type of learning activities. Today, with the addition of complementary services, such as speech therapists and psychologists, that require calm and private meeting spaces, as well as an increase in the demand for in-school childcare, schools can be used continually throughout the day (typically 7 a.m. to 6 p.m.) for different purposes by various school staff members. Around 75% of students in the province are considered to use in-school childcare services, while 85% of schools were not designed to accommodate children outside of school hours (Després et al., 2016). For example, as only 25% of primary schools have a designated cafeteria (AQGS, 2014), other types of spaces with various opportunities for daylight, outdoor views, sound absorption and natural ventilation are commonly used. Some of the rooms typically transformed into lunchrooms, such as classrooms, offer pleasant lunch settings with sunlighting patterns and adequate noise absorption and do not produce lasting nuisances after lunch as natural ventilation from operable windows quickly dissipates food smells and heat (Figure 2a and b). In other schools, rooms with few or no windows, such as gymnasiums (Figure 2c), and residual spaces, such as in basements (Figure 2d), are used during lunch. The architectural characteristics of such spaces (e.g., small windows difficult to access) can represent an obstacle to create pleasant dining spaces; climate considerations, such as snow accumulations and early winter sunsets (Figure 2d), can exacerbate the inadequacy of these childcare spaces. Thus, catering for new uses in spaces shared throughout the day can create or exacerbate issues related to the quality of the indoor environment and occupant comfort.

Figure 2. Diversity of typical lunch spaces in a sample of primary schools in Quebec City offering various daylight qualities, sound absorption and opportunities for natural ventilation. (a) Classroom in autumn with operable windows and shading devices (b) Assembly room in autumn with operable windows along the facade (c) Gymnasium without windows during winter (d) Basement in-school childcare room with snowed-in windows during winter. Photo source: Schola database.

Additional explanations for these sources of discomfort include the variable climatic conditions throughout the school year which result in prolonged time spent indoors. Four distinct seasons characterise the cold climate in Quebec, yet children attend school from late August to the end of June and therefore experience most of the school year during winter. In

Quebec City, winter temperatures tend to oscillate between 0°C and -30°C for almost half the school year, i.e., between December and early April. This cold city also faces temperature swings between the seasons with outdoor temperatures varying between -30°C and 30°C throughout the school year (see detailed description in Chapter 1). These thermal changes in the outdoor environment require buildings that ensure occupant well-being in heating and cooling seasons. Even in cold climates, uncomfortably warm temperatures often occur in classrooms. This can be explained by the influence of building type, outdoor conditions and the season (Frontczak & Wargocki, 2011). Additionally, using mechanical systems to maintain elevated indoor temperatures in winter can represent a source of discomfort as occupants tend to expect indoor temperatures that reflect the variations present in the outdoor environment. In this sense, Baker and Steemers (2000) indicate that people "seem to be more tolerant of variations in the indoor climate provided they relate logically to outdoor conditions — i.e., people expect to feel hotter on a sunny day". The opportunity for people to adjust to conditions outside their thermal comfort zone is thus important in mitigating the effects of overheating, independent of the season. Adaptive actions include personal and social elements, such as dress code working practices. They also concern factors that influence the interaction between occupants and buildings, such as the ability to draw blinds or open windows (Nicol & Humphreys, 2002). Migration to outdoor spaces represents another form of adaptive action which can increase student and teacher well-being if an adequate design of the schoolyard is provided.

The educational potential of the schoolyard in Quebec has been overlooked, apart from recess and physical education classes. Children spend nearly 400 hours a year in the schoolyard, yet a well-landscaped outdoor environment is often considered to be a luxury in the limited budgets allocated (Vivre en ville, 2014). A recent study by the *Fondation Monique-Fitz-Bach* (2018) among 374 school employees throughout the province of Quebec highlights the growing desire for more outdoor teaching spaces. In that survey, 82% of the participants believed that their schoolyard holds untapped educational potential. While school staff report that indoor temperatures are too hot at certain periods of the year (Figure 1), having the opportunity to migrate to a pleasant outdoor environment could mitigate this issue during the warmer days of August, September, May and June. Open-air classrooms offer many benefits such as the ability to vary teaching methods, to make learning tangible, and to improve the well-being of students (Day, 2007; Nair, 2014). While nature offers an educational potential for various subjects, schoolyards in Quebec generally have asphalt play areas, most often near the building (Schola, 2020). On school sites, vegetative spaces mainly consist of grassy areas and simple landscaping. As the schools in Figure 3 illustrate, natural spaces generally take the form of a row of mature trees or shrubs located in front of the main facade of the building, between the schoolyard and the parking lot or the bus drop-off, along the boundaries of neighbouring lots, or between the perimeter of the schoolyard and adjacent streets.

Area: 33 m^2/student. Asphalt: 60%. Grass: 15% Area: 38 m^2/student. Asphalt: 56%. Grass: 44%

Figure 3. Examples of asphalt dominated schoolyards in Quebec City.

Winter transforms the microclimate of the schoolyard. While portions of the schoolyard are generally covered by snow, other areas expose asphalt surfaces after the passage of a snow blower (Figure 4a and b). Whether naturally formed or shaped by people, providing a variety of snow conditions creates different microclimates in the schoolyard while also facilitating multiple forms of play (Pressman, 1995). For example, snow slopes provide sledding opportunities while open spaces offer a canvas to make statues or build forts (Figure 4c and d). Investigating children's adaptation to winter in cold climates, Enai et al. (2004) showed that "There is a relationship between the amount of time playing outdoors and the rates of positive adaptation replies to winter". This shows the importance of embracing a four-season schoolyard culture. Thus, assessing and renovating schoolyards should not only focus on their use and microclimates in summer, but also consider how outdoor settings will be used in colder months. In this sense, the type and placement of vegetation should be able to withstand snow loads and winds, for example, and enable children to continue using the schoolyard during spring maintenance. In the cold climate of Quebec, the presence of semi-outdoor or intermediate spaces could further allow activities to take place outside. Outdoor equipment such as benches, tables and gazebos can be found in some schoolyards, however few structures provide shelter during rainy-day recess or learning activities during cooler days in autumn and spring (Figure 5). The only form of outdoor protection from the sun or rain is often limited to door overhangs near the main entrance of the building. This type of shelter may not be suitable for prolonged outdoor learning activities. Particularly in the colder months, exposure to the sun and protection from the wind are generally sought after, yet building overhangs currently protect occupants from the sun and expose them to the wind. The design of schoolyards and semi-enclosed spaces therefore merits consideration to enhance or create a pleasant outdoor environment during recess and outdoor learning activities that can also positively influence the indoor environment.

Figure 4. Examples of the accumulation or removal of snow in schoolyards in Quebec City during winter and the play opportunities this creates. (a) Natural snow accumulations over the site topography (b) Exposed asphalt created by a snow blower (c) Sledding on slopes after the passage of a snow blower (d) Sliding on ice and building statues in small open spaces.

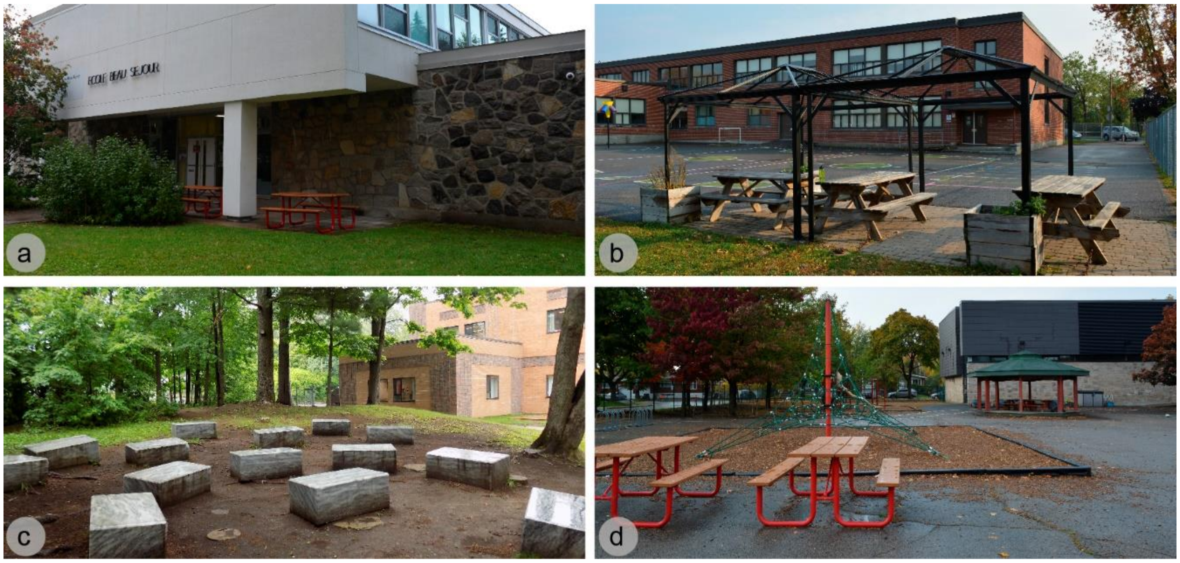

Figure 5. Examples of outdoor equipment offering partial protection from the sun, rain and wind. (a) Seating area near the street entrance protected from the sun and rain (b) Outdoor structure enabling sun and rain canopy to be seasonally added and removed (c) Trees offering some protection from the sun during summer (d) Movable tables that can follow sun availability in autumn.

Biophilic design challenges in cold climates

The relationship between architecture and climate is crucial to improving the physical ambiances of schools in Quebec. The successful design of biophilic settings has shown the possibility to foster experiences of nature that form an integral and beneficial part of the lives of children and adults. The term biophilia was first used by social psychologist Eric Fromm (1964) and later popularised by biologist Edward Wilson (1984) to describe people's innate biological connection with living organisms and life-like processes. Although Wilson (1984) popularised the use of the term biophilia, nature has been a long-standing source of inspiration or constraints for architects. Indeed, people's attraction to nature and the incorporation of biophilic elements into the built environment can be observed in different cultures through the use of local materials, the creation of spaces that imitate those available in nature, or the promotion of a lifestyle that offers proximity to the natural environment (Ramzy, 2015). Yet, as urbanist Norman Pressman states, "It is most unfortunate that the influence of climate on human well-being has generally been ignored in the cold-climate regions" (1985, p. 13). In association with the Winter Cities movement, he argues that considering climate, particularly winter conditions, is critical to design because of its profound impacts on social activities and people's appreciation of place. In school settings, considering experiences of nature during winter in the context of a renovation project offers the potential to enhance occupant comfort while also fostering the appreciation and place attachment children and school staff have towards their school.

Several interpretations of a cold climate and winter conditions exist according to considerations based on latitude, climatic elements, vegetation and cultural perceptions (Economic Commission for Europe, 2004). For the purposes of architectural design, Olgyay (1963) and Szokolay (2004) argue that a simple classification is sufficient to distinguish the basic climate areas: cool, temperate, hot arid and hot humid. Based on this system, the entire population of Quebec resides in a cold climate. The Köppen-Geiger climate map, the most widely used climate classification system, provides differentiation based on the rainfall regime and temperature variations (Peel et al., 2007). According to this classification, the climate of Quebec is cold continental with hot summers in the south of the province, continental subpolar between 50 and 58°N and polar tundra north of 58°N. In terms of energy considerations, four ASHRAE climate zones cover the province (zone 6, 7A, 7B and 8). Distinguishing these zones can help architects to balance the available natural resources, such as solar heat, with building occupancy and design features. Considering the location of primary schools in Quebec, only the ASHRAE zones make visible the climatic differences in the most populated area of the province (Figure 6). As the majority of primary schools in Quebec are located in zone 6 (58%) and zone 7A (39%)[1], the schools analysed in this thesis and the design recommendations proposed focus on the climatic particularities of these regions.

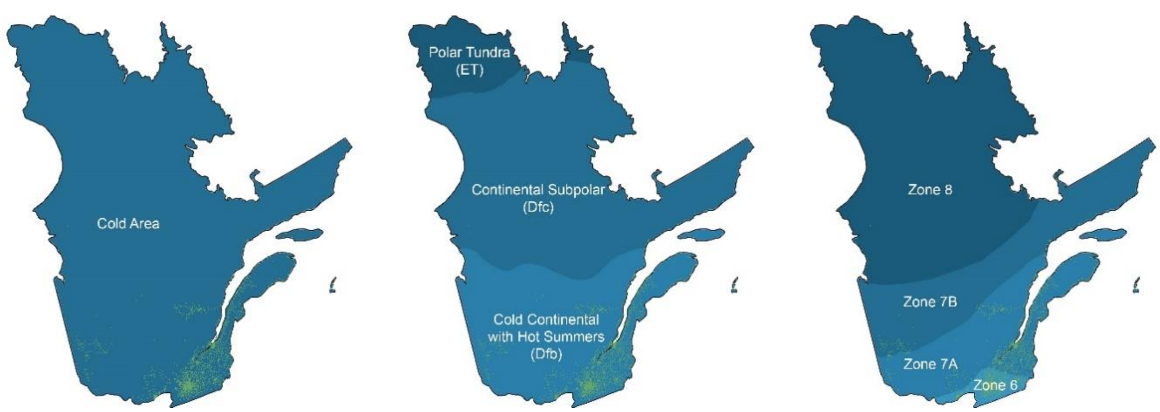

Figure 6. Primary school locations and climate zones in Quebec based on Olgyay's climate areas (left), the Köppen-Geiger Classification (centre) and ASHRAE zones (right).

[1] Only 3% of primary schools in Quebec are in zone 7B (severe cold) and 0.1% in zone 8 (subarctic).

This comparison reveals the difficulty of describing a cold climate. As argued by Norman Pressman (1995), geographic definitions of the north, a cold region, or a winter city will always be distinct from psychological perceptions of the north. For some people, winter is associated with heavy snowfall; for others, the darkness experienced after early winter sunsets is the characteristic element (further detailed in Chapter 1). Thus, the term cold climate could be defined in terms of its effects on human experiences and the built environment. By doing so, connecting indoor inhabitants to enjoyable elements in their climatic context requires the careful combination of climatic, architectural and perceptual dimensions. In biophilic architecture, climatic considerations are a key component of the *nature* that is incorporated in the design of the built environment to foster health and well-being.

While abundant literature can be found on the role and impact of nature in people's daily lives, what is and is not nature is often ambiguous or conflictual among authors. As a professor of urban and environmental planning, Beatley (2016, p. 13) considers that nature "comprises all the life and living systems in and around cities, from the birds and mammals we can see to the immense populations of invertebrate and largely invisible nonhuman life around us". In architecture, a building's relation to this "invisible nonhuman life", meaning natural forces such as sun, wind and precipitations, fundamentally influences occupant experiences and their comfort. For example, Lam (1992) considers that providing people with information on their location, the time, the weather and the presence of other living things represent some of the most important biological needs for environmental comfort. As previously discussed, certain buildings embrace this relation with environmental information, even without referring to the theoretical concept of *biophilia*. Environmental psychologists Kaplan and Kaplan (1989, p. 2) also define nature in an inclusive and broad sense, although they focus more on vegetation:

> We are referring to places near and far, common and unusual, managed and unkempt, big, small, and in-between, where plants grow by human design or even despite it. We are referring to areas that would often be described as green, but they are also natural when the green is replaced by white or brown or red and yellow.

The notion that vegetation is not necessarily green is particularly relevant for cold climates when snow-covered landscapes are generally present from November to April. As Figure 7 illustrates, nature can be visually experienced in all seasons, via leafy green trees and grass or leafless tress covered by snow. This seasonal change in vegetation also contributes to thermal experiences of nature as it provides buildings with different degrees of solar protection (see Chapter 1 and Chapter 5). Conversely to Kaplan and Kaplan, the term "nature deficit disorder" was coined by Richard Louv (2005) to describe the loss of children's free-ranging exploration of "wild lands" in cities and suburbs, as children withdrew indoors. In the context of health and well-being in the built environment, Browning et al. (2014, p. 9), from the consulting firm Terrapin Bright Green, define nature as the living organisms and nonliving components of an ecosystem. They add, "most nature in modern society is designed, whether deliberately (for function or aesthetic), haphazardly (for navigability or access to resources) or passively (through neglect or hands-off preservation)". When nature is present in Quebec schoolyards, it is often the result of deliberate actions to serve an educational purpose (such as a vegetable garden or outdoor classroom) or a circulation purpose (such as play area delimitation or building access) (Figure 8). This illustrates the importance of design decisions in shaping the definition and control of nature in children's environments.

Figure 7. Seasonally diverse nature (here, vegetation, sun and snow) in front of a primary school in Quebec City affecting visual and thermal experiences.

Figure 8. Examples of nature used for educational or circulation purposes.

Nature is generally presented as a positive and sought-after component, particularly in biophilic design. However, nature can also prompt fear, disgust, and anxiety (Kellert & Wilson, 1993). For instance, the threat of damage to the built environment from natural disasters, such as floods, is universal. This phenomenon is exacerbated when the climate is particularly harsh. As Pressman (1995, p. ix) argues:

> A plethora of winter-induced discomforts exists and must be acknowledged in architecture, planning, development policy, and urban design practice. Once this occurs, northern dwellers can benefit from built environments that will function more effectively – reducing the negative impact of winter while enhancing its positive characteristics […] If we can understand, respect and appreciate the beauty inherent in seasonal variation, then we might be capable of celebrating this pivotal season in the north.

Buildings therefore play an important role in people's experiences of nature by admitting, filtering or repelling environmental elements based on their perceived beneficial or adverse effects. Considering a range of climate-related resources, bioclimatic design can minimise the less desirable aspects of climate while taking advantage of its beneficial aspects for the comfort of occupants and building performance. In terms of biophilic design, this suggests that architecture goes beyond the incorporation or mitigation of natural light, fresh air, vegetation and views, for example, to foster the well-being of occupants. Biophilic buildings create an awareness of nature and encourage people to participate in the daily, seasonal and annual rhythms of nature. In the context of renovating diverse primary schools in Quebec, this could be achieved by identifying, recovering or enhancing the schoolyard and building features that originally encouraged children and adults to develop a positive relationship with natural forces and living organisms.

Diverse school buildings in need of renovation

The current renovation of school buildings marks a historic period for Quebec and presents a unique opportunity to adapt schools to present and future needs and practices in terms of occupant well-being. In Quebec, 3333 public buildings are used for teaching purposes, of which 2308 are primary school buildings (Schola, 2019). Two thirds of primary schools were built between 1948 and 1978 (Figure 9). These learning environments have reached the end of a first life cycle estimated at 50 years in architecture and thus require renovations to ensure quality learning environments. Despite the apparent unity of their construction period, primary schools in Quebec display a variety of site implantations, spatial configurations and facade designs. Ultimately, this diversity of school settings suggests that an ensemble of different renovation interventions could be required to improve the quality of the indoor environment.

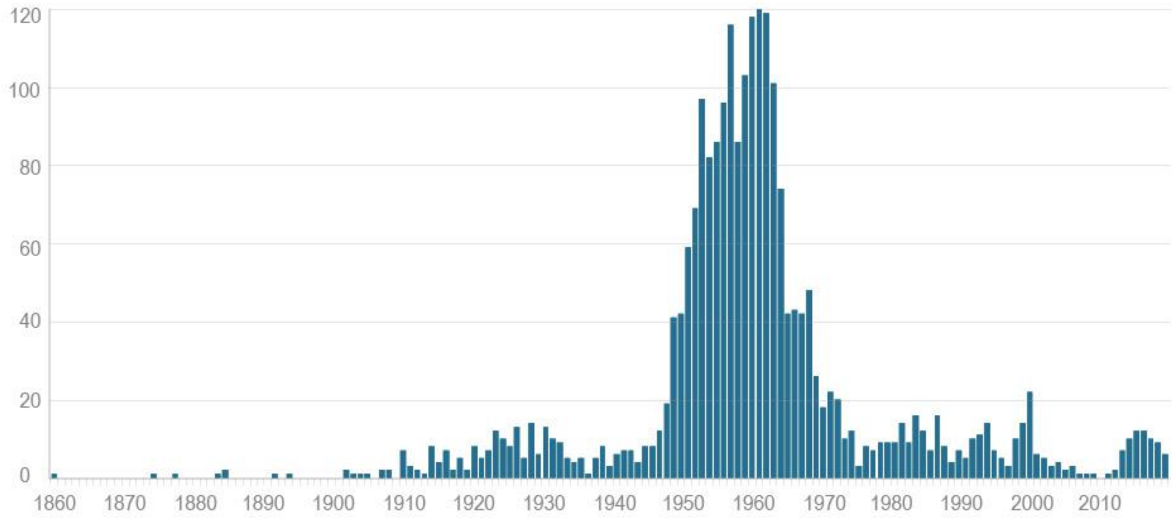

Figure 9. Number of primary schools still in use in Quebec, per year of construction. Data source: Schola database (2017).

The variety of solar orientations and positions on the site of primary schools in Quebec has important implications for the outdoor microclimate and the quality of the indoor environment. The solar orientation of a building combined with control strategies, such as overhangs, louvres, light shelves and windbreaks, influences both occupant comfort and the environmental performance of the building. For instance, buildings elongated in the east-west axis expose more surface area to the north and south for controlled daylighting and solar radiation (Mazria, 1979). In a sample of 308 primary schools in Quebec, 72% are linear buildings with a central corridor (Schola, 2020), yet the axis along which they are elongated is diverse, creating distinct challenges and opportunities in terms of daylighting, natural ventilation and noise exposure. As Figure 10 illustrates, while some schools are located at the perimeter of the site and align with the street, other buildings are located in the centre of the site. Further away from the noise of the street, a schoolyard is generated on every side of the building offering various zones exposed or protected from the sun and wind. Providing microclimate alternatives and a range of environmental conditions offers children and school staff with adaptive opportunities. It has been shown that people generally underuse outdoor spaces exposed to the wind and in the shade for most of the winter, while these characteristics tend to be sought after in summer (Mazria, 1979). The low occupancy of school sites in suburban and rural areas further offers the potential to provide a variety of microclimates fostering adaptive opportunities, such as occupant migration (see schemas in Chapter 5), when designing building additions or schoolyard renovations. Most primary schools in

Quebec occupy less than 30% of the site, half of the schools occupy less than 15% (Schola, 2020). As previously shown in Figure 3, schoolyards have a large mineralised surface, contributing to heat islands and hindering the absorption of rainwater. Given the constructive difficulty of modifying the existing orientation of a building, modifying the characteristics of a site (for example, the topography, surface types and texture, vegetation or windbreaks) could compensate or enhance the qualities of outdoor and indoor spaces in existing schools (see biophilic design schemas proposed in Chapter 5).

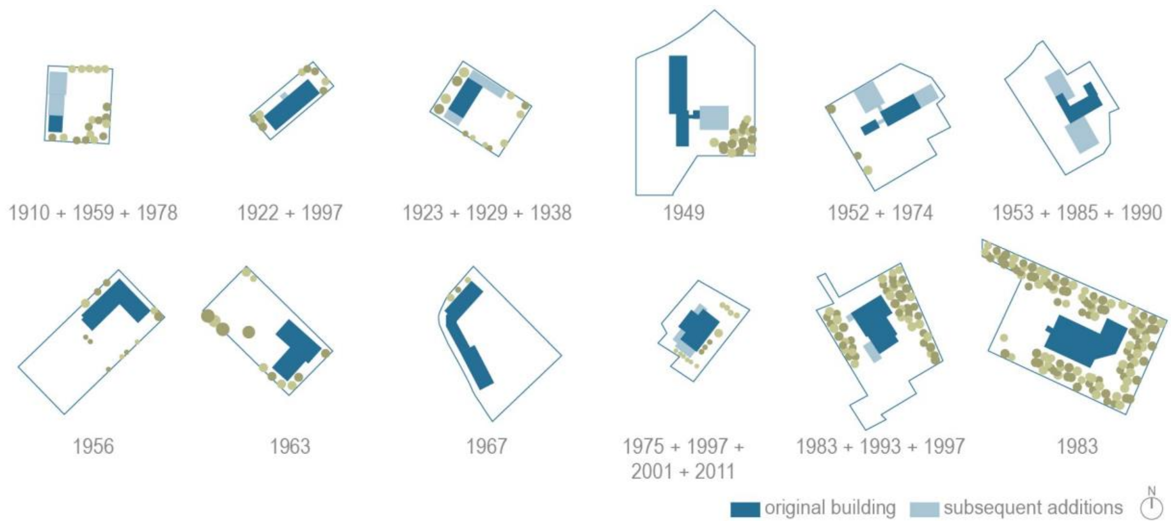

Figure 10. Diversity of building orientations and configurations in relation to the schoolyard perimeter for a sample of primary schools in the province. Data source: Schola database.

Most of the primary schools built in the first half of the 20th century in Quebec were designed with careful consideration of the local environmental conditions, although subsequent architectural transformations or building additions and changes of the occupancy periods and activities led to an increased disconnection from the outdoor conditions. The design strategies used in this earlier generation of buildings illustrate the first of two fundamental approaches Pressman (1985) identifies in terms of adaptation to harsh weather: (1) encourage occupants to adapt and learn to co-exist with nature as satisfactorily as possible or (2) construct sheltering devices to provide minimal contact with undesirable weather systems. Traditionally, the design of buildings in cold climates such as Quebec enabled indoor occupants to develop a relationship with the outdoor environment. With passive architecture strategies in mind, narrow buildings enabled cross-ventilation as well as daylight to enter deep into the classrooms. The three schools in Figure 11 illustrate the qualities of these elongated buildings. Considering a 4.5m perimeter zone for task daylighting and a 9m perimeter zone for ambient daylighting shows that these thin buildings maximise natural light in interior spaces. The 6m passive zone at the perimeter of the building further illustrates the potential to provide fresh air in interior spaces through operable windows. Thus, this generation of school buildings in Quebec may continue to offer students and school staff with certain biophilic experiences.

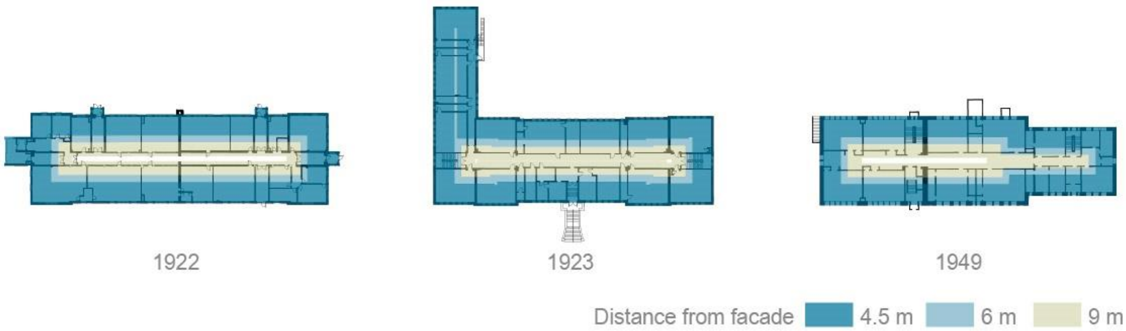

Figure 11. Examples of thin school floor plans facilitating natural ventilation and enabling daylight to enter deep into learning spaces.

As one or several additions were constructed in response to an increase in student numbers and complementary school services, the complexity of these buildings increased. A study of 308 primary schools in Quebec reveals that half have conserved their original footprint while the other half has been enlarged. Of the latter, a third of the schools have been enlarged once, 20% of schools have two additions while a few schools have exceptionally been enlarged three to five times, making the original school unrecognisable (Schola, 2020). The types of additions observed include the construction of a new building adjacent to the original school, the demolition and reconstruction of portions of the original building, the construction of a new pavilion or the acquisition of a neighbouring building. Figure 12 compares five schools from the same school board that were originally very similar. Built between 1956 and 1961, the rectangular floor plan of these buildings consisted of a central corridor with classrooms on either side. As classrooms and gymnasiums were added in the following years (between 1966 and 1969), the linear geometry became more complex, at times changing the dominant solar orientation of learning spaces. These new volumes also changed the microclimate of the schoolyard by creating a diversity of zones protected or exposed to the sun, wind and road traffic. Understanding the different construction periods of a school could therefore help to understand the discomfort issues identified today by school staff (Figure 1) and to orient the development of renovation proposals to overcome these issues by restoring or enhancing the opportunities occupants have to experience nature in school settings.

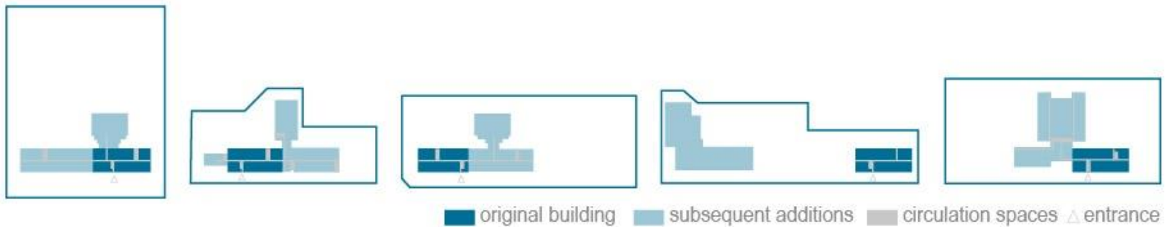

Figure 12. Additions to five schools in the same school board diversifying the common original rectangular floor plan.

The gradual replacement of classroom windows represents another transformation that contributes to the diversity of school spaces today. Prescriptions from the School regulations of the Catholic Committee of the Council of public instruction of the province of Quebec[2] of 1915 suggest that classroom windows should open both at the top and bottom to increase the efficiency of natural ventilation. Sash or hopper windows were recommended to enhance air movements by allowing fresh cool air to enter spaces at the height of student activities and enabling warm stale air to gradually rise to the ceiling and exit from the top windows. The continuity of this recommendation can be observed in a study of 48 schools built between 1947 and 1968 which revealed two predominant types of window openings: sash (50%) and hopper (42%). Of the sash windows, 35% were double hung while only 13% of the hopper windows could open at the top and bottom (Schola, 2020). The replacement of these windows in subsequent years further diverged from the recommendation of 1915, affecting the efficiency of natural ventilation in classrooms. The two examples in Figure 13 illustrate the decrease in window opening size between the original design and the renovation intervention. In the second example, the efficiency of natural ventilation decreased as the window opening to floor area fell beneath the minimum 5% requirement of the Quebec building code for naturally ventilated buildings. This type of transformation to the facade could in part explain the discomfort reported by school staff in numerous schools today (previously discussed in Figure 1).

[2] *Règlements du Comité catholique du Conseil de l'instruction publique*

Figure 13. Transformation of window opening type and reduction of opening area in two schools, from original construction to renovation (GFR: glazing to floor area ratio, OFR: opening to floor area ratio).

Schools built in the second half of the 20th century differ from earlier models as they had more compact floor plans. In comparison to the elongated school buildings in Figure 11, the schools in Figure 14 contain a larger floor area more than nine metres from the facade. At this time, adaptation to climatic conditions often became secondary to other concerns, such as integration to existing infrastructure (Zrudlo, 1994). This later generation of buildings included more mechanical and electrical systems to provide pleasant indoor conditions, which often resulted in a greater disconnection between occupants and the outdoors. As Cole et al. (2010) remark, the provision of occupant comfort has become a responsibility of consulting engineers, rather than architects, and the responsibility for the control of building systems has shifted from occupants to technology. Remarking that steady-state thermal environments prevail in many public buildings in the United States, Heschong (1979) argues that "such uniformity is extremely unnatural and therefore requires a great deal of effort, and energy, to maintain". Similarly, Baker and Steemers (2000) state that comfort issues are important to building design, but not "an obsessive application of narrow 'optimised' environmental parameters". They stress the importance of variable conditions and the ability for occupants to choose and modify these conditions if desired. In school settings, a building's spatial configuration and facade contain many opportunities or obstacles for occupants to actively transform their settings and adapt them to their comfort needs.

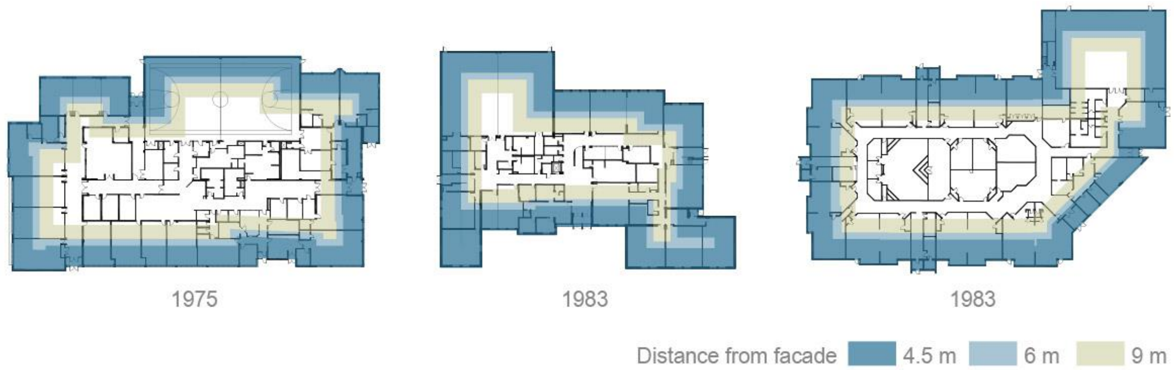

Figure 14. Examples of compact school floor plans where spaces at the core have limited opportunities of daylight, views and natural ventilation.

The spatial configuration of these thicker school buildings impacted the quality of the classroom environment and the biophilic opportunities in these spaces. For instance, schools built in Quebec before the mid-1960s tended to have rectangular classrooms with windows on the longest side of the rectangle (Figure 15). With windows that are evenly distributed over the exterior wall, this configuration provides abundant natural light and therefore requires little or no artificial lighting during teaching activities. Beginning in the late 1960s, almost one in two schools was designed with rectangular classrooms, but with the windows placed on the narrow side of the rectangle (Schola, 2019). This creates deep spaces where students' desks are further away from windows, limiting their access to exterior views, natural light and air movement. As these thick buildings prevented efficient cross ventilation, transoms were integrated in fewer classroom designs (Figure 15). This further reduced occupants' ability to adapt their settings.

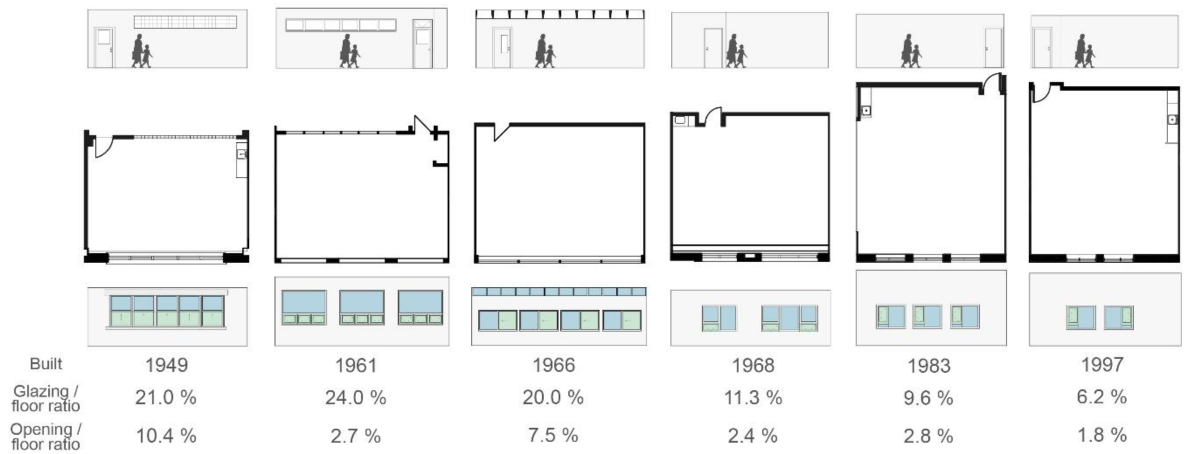

Figure 15. Diversity of classroom configurations and windows to the outdoors and to the corridor in a sample of classrooms in Quebec. Data source: Schola database.

School facades also reflect some of the major changes that occurred in the Quebec school system over the past decades. Facades represent an important architectural component in biophilic experiences as the type and placement of windows influence indoor occupants' outdoor views (e.g., sky, human activities and ground), access to daylight (e.g., quantity and distribution) and their opportunity to interact with shading devices and operable windows. At the beginning of the 20th century, the school system in Quebec was denominational. The few parish schools in urban settings from this period that are still in use today generally have two, three or four floors and a central entrance which is the focal point of a symmetrical plan (Tremblay-Lemieux, 2019). In Figure 16, the school built in 1924 is covered by large windows bringing daylight and fresh air into the classrooms, revealing it was designed with passive strategies in mind. The demographic pressures of the baby boom later led to an increase in primary and secondary school attendance. From 1944 to 1958, attendance in the province increased by 58% (from 612,896 to 1,060,996 students) (Schola, 2020). The schools built between 1940 and 1960 result from the serial models imposed by the Department of Public Instruction. In Figure 16, the school from 1956 illustrates how standardisation simplified the facade details while maintaining large openings to passively light and ventilate teaching spaces. The schools built in the 1970s exemplify the architectural explorations that occurred in Quebec and throughout the world. This generation of schools tended to have labyrinthic floor plans which made it possible to include double classrooms with movable walls (Tremblay-Lemieux, 2019). As discussed previously, these more compact floor plans tended to rely on mechanical and electrical systems to create comfortable indoor conditions.

The presence of fewer and smaller facade windows reflects this change. After major financial cuts in the education sector in the 1990s had a devastating effect on building maintenance, a small demographic boom in the 2000s led to the construction of new schools and school additions. In the context of a growing awareness of climate change, many of these schools implemented sustainable design strategies and some aimed to achieve building certifications (such as LEED). Thus, these four examples in Figure 16 suggest the importance of the facade for indoor occupants' experiences of nature.

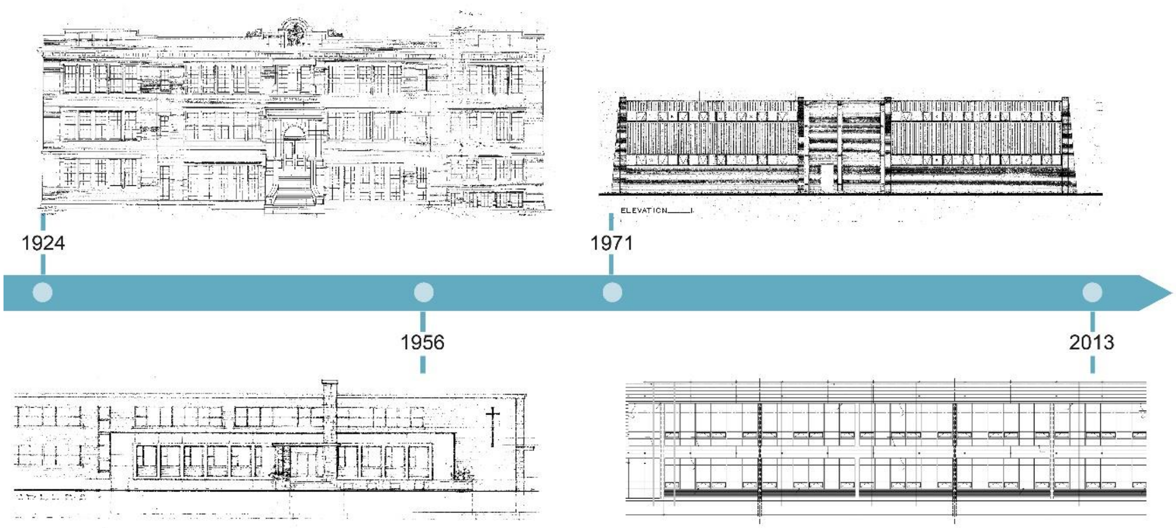

Figure 16. Examples of school facades reflecting major changes in the school system. Image sources: Schola database.

This historic overview shows some of the dominant trends in facade design over the decades that affect how students and school staff can have multisensory experiences of nature. However, within each decade, a diversity of window sizes, types and positions can be observed. A study of 81 classrooms in Quebec reveals the variation in window glazing and opening to floor area ratios by construction date (Figure 17). While there are noticeable differences in the glazing and opening ratios in schools before 1970 and after 1980, the schools built between 1950 and 1970 also present important differences. For example, glazing ratios vary between 5 and 40% of the floor area. On large windows, shading devices are important to control glare and heat gain or loss. Particularly in a cold climate like Quebec, windows present a source of potential conflict between providing outdoor views and natural light while supporting thermal, olfactory and auditory exchanges and energy performance. In addition to glazing size, the position of windows on the facade influences the daylight and views available for children and adults. Prescriptions from the School regulations of the Catholic Committee of the Council of public instruction of the province of Quebec (1915) reveal that windowsills had to be located at a minimum height of 1.2 m (4 ft) from the floor to prevent students from being distracted by outdoor activities, while still benefiting from natural light and sky views. This aligns with daylighting guides that recommend omitting glazing area below desk height as it wastes energy and causes discomfort (especially in winter) (O'Connor, 1997). In fact, the higher the window, the deeper the daylighting zone (generally 1.5 times the window head height). The position of windows in Quebec classrooms generally reflects these recommendations (Figure 18). In terms of window span, the position of windows is often influenced by the type of structure of the building.[3] In classrooms, a variety of window configurations can be observed, such as an alignment of individual windows, groups of windows and strip windows (Figure 18). Using strip windows provides more uniform light throughout the teaching space. Punch windows, on the other hand, with breaks between the windows, create contrasts between light and dark areas. While objectively offering the same glazing or opening surface area, these different window positions influence the subjective experience of daylight, outdoor views and air movement. Thus, a combination of measurable architectural features (such as the glazing to floor area ratio) and subjective occupant experiences (such as the perceived thermal variability) could offer a more exhaustive analysis of existing spaces and better inform their renovation to foster occupant well-being.

[3] A study of 237 primary schools in Quebec (Schola, 2020) found that in concrete structures, classrooms tend to have a single opening with strip windows. In wooden structures, classrooms often display four structural bays on the facade with one or two groups of windows in each bay. Two trends were observed for schools with steel structures. Before 1965, classrooms had two or three structural bays with two or three groups of windows in each bay. After 1965, window distributions in most schools with a steel structure resembled those in concrete structures.

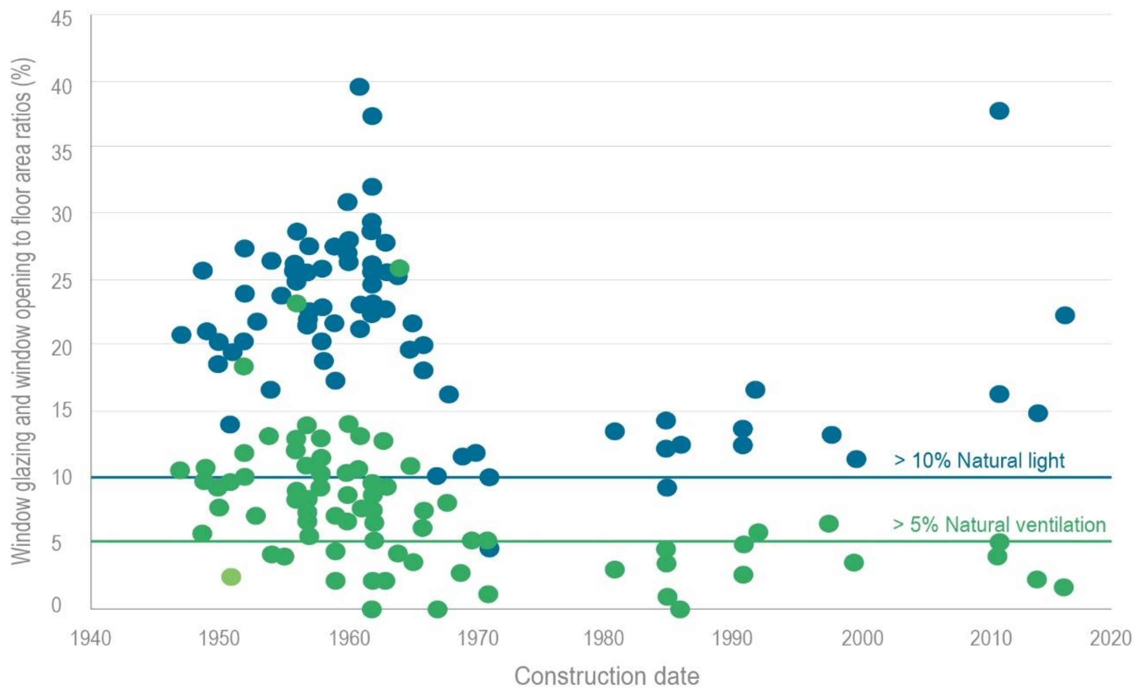

Figure 17. Window glazing and opening to floor area ratios in classrooms by construction date (n=81). Data source: Schola database.

Schools that offer children and staff the opportunity to adapt the built environment (e.g., windows, shading devices) and the location of their activities (e.g., room selection, outdoor learning) based on their activities and weather conditions can positively contribute to the creation of pleasant and stimulating settings. Particularly in the case of learning environments, "buildings that invite participation can help students acquire knowledge, discipline, and useful skills that cannot be acquired other than by doing" (Orr, 1993). In many primary schools in Quebec, the adaptive strategies originally present in earlier school constructions to facilitate occupant interactions with the building are often condemned or non-functional. For instance, of the 176 school employees who reported that transoms are present in their teaching space, 66% mentioned they were sealed shut, broken or inoperable (Schola, 2018). The control of shading devices is another adaptive opportunity present in classrooms. Shades are often drawn to facilitate the use of smart boards and computers in learning activities. However, numerous school visits show that shading devices remain closed, even after the sun has turned, resulting in spaces that prevent views to the schoolyard and natural light from entering. Passive buildings require active occupants who modify their interactions with architectural components according to the opportunities or obstacles present in the natural environment (Cole et al., 2010; PLEA, 2009). This combination of fewer adaptive opportunities provided by the building and infrequent personal actions impacts user comfort and tends to increase occupants' reliance on mechanical and electrical services to overcome this issue. Renovating these buildings offers the opportunity to encourage active occupants in passive buildings to create pleasant multisensory experiences via biophilic design strategies. To assess architectural settings, determine the impacts of buildings on people and generate design solutions that achieve these performance criteria for occupant well-being, multiple methodological approaches and tools can be considered.

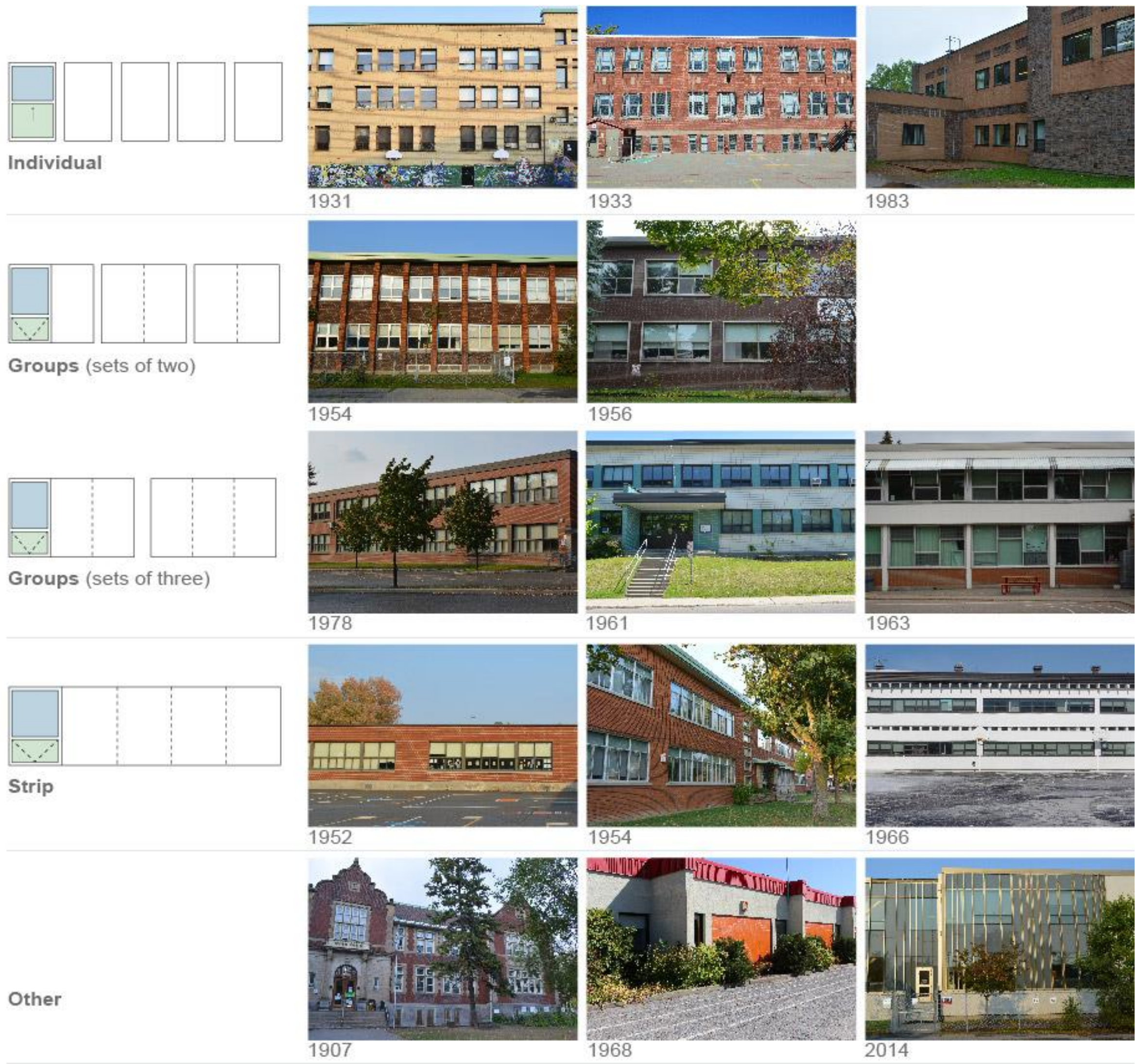

Figure 18. Window positions influencing the distribution of light and views from classrooms (date of original construction).

Diagnostic and design methods for multisensory biophilic experiences

Both measurable and perceptual determinants of biophilic architecture comprise their advantages and shortcomings which may dictate their role and importance throughout the preliminary design stages. While some research favours objective methods (such as the analysis of *in situ* indoor environmental quality measurements, architectural drawings or measurable occupant health and performance variables), subjective approaches (such as occupant surveys or designers' perceptions during site visits) offer a complementary understanding of the existing built environment. Post-occupancy evaluations enable a systematic study of buildings after they have been constructed and occupied for some time. This allows lessons to be learnt about ways to improve the conditions in the building and guide the design of future buildings (Preiser et al., 1988). According to Donna Duerk in her seminal book *Architectural Programming: Information Management for Design* (1993), two main areas of concern should guide architects in the preliminary stages of design. This consists in the analysis of the existing state, namely the context of the design project (site analysis, user profiles, codes, constraints, climate). This information then serves the projection of the future state which can be characterised by a series of criteria that address the mission, objectives, and performance criteria. Targets for occupant well-being are increasingly becoming recognised, documented and applied in the design and evaluation of architecture. For example, the creation of the WELL Building Standard in 2014 provided the first certification system for buildings, interior spaces and communities "seeking to implement, validate and measure features that support and advance human health and fitness" (WELL Building Institute, 2017). Many of the proposed well-being criteria align with the intended outcomes of biophilic design, in particular the criteria of visual well-being that encourage natural light in buildings. However, there is room for improvement, particularly for biophilic design in cold climates.[4]

Understanding the diversity of visual, thermal, olfactory and auditory conditions in primary schools in Quebec informs the development of renovation proposals that foster the health and well-being of children and school staff. Many studies resort to client-based metrics, surveys of occupants and field measurements of indoor environmental conditions to examine the links

[4] Appendix A offers a more detailed analysis of the WELL Building Standard and the Living Building Challenge in terms of physical ambiances in cold climates.

between nature and student academic performance and well-being. Metrics already used by the client, such as absenteeism, perceived comfort or test scores, are currently suggested to help architects understand and assess biophilic design (Browning et al., 2014). In school settings for example, test scores have been used as indicators of the impact of the built environment on learning progress (Barrett et al., 2015; Heschong-Mahone Group, 2003). While some research has identified natural elements that affect well-being (see review in Chapter 1), measures of nature experiences that can directly inform architectural design account for a smaller portion of this research.

Investigating the impact of the indoor environment on building occupants tends to focus on identifying and correcting negative features that create uncomfortable or unhealthy situations (Bluyssen, 2009). Summertime overheating, excessive noise, and high concentrations of indoor contaminants represent a few examples of unpleasant situations that are often the interest of indoor environmental quality (IEQ) assessments. While some comfort studies include desirable features of the indoor environment and consider the relationship between indoor spaces and environmental contexts, biophilic design tends to look for an enhanced positive connection between indoor and outdoor spaces, and not simply one that does not make people sick or unwell (Kellert et al., 2008). For example, in addition to glare considerations, sun penetration and visual control, measures of biophilia pertaining to visual well-being can include the quality of landscape views and the regulation of the circadian system.

Questionnaire-oriented studies have analysed well-being outcomes based solely on participants' perception of nature experiences and their self-reported evaluations (e.g., Collado et al., 2015; Norðdahl & Einarsdóttir, 2015). In Quebec, the survey *Renseignez-nous!* (Schola, 2018) identified the daily routines and satisfaction levels of more than a thousand teachers, in-school childcare educators, maintenance workers, administrators and principals from 200 primary schools.[5] Objective descriptions and measurements of the quantity and quality of nature provided by the settings are therefore unavailable. Research that focuses on satellite data or cartographic datasets reveals associations between biophilia

[5] Appendix B presents some of the participants' responses for the portion of the survey titled "Daylight and comfort". A more detailed analysis of the survey is available in *Fascicule A: Apprendre* (Schola, 2020).

and urban design, yet these remain restricted to the outdoor environment (e.g., Dadvand et al., 2015; Hodson & Sander, 2017; Kweon et al., 2017). Limited research has considered the spatial geometry of buildings to analyse biophilic design. Roös et al. (2016), for example, visually located biophilic design strategies on the floor plan of a railway station project, but omitted an analysis of the measurable physical data, such as building proportions and window ratios. Similarly, Terrapin Bright Green (2019) used floor plans and section drawings to provide the visual locations of biophilic elements in ten case studies. These examples allow a visual and qualitative assessment of the location of natural elements in the building or on the site. An analysis of geometric space could contribute to a more objective, although simplified, evaluation of sensory connections between the indoor and outdoor environment in the preliminary stages of a renovation project. Several intervention studies have compared architectural settings to determine which generate more favourable outcomes (e.g., Kelz et al., 2011; D. Li & Sullivan, 2016; van den Berg et al., 2017). In these studies, the impacts on the health or performance of people are often measured in more detail than the architectural intervention variables, which are limited to the modification of a single parameter (e.g., green walls, interior finishes, outdoor views). Studies that have included site visits tend to offer the most valuable information for architects. Environmental information that has been gathered typically includes architectural variables such as building and room characteristics (e.g., dimensions, orientation) and measures of environmental conditions (e.g., noise, temperature, and lighting levels) that are complemented by subjective evaluations either by occupants or researchers. Measuring tools and methods exist to assess the quality of the indoor environment from the perspective of building occupants (such as Candido et al., 2016; Cochran Hameen et al., 2020; Heinzerling et al., 2013) and previous research has investigated the potential of architectural representation to discuss measured field data (examples include Demers & Potvin, 2021). Expanding on this knowledge would enable a representation of the subjective aspects of biophilic experiences during building walkthroughs.

The experience of the built environment embodies more than the addition of each sensory stimulus. No comprehensive measure of the overall quality of the environment exists to combine visual, thermal, acoustic and air quality considerations even though the senses, as interconnected systems, continually provide information about the environment (Gibson, 1966). "Such complexities mean that it is impossible to combine the different aspects of an environment into a single number that describes the overall environment in terms of its comfort or quality" (Humphreys et al., 2016), whereas energy related to heating, cooling, and lighting can be accounted for by annual use and costs. This makes measuring and predicting biophilic qualities in architecture more complex than estimating energy performance. It is the simultaneity and the interaction of the senses that connect people and their environment (Merleau-Ponty, 1945). An occupant's response to an environmental stimulus can be affected by its interaction with other stimuli thus requiring a systemic assessment (Humphreys et al., 2016). Therefore, the design methods used to renovate learning environments should consider how architecture appeals simultaneously to the senses to prompt an authentic and sincere relationship with nature.

Creating a coherent design that considers the multiple factors at play can be challenging, particularly when correlations between design parameters and well-being outcomes are small (Barrett et al., 2017). However, if nature is included into the built environment in the belief that it will encourage well-being, the risk of being wrong may be minimal as long as the strategies included also consider other potential consequences, such as environmental performance. Despite the importance of evaluating existing buildings and understanding their impact on people, an architect's main task concerns the transformation of the knowledge available in current environments into the design and creation of new settings. Due to the complexity of considering multiple, and at times conflicting, issues during the design process, various design tools exist to facilitate and optimise these different design considerations.

No consensus exists among design theorists on a clear methodology and a definitive classification of design methods. However, design can be defined as an exploration within an immense labyrinth of possibilities that describes the environment (Simon, 1969). Success in solving the design problem involves narrowing down the range of possibilities to select the design options that correspond best to the design targets. Intuition, artistic inspiration and professional experience generally guide architectural design (Sailer et al., 2008). However, in complex projects, such as schools, the scope of designers' decisions emphasises the importance of supporting them with credible data. This practice is part of evidence-based design, an approach that guides architectural decisions based on the best available evidence.

It uses post-occupancy studies and other empirical means to evaluate the success of designs in achieving their intended goals (Gifford, 2014).

Building simulation is commonly used to estimate the impact of architectural design decisions on the resulting indoor environment (Anderson, 2014). While simulation results are often interpreted as predictions, the point of building simulation in the design stage is to explore design alternatives through a series of what-if scenarios. A considerable amount of financial resources and time would be necessary to test the potential outcomes of each design scenario if physical models were used, yet numerical simulations offer the potential to test and refine a multitude of design parameters while controlling for climate conditions (Jankovic, 2017). Within the Schola project, a typical classroom model was elaborated to test a variety of architectural strategies (e.g., window dimensions and position, window opening schedules, interior finishes) and understand their impact on the quality of the indoor environment. A single parameter was changed per simulation offering a pedagogical opportunity to discuss its effect on occupant comfort, propose diagnostic tools for architects or other professionals who will assess schools and make recommendations to improve current learning environments. Nonetheless, the realism and validity of numerical simulations represent limitations of the approach (Groat & Wang, 2013). In this sense, predicting "the integral building performance as experienced by the end user is still a bridge too far" (Bluyssen, 2009). In terms of biophilic design, simulations can help architects assess certain measurable environmental stimuli, but fail to assess other important perceptible dimensions. For instance, excellent light does not refer strictly to the quantity of light, but also includes its quality, which may even be more important (Rasmussen, 1964). The quality of light in an indoor space is determined by the source of light present (natural, artificial or a combination of natural and artificial), the distribution of light in the space and the way it is perceived (Bluyssen, 2009). Several metrics have been developed to assess daylighting performance (e.g., daylight factor, daylight autonomy, useful daylight illuminance). These climate-based metrics offer the potential to include, to some extent, biophilic design principles that encourage "varying intensities of light and shadow that change over time to create conditions that occur in nature" (Browning et al., 2014). Olfactory stimuli, on the other hand, are more challenging to analyse in building simulations. In biophilic design, the evaluation of the olfactory experience goes beyond clean air to include the appreciation of certain odours that create a connection with nature. For example, Browning et al. (2014) discuss the benefits of natural ventilation in regard to fragrances of herbs and flowers it brings into the built environment. Measuring the qualitative character of odours is even more complex than pollutant concentrations and ventilation rates. Perceived odour intensity or perceived air quality may differ from objective measurements of the air in a space. Moreover, continuous exposure to an odour decreases the perceived odour intensity and increases the odour threshold (Bluyssen, 2009). Olfactory adaptation therefore makes it difficult to model and predict how occupants will respond to the olfactory environment. Thus, while computer simulations can grasp and mirror some objective environmental stimuli that relate to biophilic design, subjective impressions are more challenging to achieve.

Architects often use design patterns and design precedents as a source of knowledge when starting a renovation or construction project. Using such patterns or precedents creatively in the design process implies recognising relevant characteristics in a source then converting them into the target project (Zarzar & Guney, 2008). In the cold climate of Quebec, this may also imply adapting design strategies to the seasonal diversity experienced throughout the year. Design guidelines and rules of thumb can also assist architects to develop climate-responsive buildings that foster pleasant visual, thermal, olfactory and auditory experiences. For example, DeKay and Brown (2014) present 150 analysis techniques and design strategies to help "architects to design net-zero energy buildings by assisting them in creating sustainable designs based on site forces of sun, wind and light". In terms of design guidelines that specifically target biophilic architecture, a detailed analysis of the biophilic design recommendations presented by various authors in diverse publications reveals over 80 design principles (see review in Chapter 1). However, this literature fails to describe how the elements within a category relate to each other and how they can be combined with elements from other categories. 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). For example, the *pattern language* developed by Alexander et al. (1977) discusses the relationships between form and events and is primarily focused on social relationships, but also includes natural events. Despite being criticised and misunderstood (Dovey, 1990; Salingaros, 2000), design patterns are a powerful tool to understand and control complex processes. In this sense, narrowing down the architectural possibilities in the preliminary design stage by using a classification of biophilic design patterns that foster experiences of nature while meeting or exceeding occupant well-being and environmental performance criteria in a specific climatic context could facilitate architects' tasks when renovating buildings.

Research objectives and thesis structure

The overarching objective is to identify the design opportunities fostering multisensory experiences and well-being in the context of renovating primary schools in Quebec to improve academic achievement. This research values visual, thermal, olfactory and auditory experiences which are currently reported as inadequate in many schools in Quebec. In this aim, this thesis develops an ensemble of architectural tools to support the realisation of diagnoses and to identify solutions at several building scales that promote multisensory experiences of natural forces and living organisms (such as light, wind, snow and vegetation). It characterises both objectively and subjectively the various determinants of biophilic architecture in cold climates within a post-occupancy evaluation and evidence-based design framework.

Chapter 1 serves to emphasise the importance of children's experience of nature for their immediate and long-term health and well-being. It aims to provide insights into the gaps in current knowledge of biophilia in cold climates. Using a narrative review method, literature regarding biophilic design, cold climates and learning environments is synthesised to provide an understanding of the current knowledge. This study highlights climate considerations affecting biophilic design, namely sunlight, cloud coverage, temperatures, natural ventilation and the variety in nature's colours, sounds and smells. It further discusses the implications of these gaps for the application of biophilic design principles in cold climate schools.

Chapter 2 aims to diagnose the biophilic qualities of existing schools in Quebec. It proposes a simplified quantitative assessment method based on spatial geometry, as the limited research that has considered the spatial geometry of buildings to analyse biophilic design has focused on qualitative assessments and the location of natural elements in the buildings. Using a study of three primary schools, the chapter critically analyses architectural plans, sections and elevations based on biophilic guidelines, building certification standards and bioclimatic design principles. This exploration illustrates a replicable process to capture the biophilic characteristics of buildings. The results highlight areas of the schools with biophilic qualities and opportunities for an increased contact with nature. Additionally, the proposed diagnostic method allows architects, before site visits, to identify which indoor environmental parameters may fall below the recommended thresholds and those areas of the school in which they are likely to occur.

Chapter 3 discusses how natural elements such as daylight and snow illustrate sensory experiences during site visits in cold climate schools. It documents observations and field measurements of light, temperature and sound that contribute to the evaluation of the indoor environmental quality and potential biophilic qualities of existing spaces. It complements the assessment of the biophilic qualities in three primary schools presented in Chapter 2 by evaluating the indoor and outdoor conditions of these schools in different seasons. While *in situ* measurements are often used during post-occupancy evaluations, the novelty of the approach proposed is to discuss environmental surveys in relation to positive multisensory experiences of nature.

Chapter 4 develops an architectural diagnostic tool that subjectively represents designers' experiences of nature during site visits in post-occupancy evaluations. The aim is to facilitate the assessment of biophilic experiences during building walkthroughs in the preliminary design stages of renovation projects. The Biophilic Experience Representation Tool (BERT) was used during site visits that took place in two Quebec primary schools in winter. This highlighted its potential as a way of presenting and discussing subjective dimensions of biophilic architecture. It further emphasised the importance of seasonality when assessing and designing biophilic buildings in cold climates.

Chapter 5 aims to examine the forms and spatial configurations that engender biophilic experiences. 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 the focus on empirical validation and broad theoretical generalisations, leaving designers wanting for design methods and generative approaches. Two design tools are developed: a *vocabulary of biophilic design* and an ensemble of *biophilic design schemas*. The proposed vocabulary combines selected aspects of biophilic design strategies and the logic of a visual language to provide a critical knowledge base about biophilic experiences in terms of spatial enclosure, adjacency, abiotic nature and biotic nature. The strength of the biophilic design schemas rests in their organisation across scales and among indoor, semi-enclosed and outdoor spaces.

Finally, the concluding chapter summarises the findings related to the diagnostic and design tools. It shows how the assessments based on spatial geometry, site visits, designers' experiences and an architectural vocabulary are combined to provide an enhanced understanding of the biophilic opportunities and challenges in existing buildings. This includes a reflection on potential applications of this research for the current renovation of primary schools in Quebec. Following a general discussion about limitations, an overview of next steps is provided. It further reflects on the pedagogical opportunities of the tools for architecture students, design professionals and school stakeholders.

Approaches

The research and design approaches developed in this thesis aim to inform the design process of practising architects. Architects could incorporate the tools presented in this thesis into their professional work to renovate schools in Quebec in the coming years. This responds to the need identified by the research project Schola to help designers and building managers develop renovation proposals based on credible evidence that is appropriate for the climatic particularities of schools in Quebec. In exploring the use of the tools proposed as part of this thesis, their pedagogical potential became apparent. For instance, certain tools helped to make university students more aware that preferred experiences of nature differ among people, spaces and times of the day. Architecture students and young design professionals could therefore also be considered as stakeholders of the thesis work.

The methodological approaches selected in this thesis also aim to help close the loop between the design and the use of buildings. After renovations of primary schools are completed, the tools could also be used by design professionals and researchers to examine the changes made and to document occupants' perceptions against the original design intentions. This makes it possible to study the actual experiences of nature in buildings rather than those anticipated during the development of the design proposal. Considering the large number of schools in need of renovation in the province, this feedback generates lessons that could later be used to define design targets for future renovations. The design decisions that generate favourable outcomes could in turn be included within guides of "good practice" that inform future decision-making. Repeated post-occupancy evaluations using these tools immediately after handover and after a few years of occupancy could also verify that the changes made continue to offer pleasant experiences and contribute to the multisensory well-being of students and school staff. Therefore, the examination of multisensory biophilic experiences could be included as part of the assessment of the environmental performance of buildings or the quality of the indoor environment as well as during the design process.

To achieve these aims, the methodology developed in this thesis is in many ways analogous to the design process. The metaphor of a spiral process appears useful to describe how the various reflections, methods and tools in this thesis fit together. As Zeisel (1984, p. 14) indicates:

> A spiral process reflects the following characteristics of design: (1) designers seem to backtrack at certain times – to move away from, rather than toward, the goal of increasing problem resolution; (2) designers repeat a series of activities again and again, resolving new problems with each repetition; and (3) these apparently multidirectional movements together result in one movement directed toward a single action.

In the context of this thesis, such a spiral process involves breaking down the notion of experiences of nature into smaller concepts that can be investigated with simple tools readily available and usable by architects and emerging design professionals. It embraces the idea of cumulative learning via the repeated use of a tool. For example, conducting field measurements in different conditions can reveal how people's experiences are modulated by clear and overcast skies, hot and cold outdoor temperatures and the presence of snow or rain. The thesis also tackles the notion of multisensory biophilic experiences of nature from different angles to better develop ways of representing people's experiences. For instance, certain chapters of the thesis adopt unobtrusive methods, such as analyses of architectural drawings, to gather objective information on potential environmental conditions (such as in Chapter 2). Other chapters present more intrusive and empathetic methods that involve personal experiences during building walkthroughs (such as in Chapter 4). Thus, while the tools developed may at times appear disconnected or only addressing specific issues of biophilic architecture, they are all directed towards developing a better understanding of nature experiences to inform the renovation of primary schools in a cold climate. This is most readily apparent when the results obtained from each tool are combined. The concluding chapter of this thesis illustrates how the information gathered using each of the tools can be amalgamated and confronted to obtain a more synthetic and complete understanding of the biophilic characteristics of a school space.

Moreover, multiple methods were adopted in this thesis to reflect the multidisciplinary nature of biophilia and the complexity of the variables to be considered in biophilic architecture. Environmental design research typically addresses the dynamics of physical settings, human responses and interpretations over time. Hence, it often encompasses a broader range of methodological designs than other fields or disciplines. It has been argued that advocates for mixed method research designs are particularly present in fields that involve "a dynamic interplay with creative practice in highly practical fields" (Greene, 2008). As Groat and Wang (2013, p. 441) state:

> Increasingly, researchers in many fields, including architecture, are advocating a more integrative approach to research whereby multiple methods from diverse traditions are incorporated in one study. Because each typical research strategy brings with its particular strengths and weaknesses […] combining methods provides appropriate checks against the weak points in each, while simultaneously enabling the benefits to complement each other.

This thesis combines both quantitative and qualitative methods to characterise the determinants of biophilic architecture in a cold climate. It draws on methods commonly used in evidence-based design frameworks and post-occupancy evaluations such as site visits, surveys and instrumental measurements of environmental conditions. This assists in identifying the architectural opportunities that could enhance occupant experiences and well-being in the context of renovating primary schools in Quebec. These different approaches illustrate the immense complexity, if not the impossibility, of a complete and objective reading of biophilia while recognising the importance of a subjective reading. Thus, the complementary strengths of the chosen methods compensate, where possible, for their weaknesses.

In the context of this research, multisensory experiences in the built environment can be seen as variables in a complex system, although they are not necessarily noted or noticed systematically by people in an integrated manner. Indeed, architectural ambiances result from a combination of diverse acoustic, thermal, visual and olfactory perceptions of the built environment. It is important to consider the ensemble they create in addition to their individual contribution to the experience of space. The methodological strategy acknowledges the complexity inherent to built environments and shares similarities with a systemic approach. Donnadieu et al. (2003) explain that complex systems, unlike simple systems, involve several variables whose effects of their interactions remain elusive. Additionally, as Thomas (1995) remarks, "You cannot meddle with one part of a complex system from the outside without the almost certain risk of setting off disastrous events that you hadn't counted on in other, remote parts". Given the interdependence of sensory experiences, this thesis considers that it becomes necessary to understand the system of environmental and architectural parameters. To do so, architects need to analyse and to represent these ambient parameters before seeking to improve them to foster positive experiences of nature.

Discussing multisensory stimuli contributes to a more precise representation of complex situations. Due to the interrelation of the senses, an optimal lighting atmosphere, for example, may not foster delight if thermal or acoustic conditions appear unsatisfactory. In this sense, the overlapping interactions among sensory systems are considered as an essential characteristic of daily experiences in buildings. Therefore, this thesis focuses on wide-ranging sensory, scalar and seasonal considerations for biophilic experiences rather than an in-depth examination of a single sensory system at a particular building scale in a specific season. This enables a more holistic understanding of biophilic design than in previous studies, which have typically examined its desirable outcomes for the health and well-being of building occupants with restricted descriptions of architectural settings (as previously discussed in the Introduction and further presented in Chapter 1). In turn, this can inform design decisions in early stages of renovation projects.

The analysis of existing primary schools in Quebec to understand current biophilic experiences was facilitated by the research project Schola. Within this project, information was collected from diverse sources with different methods offering the potential for data triangulation. For a random sample of 308 schools, the Ministry of Education and local school boards provided information related to building occupants (such as the number of students and school staff) as well as data concerning the buildings themselves (such as construction date, floor plans and current uses). An online survey conducted by the Schola research team provided insights into how school staff perceive their work environment. Appendix B presents some of the survey results that relate to issues discussed in this thesis. The agreements between school boards and Schola facilitated the organisation of visits to schools within the sample. This enabled more intrusive methods to be used in certain phases of the research process. Thus, the research being conducted by other members of the Schola project provided the opportunity for the present research to focus on multisensory experiences in primary school settings.

The research presented in this thesis combines different methodological strategies in a sequence of distinct phases. The reliance on multiple sources of evidence gathered by quantifiable or qualifiable approaches enables data to converge in a triangular fashion in the concluding chapter of this thesis. An advantage of this approach is that the materials and methods associated with each strategy are presented distinctly in each chapter. The outcomes and lessons that designers can learn from using each diagnostic and design tool are further discussed independently based on the data collected. However, a disadvantage of this approach is the potential for a perceived lack of connection or coherence among the strategies. Each chapter therefore begins with a brief explanation of how the strategies are complementary and conceptually linked. It further presents how they inform the larger thesis objective of fostering sensory experiences in biophilic school architecture.

The level of complexity of the thesis and the diagnostic and design tools proposed in each chapter are represented in Figure 19. It presents the variety of approaches used at each stage of the research. Theoretical aspects of the research framework are presented in Chapter 1 as a result of a narrative review. The insights collected then served in Chapters 2, 3 and 4 to discuss the diagnosis of physical environments and biophilic principles linked to school environments. Based on architectural drawings, on-site visits during different times of the year, analyses of architectural precedents and architectural workshops, this thesis integrates a wide variety of analysis methods, thus enabling the creation of diagnostic tools based on the analysis of real school environments. Finally, Chapter 5 presents explorations linked to the creation of interior-exterior interfaces. This process and these tools allow designers to begin with methods that are less disruptive for students and school staff and to target specific issues or areas of the school to conduct activities that could potentially be more disruptive for building occupants. It also enables designers to begin with simple analyses and to follow up with more complex analyses throughout the design process.

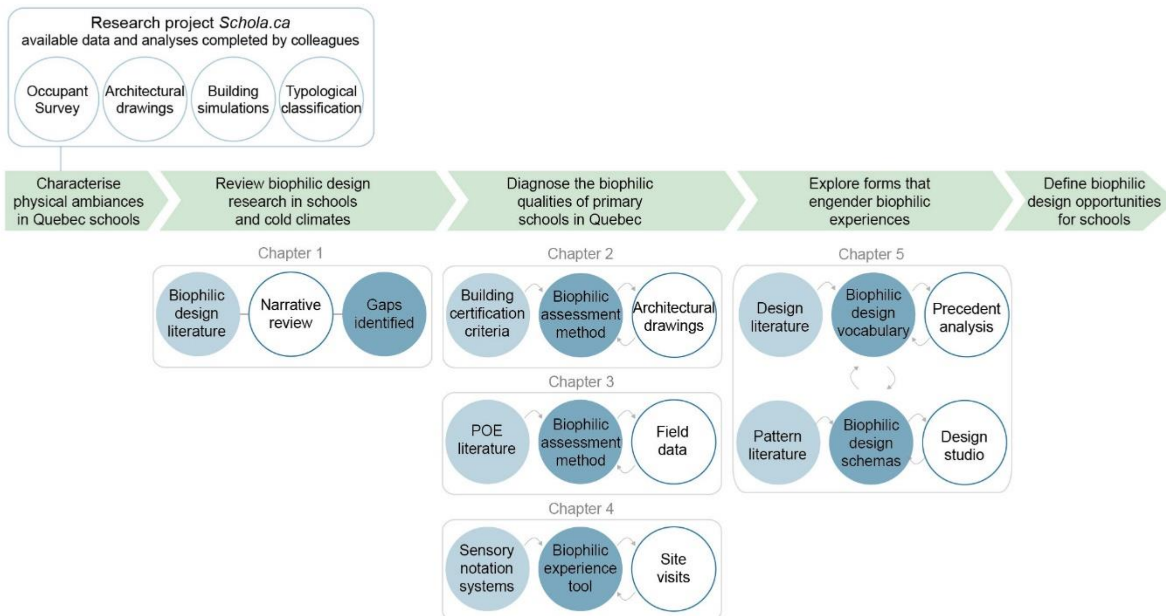

Figure 19. Diagram of the research process, aims and methods.

A representative sample of schools was investigated in the different phases of the research to obtain detailed and nuanced information on multisensory experiences of nature embedded in the real-life context of primary schools in a cold climate. Three schools were selected to serve as a base line for the different tools developed in the thesis. Among the sample of schools used by Schola, these schools were chosen to reflect common construction periods, site implantation, spatial configurations, floor area, number of floors and student population in Quebec (Table 1). The three buildings are identified as Schools L, T and C based on their spatial configuration. Addressing the same three schools through different lenses in the thesis enabled cumulative learning. As previously discussed, analyses of nature experiences that can directly inform architectural design account for a smaller portion of existing research. Previous research has generally focused either on people’s perception of nature experiences and their self-reported evaluations, measurable health or performance benefits of nature settings, the spatial geometry of buildings or measures of environmental conditions. Increasing and combing these research approaches would enable a representation of subjective and objective aspects of biophilic experiences that could help architects to design biophilic settings during the preliminary design stages and to validate their biophilic qualities during post-occupancy evaluations. In this sense, the information learnt from an analysis based on spatial geometry (Chapter 2) was then used to prepare and conduct site visits (Chapter 3). This facilitated the selection of spaces to analyse and issues to further document. Subsequently, the measurable outcomes from the spatial and *in situ* analyses served to discuss subjective experiences in relation to the architectural and environmental variables (Chapter 4). In addition to analysing the current state of the schools in terms of multiple variables, it became possible to explore the potential future state of these schools based on current needs.

Table 1. Main characteristics of the schools analysed in the chapters of the thesis.

School characteristics								Thesis chapters				
School	Spatial configuration	Date of construction	Date of building addition(s)	Storeys	Total floor area (m^2)	Students (2018)	City	2	3	4	5[1]	5[2]
L	L	1949	1968	4	5442	197	Quebec	●	●			
T	T	1961	1966	3	6811	346	Quebec	●	●	●		
C	compact	1983	1997	2	6083	376	Quebec	●	●	●	●	●
1	linear	1922	1997	4	4970	186	Quebec				●	
2	L	1951	-	2	2953	328	Levis				●	
3	L	1952	1974	3	5218	63	Quebec				●	
4	T	1953	1985 1990	2	3836	493	Quebec				●	
5	L	1956	-	3	2773	213	Quebec				●	
6	linear	1962	-	3	1391	136	Neuville				●	
7	linear	1910	1959 1978	3	3603	196	Montreal					●
8	L	1923	1929 1938	4	4231	432	Montreal					●
9	T	1949	-	3	5049	395	Saguenay					●
10	L	1963	-	2	1977	230	Montreal					●
11	compact	1975	1997 2001	2	5069	509	Quebec					●
12	compact	1983	-	1	3564	314	Sorel-Tracey					●

[1] Design studio taught by professors Claude Demers and André Potvin, Université Laval.

[2] Design studio taught by professor Mark Dekay, University of Tennessee Knoxville.

Renovation and building addition scenarios were generated in two design studio courses based on the knowledge gathered from the analyses in preceding chapters. This aimed to address current gaps in the biophilic design literature such as the lack of consideration for winter and of guidance on spatial configurations fostering biophilic experiences. It responds to the need to offer designers an ensemble of renovation interventions to improve the quality of the indoor environment given the variety of site implantations, spatial configurations and facade designs of primary schools in Quebec. The design tools developed in this thesis and used by architecture students in these studios draw inspiration from design guidelines and rules of thumb targeted at designers with other aims. As explained in Chapter 5, they present similarities with the analysis techniques and design strategies offered by DeKay and Brown (2014) as well as the pattern language developed by Alexander et al. (1977). The first exploration took place during the winter 2019 semester in the design studio led by Claude Demers and André Potvin at *Université Laval*. In teams of three or four, 30 master students in architecture developed design proposals for seven primary schools in the Quebec City area. This design studio course explored the environment-comfort equation through the systemic study of thermal, lighting and acoustic environments. Students had to consider how multiple natural fluxes, including sun, wind, ice and snow, impacted their design proposals. The aim of the systemic approach was to optimise the energy performance of a proposed architectural design as well as the health and comfort of the occupants while minimising the negative impacts on the environment in terms of energy and resources. Using bioclimatic design tools, designers can therefore modulate, firstly, the indoor-outdoor interface using architectural variables to resolve the environment-health-comfort equation and secondly, integrate, if necessary, mechanical systems. This systemic approach required an investigation at the urban (local microclimate effects), architectural (spatial organisation of the building), and material (physical and environmental properties of materials) scales. The second exploration occurred during the fall 2019 semester in the Integration Design Studio taught by Mark DeKay at the University of Tennessee, Knoxville. In teams of two, fourteen fourth-year architecture students developed design proposals for seven schools throughout the province. The reflections and tools developed as part of this thesis were shared with the students during weekly supervision meetings and critics during the semester. The outcomes from both studios in relation to the biophilic design issues of the thesis are presented in

Chapter 5. Table 1 summarises the main characteristics of the schools analysed in the different chapters of this thesis. It emphasises the three schools investigated in more than one chapter and further illustrates the different lenses that were used to better understand each school. This is particularly applicable to School C which was used in each stage of the research, including in both design studios. Synthesised in the concluding chapter of the thesis, the combined analysis of spaces in these schools is thus more complete due to the complementary nature of the chosen approaches.

In sum, this thesis uses a spiral diagnostic and design process and a combination of quantitative and qualitative methods in a sequence of research phases to generate both knowledge about biophilic design and contribute to real-world solutions in the context of renovating primary schools in Quebec. It rests on knowledge exchange and multidisciplinary conversation. In this sense, the thesis incorporates aspects of biophilia and biophilic design which have been discussed in many design fields in addition to fields such as environmental psychology and health sciences. Similarly, to better inform the renovation of schools, members of the Schola project have research interests in complementary fields, such as education and interior design. Combining perspectives from these fields offers the potential to provide a more complete understanding of experiences of nature in architecture. It can also generate positive outcomes for the diverse school stakeholders, including school children, teachers and building managers, who would ultimately benefit from design decisions supported by credible evidence that considers the particularities of cold climate schools to create multisensory experiences of nature.

Chapter 1 Biophilic school architecture in cold climates

This chapter provides insights into the gaps in current knowledge of biophilia in cold climates. Using a narrative review method, literature regarding biophilic design, cold climates and learning environments is synthesised. The implications for the application of biophilic design principles in cold climate schools is discussed. The findings aim to support the development of renovation projects on existing school buildings based on reliable and credible knowledge. This chapter presents the article "Biophilic school architecture in cold climates" by Mélanie Watchman, Claude M. H. Demers and André Potvin. It was published in the journal *Indoor and Built Environment* (Volume 30, Issue 5, Pages 585–605) and is available online since March 2020 (https://doi.org/10.1177/1420326X20908308).

1.1 Résumé

La conception d'écoles offrant une expérience satisfaisante de la nature et améliorant le bien-être serait avantageuse pour les enfants et le personnel scolaire, mais dans les climats froids, les périodes prolongées de précipitations, l'ensoleillement limité et les températures basses peuvent représenter un obstacle. Cet article recense la recherche sur les relations entre le design biophilique et le bien-être, avec une attention particulière pour les environnements scolaires en climat froid. Les élèves passent beaucoup de temps à l'école et la plupart de leurs activités d'apprentissage se déroulent à l'intérieur. L'article cerne les lacunes actuelles des stratégies d'architecture biophilique et identifie l'importance des conditions climatiques pour créer des expériences satisfaisantes de la nature. Pour que la recherche sur le design biophilique conduise à des écoles plus saines et plus confortables, qui connectent davantage les espaces d'apprentissage et l'environnement naturel, il importe de définir des recommandations se traduisant facilement en architecture.

1.2 Abstract

Designing school settings that provide a satisfying experience of nature and enhance well-being could be advantageous for children and teachers, though in cold climates prolonged periods of precipitation, restricted sunshine and low temperatures represent non-ideal conditions for fostering a connection with nature. This paper reviews research into the relationships between principles of biophilic design and well-being, with specific

consideration for learning environments in cold climates. Children spend more time in school than any other place, except the home and most of their learning activities occur indoors. Given the large portion of the day children and teachers spend within the built environment, an architect's perspective investigates these relationships. The paper examines the concepts and research findings that appear to offer the greatest potential for future architectural applications in children's learning environments. It also identifies gaps in biophilic design strategies in relation to schools and the importance of considering climatic conditions to create satisfying experiences of nature within the built environment. If biophilic design research is to lead to healthier, more comfortable school settings that present a greater connection between learning spaces and the natural environment, then to identify and define beneficial guidelines that translate readily into architecture is essential.

1.3 Introduction

Biophilic architecture appeals to people's innate connection with nature. Growing evidence suggests that incorporating natural elements in built environments can offer satisfying experiences and be beneficial for the health and well-being of children and adults (Chawla, 2015; Faber Taylor & Kuo, 2006; Kellert et al., 2008). Given people's increased urbanity and time spent indoors, the need for architecture to contribute to well-being is even more essential. The design of children's main learning environment presents particular interest to integrate current knowledge of biophilic design and potential well-being outcomes because "elementary school children tend to spend the majority of their school time in one classroom with one teacher" (Heschong, 1999). Thus, this paper arises from an architect's perspective on research that might be useful to enhance these relationships in learning environments, especially in cold climates. Despite decades of research to support the biophilia hypothesis (Browning et al., 2014), little is known about biophilia in cold climates or during the winter (Brooks et al., 2017). Season can influence people's connection to nature in urban environments (Duffy & Verges, 2010) and it has been suggested that winter may decrease well-being given the limited availability of pleasant outdoor experiences (Nisbet et al., 2011) and the increased time spent indoors due to the cold weather. Children are particularly vulnerable to cold temperatures (Rasi et al., 2017) and school recreation time can be reduced or spent indoors if outdoor conditions are deemed unfavourable. In this context, biophilic school architecture could enhance the connection between indoor and outdoor spaces and encourage greater well-being.

This paper considers the Quebec City region of Canada to illustrate the climatic issues of biophilic school design in a cold climate. Many interpretations of cold climates and winter conditions exist based on considerations such as latitude, climatic elements, vegetation and cultural perceptions (Economic Commission for Europe, 2004). Building on definitions by Rogers and Hanson and the Winter Cities Forum, urbanist Norman Pressman defines a winter city as “one in which the average maximum daytime temperature is equal to or less than 32 degrees F. (zero Celsius) for a period of at least two months or longer” (Pressman & Mänty, 1988). However, perceptions of the cold may vary with different amounts of snowfall or temperatures. In all cold climates, five basic elements characterise winter: temperatures normally below freezing, precipitation usually in the form of snow, restricted hours of sunshine and daylight, seasonal variation and prolonged periods of cold temperatures, precipitation and restricted sunshine (Pressman & Mänty, 1988). Winter conditions in the province of Quebec, Canada, fit these criteria. According to the Köppen-Geiger climate classification (Peel et al., 2007), the climate in Quebec is categorised as continental cold with warm summers (Dfb) in the southern and most populated region, cold with cold summers (Dfc) between 51 and 58°N and polar tundra (ET) above 58°N.

1.3.1 Cold climate challenges in architecture

Cold climates can present challenges for human well-being, especially during winter. Northern regions experience more significant cold-related health problems than those caused by heat (Chen et al., 2016; Rasi et al., 2017). Regarding adaptation to the cold in northern latitude nations, Pressman (1985) provides two fundamental approaches. The first proposition, offer as much protection from the weather as possible, suggests that architecture should shield occupants from undesirable weather elements. As suggested by Olgyay (1963), given the human body’s limited physical capacity for adaptation to the environment, buildings should filter, absorb or repel undesirable conditions to provide liveable conditions. Pressman’s second proposition, do not overprotect man from nature, appears more in line with the biophilia hypothesis. It highlights the need to co-exist with nature, rather than hide from it. This approach favours adaptive actions “to endure nature’s inconveniences without heavy reliance on technology" (Pressman, 1985). This may be even more important in children's environments because the adaptive behaviours they learn can continue into adulthood. Given the negative impacts winter can have on health and well-being, investigating biophilic architecture as a means of enhancing winter's positive characteristics may offer opportunities for innovation in building design.

1.3.2 History and current conditions of cold climate learning environments

The transformation of architectural design over the past century indicates pendulum swings between buildings that connect occupants with the outdoor environment and those that create a disconnection. Traditionally, the design of buildings in cold climates enabled occupants to learn to co-exist with the outdoor environment. Strategies available to do this include maximising windows that permit passive solar heating and minimising windows that face the direction of prevailing strong winds and storms (Matus, 1988). Primary schools built in Quebec at the beginning of the 20th century offered an adapted response to the climate. Their design encouraged the use of daylight and natural ventilation while providing protection from the harsh winter winds. In the following decades, adaptation to climatic conditions often became secondary to other concerns, such as integration to existing infrastructure (Zrudlo, 1994). Thus, this later generation of buildings included more mechanical systems, such as electric lighting and mechanical ventilation, to provide pleasant indoor conditions. This often resulted in a greater disconnection between occupants and the outdoors. Rather than adapting to the climate, these schools overprotected students in classrooms with few or no windows. Similarly, the use of mechanical heating, cooling and ventilation systems tended to create uniform, predictable and automated indoor conditions, but as Heschong (1979) suggests, maintaining these unchanging environments is unnatural and ultimately requires a lot of energy.

Passive and low-energy buildings have begun to reverse this trend by creating comfortable buildings while avoiding the use of excessive mechanical systems. Relying on bioclimatic architectural strategies not only improves the environmental performance of a building, but also includes opportunities for increased occupant comfort (Cole et al., 2010). The goal of shifting to a lower-carbon society has led to new definitions of comfort that extend beyond the traditional physiological comfort of individuals (Cole et al., 2008). Pursuing a biophilic design approach appears to push the pendulum further towards buildings that consider their climatic and environmental context in order to promote the well-being of occupants. It adopts a more occupant-oriented approach by favouring dynamic, adaptable and participatory occupants that respond to the changing conditions of the indoor and outdoor environments (Figure 1.1). In this biophilic framework, technological solutions aim to imitate the natural environment rather than create indoor environments that appear disconnected from their settings. For example, shade automation and variable lighting provide changing environments that offer views to nature and pleasant indoor lighting settings that reflect natural changes throughout the day.

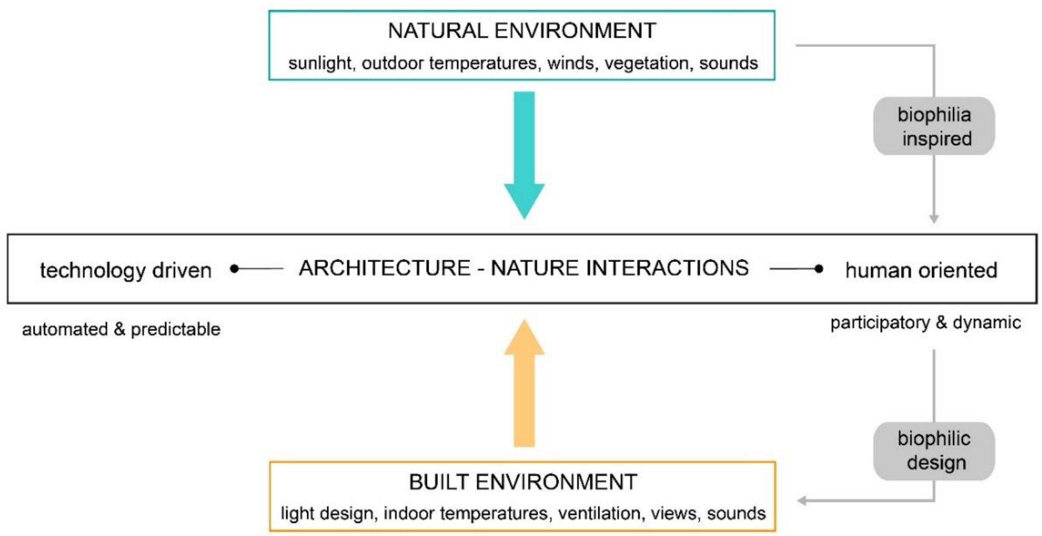

Figure 1.1 Position of biophilic design among different architecture-nature interactions.

1.3.3 Health priorities in schools

"Children spend more time in schools than in any other place except at home" (Bluyssen, 2017). The current disconnection between urban children and natural systems has implications for their current and future well-being. Growing research indicates that a connection with nature and the outdoor environment may contribute to adult and child well-being in learning settings. The reported benefits include increased physical activity, enhanced child development, better learning and achievement and improved social behaviour as well as less stress, inattention and hyperactivity symptoms and absenteeism (Chawla, 2015; Gill, 2014; McCurdy et al., 2010).

Two frameworks explain the well-being benefits of contact with nature: attention restoration theory and stress recovery theory. Attention restoration theory (ART) suggests that exposure to nature replenishes the cognitive resources needed to direct or maintain attention for an extended period of time (Kaplan & Kaplan, 1989; Kaplan, 1995). Urban environments capture interest dramatically and require more directed focus (e.g., to avoid collisions with moving vehicles), while natural environments, filled with intriguing stimuli, only moderately require attention (e.g., sunsets) (Berman et al., 2008). Stress recovery theory (SRT) draws on evidence of how natural environments can reduce physiological arousal following stress (Ulrich, 1983; Ulrich et al., 1991). The benefits are argued to arise from interest in and positive appraisals of natural environments that are appropriate to the situation or encourage behaviours to foster well-being (Ulrich et al., 1991). The impacts of school buildings on health and cognitive performance therefore deserve consideration from an architect's point of view to further determine which architectural strategies can enhance these benefits.

Considering the growing number of reviews on the relationships between biophilia and well-being (Blair, 2009; Chawla, 2015; Faber Taylor & Kuo, 2006; Lester & Maudsley, 2007; McCurdy et al., 2010; Soderlund & Newman, 2015), this paper further examines the gaps in our current knowledge of biophilia in cold climates in the hope of encouraging future research on architectural strategies that can enhance well-being in learning spaces. The search for relevant referred articles and chapters in academic books used keyword combinations including nature, biophilia, biophilic design, cold climate, child, school, well-being, daylight, temperature, ventilation and sound in the databases of Web of Science, Avery Index to Architectural Periodicals, PsycInfo and ERIC (Education Resources Information Center). The documents discussed in this paper emerge from the fields of architecture (49), environmental psychology (30), health sciences (24), landscape architecture (9), environmental sciences (5) and interior design (3). Using a narrative review method, literature regarding biophilic design, cold climates and learning environments is synthesised to provide an understanding of the current knowledge. Beginning with an analysis of existing biophilic guidelines and how they can relate to learning environments, the core of this paper examines climate considerations affecting biophilic design, namely sunlight, cloud coverage, temperatures, natural ventilation and the variety in nature's colours, sounds and smells. It concludes with a discussion on the implications for biophilic school design in cold climates.

1.4 Biophilic design guidelines applicable in schools

Biophilic design guidelines present the qualities and conditions of nature that should be expressed in biophilic architecture. The term "guideline" refers to the general rules or principles that help architects and designers make decisions. Researchers and practitioners attempt to define these guidelines based on different important aspects of the human-nature connection. Five complementary documents exist to emphasise a feeling of nature in the built environment. These guidelines do not specifically concern cold climates; although most design principles remain relevant to cold conditions, they may require adjustments given the seasonal variability of nature. Kellert et al. (2008) present a detailed classification that includes a variety of ways to incorporate nature in the built environment. The 71 design principles proposed by these authors are regrouped in six design categories. Overall, two general dimensions emerge: organic or naturalistic and place or vernacular. The three biophilic design categories in Kellert and Callabrese (2015) appear to simplify and subdivide differently these design principles distinguished in previous work by Kellert et al. (2008). This classification, including direct experience of nature, indirect experience of nature and experience of space and place, shares similarities with the three categories found in Browning et al. (2014): nature in the space, natural analogues and nature of the space. Used by Terrapin Bright Green LLC in consultancy projects, these general and broad categories seem simply communicable to non-architects during the design stages. Environmental psychologist Judith Heerwagen (Heerwagen & Gregory, 2008; Heerwagen & Hase, 2001) offers similar recommendations regarding the principles of biophilic design. These concise lists, that overlap with the more comprehensive list proposed by Kellert et al. (2008) emphasise the characteristics associated with people's preferences for nature. They express the qualities of biophilic architecture (e.g., serendipity, variations on a theme, resilience, sense of freedom) without referring to specific features of the built environment. Overall, the distinctions and classifications made by authors from different fields illustrate that biophilic design remains flexible and adaptable to new perspectives and future knowledge.

A detailed analysis of the biophilic design recommendations presented by these authors in diverse publications reveals over 80 design principles (Table 1.1). Building on the previously made distinctions between different biophilic design principles and the learning opportunities they provide, five categories are proposed to analyse biophilic design in school environments.

The principles within each category are organised according to the frequency of citation and then in alphabetical order. The first category, “natural features”, evokes a contact with nature through the senses. The principles included in this category encourage visual, thermal, olfactory and auditory connections with nature. Secondly, “natural patterns and processes” refer to changes that can be found in nature. This includes the daily and seasonal variations of the natural environment. It also considers connections and sequences among spaces in a building, with principles such as transitional spaces. Thirdly, “natural shapes, patterns and forms” allude to natural or man-made elements that draw inspiration from designs found in natural settings. Fourthly, “connection to place” regroups notions of geography, history, ecology and culture to create a sense of *genius loci*. Finally, human-nature relationships aspire to form bonds with the natural environment. This includes notions such as prospect, refuge, order, complexity and change.

Table 1.1 Biophilic design principles presented by various authors.

Biophilic principles	1	2	3	4	5	Biophilic principles (continued)	1	2	3	4	5
Natural features											
Air	•	•	•		•	Light and shadow		•	•		
Natural materials	•	•	•		•	Light pools		•	•		
Plants	•	•	•		•	Simulation of natural light and air	•	•			
Sunlight / Natural light	•	•	•		•	Weather	•	•			
Water	•	•	•		•	Biodiversity					•
Animals	•	•	•			Filtered and diffused light			•		
Colour / Natural colours	•	•	•			Light as shape and form			•		
Views and vistas		•	•		•	Non-visual connection with nature		•			
Facade greening		•	•			Reflected light			•		
Fire	•		•			Visual connection with nature		•			
Geology and landscape		•	•			Warm light			•		
Habitats and ecosystems	•		•								
Patterns & processes											
Sensory variability		•	•		•	Evoking nature	•				
Age, change and the patina of time	•		•			Growth and efflorescence			•		
Fractals			•		•	Hierarchically organized ratios and scales			•		
Integration of parts to wholes	•		•								
Bounded spaces			•			Linked series and chains			•		
Central focus point			•			Non-rhythmic sensory stimuli		•			
Complementary contrasts			•			Patterned wholes			•		
Dynamic balance and tension			•			Transitional spaces	•		•		
Shapes, patterns, forms											
Biomimicry	•		•		•	Egg, oval and tubular forms			•		
Biomorphic forms & patterns		•	•			Geomorphology			•		
Images of nature	•	•				Inside-outside spaces			•		
Naturalistic shapes and forms	•				•	Natural geometries	•				
Shapes resisting straight lines			•		•	Shells and spirals			•		
Simulation of natural features		•	•			Space as shape and form			•		
Animal (mainly vertebrate) motifs			•			Spaciousness			•		
Arches, vaults, domes			•			Spatial harmony			•		
Botanical motifs			•			Tree and columnar supports			•		
Place connection											
Cultural connection to place	•		•			Indigenous materials			•		
Ecological connection to place	•		•			Integration of culture and ecology			•		
Landscape ecology		•	•			Landscape features defining building form			•		
Avoiding placelessness			•								
Geographic connection to place			•			Landscape orientation			•		
Historic connection to place			•			Spirit of place			•		
Human-nature relationships											
Prospect & refuge	•	•	•	•	•	Mastery & control			•		
Change & metamorphosis		•	•			Motion				•	
Information & cognition		•	•			Resilience				•	
Mobility & way-finding	•	•				Reverence & spirituality			•		
Mystery / Curiosity & enticement			•		•	Security & protection			•		
Order & complexity	•		•			Sense of freeness				•	
Affection & attachment			•			Sense of playfulness					•
Attraction & beauty			•			Serendipity				•	
Exploration & discovery			•			Variations on a theme				•	
Fear & awe / Risk-peril			•								

[1] Kellert & Calabrese, 2015. [2] Browning et al., 2014. [3] Kellert et al., 2008. [4] Heerwagen & Gregory, 2008. [5] Heerwagen & Hase, 2001.

Prospect and refuge are the only principles considered by all five publications. Prospect emphasises long open views and the identification of opportunities and danger. For urban schools or interior school spaces, prospect can be expressed through the ability to see from one space to another or through multiple spaces. Refuge, on the other hand, reflects the provision of a safe and protected setting. This can be interpreted as weather protection, speech or visual privacy and reading nooks (Browning et al., 2014). Several biophilic principles are presented by at least four publications; these include water, air, sunlight, plants and natural materials. As these principles offer a direct contact with nature, they also represent a learning opportunity for children. Children learn in schools, but also from the school environment. As Orr (1993) suggests, "buildings that invite participation can help students acquire knowledge, discipline and useful skills that cannot be acquired other than by doing". In this sense, the most valued biophilic design principles in school settings may be those that bring awareness to the interconnections between natural and built environments.

Some of the qualities of biophilic design can be quantified and measured in the built environment, such as light quantities and sound levels. However, several principles allude to the subjective experience of space. In terms of auditory stimuli, for example, biophilic design is more directly informed by psychoacoustics (the perception of sound) than by building acoustics. This distinction between measurable and perceivable biophilic design principles could in part explain their unequal documentation in terms of health and well-being benefits. Studies examining well-being in learning environments can be grouped in two broad categories: those investigating the negative impacts of undesirable settings and those oriented towards positive impacts of an enhanced connection with nature. The following section reviews associations between biophilic design principles critical in cold climates and impacts on well-being in learning environments (Table 1.2).

Table 1.2 Selected occupant-related benefits of biophilic design principles for studies performed in learning environments.

Critical biophilic design principles	Examples of references			Occupant-related benefits	Good health	Child development	Learning achievement
		School context	Country				
Natural outdoor surfaces and plants							
Vegetation volume and grass covering	Bagot et al., 2015	14 schools, 550 children (mean 9.73 years)	Australia	Increased perceived restorativeness	+		
Wooded area for recess play	Chawla et al., 2014	2 primary and 4 high schools, 258 children (6-13 years)	USA	Less stress, more competence, supportive social groups and improved focus	+	+	+
Vegetative (bamboo, flowering shrubs, grass) and natural (boulders, gravel, sand, stone pavers) surface materials	Brussoni et al., 2017	2 childcare centres, 45 children (2-5 years)	Canada	Less depressed affect, stress and injury. Improved self-confidence, problem-solving, focus and creativity	+	+	+
Increase greenery (shrubs and plants)	Kelz et al., 2015	3 middle schools, 133 children (13-15 years)	Austria	Low physiological stress levels, increased psychological well-being and perceived restorativeness	+		
Green land cover (grass, shrubs, trees)	Kweon et al., 2017	219 schools	USA	Higher mathematics and reading performance			+
Views of trees and shrubs (vs. built space or no view)	Matsuoka, 2010	101 high schools	USA	Higher standardised test scores and graduation rates			+
Higher values on normalised difference vegetation index	Dadvand et al., 2015	36 primary schools, 2593 children (7-10 years)	Spain	Reduced exposure to air pollution and inattentiveness. Enhanced working memory	+		
Time spent outside							
7 daily outdoor hours	Ulset et al., 2017	562 children (mean 4.37 years)	Norway	Reduced inattention-hyperactivity symptoms. Better memory test scores	+		
1 additional hour of outdoor time per week	Yang et al., 2018.	166 children (6-8 and 11-13 years)	Canada	Reduced prevalence of myopia	+		
View to nature							
Views of trees and shrubs (vs. built space or no view)	Matsuoka, 2010	101 high schools	USA	Higher standardised test scores and graduation rates			+
Views of green space (vs. built space or no view)	Li & Sullivan, 2016	5 high schools, 94 students	USA	Better recovery from stress and task performance	+		+
Simulated nature (vs. built space or no view)	Felsten, 2009	1 university, 236 students (mean 23.2 years)	USA	Increased perceived restorativeness	+		

(continued)

Table 1.2 Continued.

Critical biophilic design principles	Examples of references			Occupant-related benefits	Good health	Child development	Learning achievement
		School context	Country				
High daylighting levels							
5-point scale (adequate daylight to no windows)	Heschong, 1999	2000 classrooms	USA	Higher mathematics and reading performance			+
Average classroom illuminances vary between 200 lux and 3800 lux	Küller & Lindsten, 1992	4 classrooms, 90 children (8-9 years)	Sweden	High levels of morning cortisol associated with sociability, moderate or low levels promote individual concentration		+	
Short wavelength morning light	Figuerio & Rea, 2010	1 middle school, 11 children (13-14 years)	USA	Entrainment of the circadian system	+		
Natural ventilation / air quality							
5-point scale (adequate to no windows)	Heschong, 1999	2000 classrooms	USA	Faster educational progress			+
Air pollution (O3, PM10)	Gilliland et al., 2001	2081 students	USA	Increased respiratory problems and absenteeism	−		−
Increased airflow rate (3 to 8.5 L/s/person)	Wargocki & Wyon, 2007b	2 classrooms, children 10-12 years		Increased task performance			+
Ventilation mode	Toftum et al., 2015	820 classrooms in 389 schools	Denmark	Lower achievement indicator in naturally ventilated schools than in balanced mechanically ventilated schools			-
Increased outdoor airflow rate	Smedje & Norbäck,	39 primary and high schools, 1476 children	Sweden	Reduction of asthmatic symptoms	+		
Air pollution (CO2, VOC, HCHO)	Daisey et al., 2003		Review	Increased risks for allergen sensitivities, chronic irritation	−		
Increased airflow rate (1 to 8 L/s/person)	Bakó-Biró et al., 2012	8 primary schools, >200 children	England	Increased task performance			+
Temperature							
Reduction from 25°C to 20°C	Wargocki & Wyon, 2007a	166 children (6-8 and 11-13 years)		Improved academic performance			+
Noise							
Reverberation and noise	Klatte et al., 2010	21 classrooms, 487 children	Germany	Better speech perception and short-term memory			+
Aircraft and road traffic noise	Paunović et al., 2011		Review	Increased blood pressure	−		
Road traffic noise	Xie et al., 2011	96 high schools	England	No association with academic achievement indicators			±

+: positive association; −: negative association; ± no significant association.

The reported associations between biophilic design principles and the health, level of achievement and well-being of children indicate that architects should not only avoid creating undesirable settings, but also aim to achieve an enhanced connection with nature. Special consideration should be given to school site selection, schoolyard design and building design to maximise the biophilic potential of indoor spaces. Additionally, daylight, natural ventilation, pleasant temperatures and enjoyable sounds should play an important role in the design of learning environments. The perception of these biophilic design principles presents diversity in cold climates due to seasonal variability. The climatic context of learning environments therefore represents an unavoidable consideration that may alter the expression of nature in the built environment.

1.5 Climate considerations affecting biophilic design

In cold climates, nature is expressed in distinct seasons that present great variety and variability. Pressman (1988), in conjunction with the winter cities movement, promotes appreciating "the value of each and every season with all of nature's shifting nuances". In a biophilic design approach, the design of indoor learning spaces should respond to the availability of natural elements to provide sufficient connection between indoor and outdoor spaces throughout the year. The design of outdoor spaces around the school should also be sensitive to these seasonal variations, given the potential influences of the outdoor microclimate on the quality of the indoor environment. Children in Quebec attend school from September to June and therefore experience most of the school year during winter. Although cold weather is not an obstacle to children's outdoor life, it shortens the duration of outdoor activities, even during relatively mild winters, which results in more time spent indoors (Ergler et al., 2013). In Canada, the outdoor physical activity of children and adolescents is higher during summer months than in winter months (Bélanger et al., 2009; Castonguay & Jutras, 2010). Swedish architects Ralph Erskine and Boris Culjat (1988) suggest that the comfortable outdoor season can be extended up to six weeks using microclimatic design principles. Outdoor microclimates emerge from the interaction of weather conditions and landscape design parameters. Studies show that site geometry, vegetation, water bodies and pavement features represent some of the major microclimate design parameters influencing human comfort in the outdoor environment (Y. Li et al., 2019). By adding a biophilic component to microclimatic design, the outdoor climate would not only be comfortable, but also contribute to people's well-being. Furthermore, providing children and teachers with opportunities to adapt to seasonal variations could enhance indoor well-being. This suggests that biophilic architecture in cold climates should consider the cyclic variability of natural elements such as sunlight, outdoor temperatures, colours, sounds and smells.

1.5.1 Sunlight availability

"Light can affect human behaviour, mood and health via pathways other than the visual system" (Figueiro, 2013). The non-visual processing of light over time is primarily performed by the intrinsically photosensitive retinal ganglion cells (ipRGCs) in the eye. These cells along with rods, cones and various connector cells transmit neural signals to the suprachiasmatic nucleus (SCN), the body's circadian clock. Sunlight availability, intensity and the presence of a specific range of wavelengths of light to which ipRGCs are sensitive signal the body to suppress levels of the sleep-related hormone melatonin in order to increase feelings of alertness (Boyce, 2010). The circadian system is particularly sensitive to short wavelength (450 nm to 480 nm) light (Rea et al., 2002). Sunlight is an excellent source of appropriate light, especially compared to most electric lighting solutions which lack light at this wavelength. Lighting that is variable in illuminance and colour temperature can improve general conditions for school learning and has been shown to improve student performance and contribute to a positive evaluation of the environment (Barkmann et al., 2012). Research by Wessolowski et al. (2014) also suggests that variable light could "reduce pupil's restlessness and improve their social behaviours".

Although various metrics exist to characterise and quantify the non-visual effects of light on the circadian system, the approximated measures appear sufficient to draft guidelines for the built environment (Enezi et al., 2011; R. J. Lucas et al., 2014). The WELL Building Standard adopted equivalent melanopic lux (EML) criteria to account for the response to light of the non-visual photoreceptors (ipRGCs) in the human retina (WELL Building Institute, 2018). If only electric light is available, it requires exposure above threshold levels that range from 150 EML to 240 EML and slightly less (120 to 180 EML) with a combination of electric and daylight. While electric lighting with adequate EML could contribute to positive indoor environments, exposure to sunlight appears the simplest way to obtain the appropriate quantity, spectrum, timing and duration needed for circadian health. In this sense, classrooms without windows should be avoided for permanent use because they disturb the chronobiological system regulating the production of hormones (Küller & Lindsten, 1992). A study of students (ages 13-14) has found that removing short wavelength (blue) light in the morning hours delays the circadian phase, which likely delays sleep times as well (Figuerio & Rea, 2010). It therefore seems necessary to expose students to short-wavelength light at the beginning of the day. Research to understand the human circadian system remains in development and until interactions and side effects are identified, architects and designers should use caution when manipulating light (Boyce, 2003).

In northern latitudes, the availability of daylight linked with seasonal change can affect mental health and well-being. Individuals that experience seasonal affective disorder suffer from depression and negative moods during the winter months (Sigmon et al., 2007; Westrin & Lam, 2007). Even people without a clinical diagnosis express feeling the “winter blues” at times (Keller et al., 2005). Lack of sunlight is the main cause of this disorder, but other factors may be involved, such as increased time spent indoors and the proportion of cloudy days. Thus, “in northern latitudes, the importance of daylight must never be underestimated” (Matus, 1988).

In terms of school environments, the abundance of natural light in classrooms has been associated with higher learning performance. A study by the Heschong Mahone Group (1999) analysed the exposure to daylight in 2,000 classrooms in California, Colorado and Washington State. Results indicated that students exposed to more daylight throughout the year progressed faster on mathematics (20%) and reading (26%) tests than students with less daylight in their classrooms. Rather than being a distraction to the learning process, windows provide relief to students and fulfil their biological needs. Biophilic school design should therefore favour natural light as a main light source in frequently used spaces.

Primary school children in Quebec City are exposed to sunlight during teaching hours (usually 8 a.m. to 3 p.m.) throughout the year (Figure 1.2). However, most children use in-school childcare services that are provided before and after school, typically between 7 a.m. and 8 a.m. and again between 3 p.m. and 6 p.m. (Després et al., 2017). Given the limited out of school hours during which children are exposed to sunlight, it appears important to enable children to obtain enough sunlight exposure while in school. In terms of daylight availability in this cold climate, the most critical period is after school during the winter, when sunset occurs as early as 4 p.m. Early sunsets and cloudy skies limit the quantity and duration of sunlight in the outdoor environment, especially during winter. However, the high albedo of snow can enhance the reflections of natural light on the ground and brighten both the outdoor and indoor environments, provided there are adequate reflective indoor surfaces. The sun is the main source of daylight, but reflections from the sky, the ground and adjacent objects and surfaces contribute to externally reflected daylight. Typical school ground surfaces include asphalt and grass that have low reflectance values (below 10%), but in winter, fresh snow has a reflectance of 74% (Illuminating Engineering Society [IES], 2011). Snow accumulations in the school yard during extended periods of darkness therefore reflect light and brighten the outdoors. Ground-level light reflections can also impact light exposure in indoor learning environments provided architectural features, such as light shelves or white ceilings, contribute to capturing and dispersing this light. The biophilic design principles regrouped in the categories "natural features" and "place connection" (Table 1.1) can contribute by increasing the amount of sunlight in classrooms.

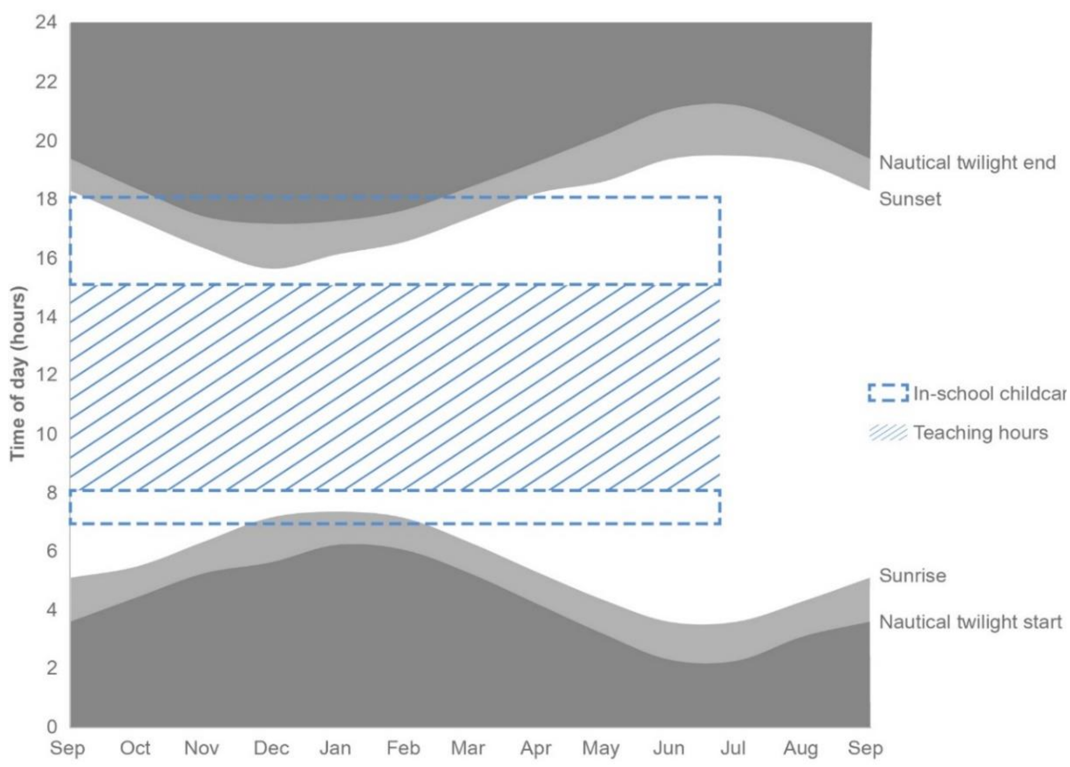

Figure 1.2 Daylight availability in Quebec City and primary schools operating hours, 2016-2017. Climate data from National Research Council Canada (2018).

Increased exposure to outdoor environments can contribute to children's health and cognitive development. Ulset et al. (2017) followed 562 Norwegian children in preschool over four years and documented their attendance, health, well-being and academic grades. The outcome was the observation of positive short- and long-term benefits between time spent outdoors and child development in preschool and the first grade. An increased amount of outdoor time also contributed to a reduction in the symptoms of inattention hyperactivity.

Increased time spent outside can also positively influence eye health. Deteriorating eye health is recognised as an increasing global problem, but recent studies indicate that increased time spent outdoors may protect young children from developing myopia (McCullough et al., 2016). A study of Canadian schoolchildren showed an increase in the prevalence of myopia from 6% to 28.9% between the ages of six and 13 (Yang et al., 2018). However, the study also showed that "one additional hour of outdoor time per week lowered the odds of a child having myopia by 14.3%". The positive effects of time spent outdoors may be explained by exposure to the high light intensity, the chromaticity of daylight or increased vitamin D levels (Ramamurthy et al., 2015). Hence, as indicated by Kocak and Sherwin (2016) increasing time spent outdoors represents, in most environments, a low-cost way to delay the development of myopia and its progression with little additional risk for children. While increasing the time spent outside in a school context is an administrative decision, architects can contribute to creating a pleasant outdoor microclimate. This enables children to play outside longer, to benefit from available sunlight before early winter sunsets and to have a direct and multisensory contact with nature. School buildings should therefore generate a pleasant outdoor microclimate to encourage outdoor activities especially during the winter.

1.5.2 Cloud coverage

Cloud coverage hinders the presence of direct sunlight indoors and produces diffuse light conditions. Sky conditions are typically described as clear, overcast or partly overcast, even though various types of cloud coverage can be found throughout the day (Jafarian et al., 2017; Poirier et al., 2017). In Quebec City, overcast to partly overcast skies occur 63% of the year (Demers, 2001). The sky is typically covered 8 to 10 tenths in this Nordic city, especially during winter when over 400 hours of cloud coverage are observed (Figure 1.3). This reduced presence of direct sunlight impacts the visual appreciation of the indoor environment. Direct sunlight generates high contrasts and produces sharp shadow patterns (Demers & Potvin, 2016). Contrarily, diffuse light means less sunlight intensity and less shadow variations. Drawbacks of daylighting strategies include glare and thermal discomfort. Direct sunlight can create undesirable reflections or reduce contrast for interactive whiteboards, laptops and tablets that result in disability glare (Winterbottom & Wilkins, 2009). Additionally, solar gain can produce thermal asymmetries between classrooms with opposite orientations and decrease comfort. Teachers and students can overcome these issues by using window-shading devices, although their sustained use limits visual connections with the outdoor environment.

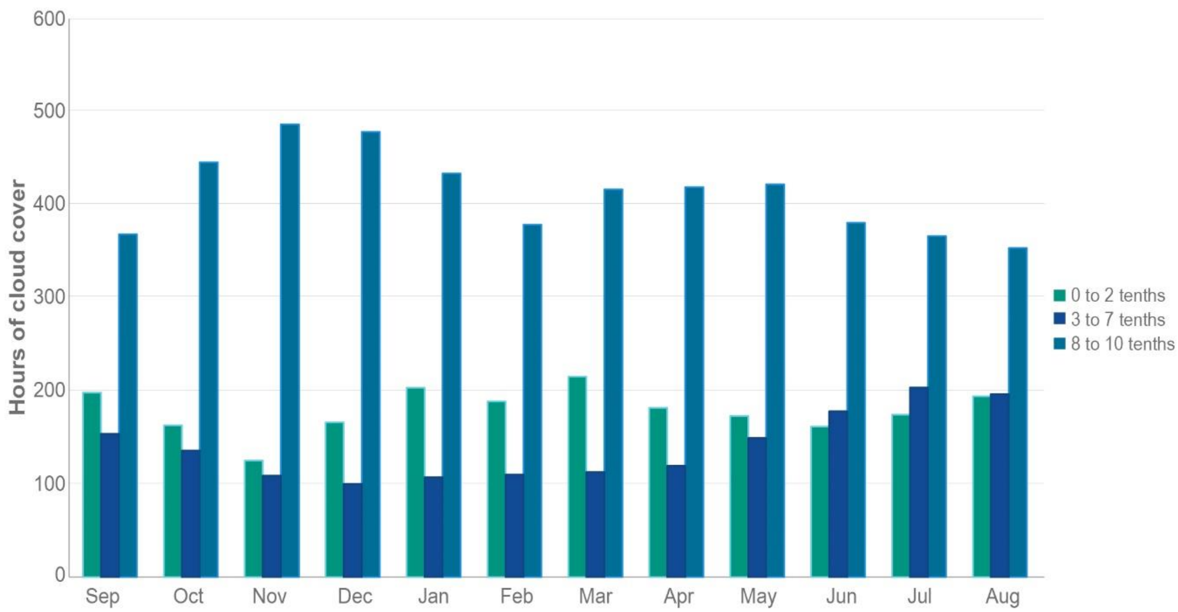

Figure 1.3 Hours of cloud cover in Quebec City, 1980-2010 monthly averages. Data from Environment and Climate Change Canada (2018a).

While natural light is a key biophilic design element, the sunlight supply diminishes with increasing latitude. Design strategies used in multiple climates to improve daylight exposure may therefore need adjustments at higher latitudes. The architectural strategies that make tangible the principles in the “natural features” category (Table 1.1) include well-placed windows to maximise sun capture, easily adjustable shading devices that encourage occupants to reopen them when no longer necessary, the use reflective devices and surfaces to amplify diffuse light or rooms that encourage flexible use or occupant migration to other parts of the building to adapt to the varying outdoor conditions.

1.5.3 Winter temperature

Studies during the winter in schools tend to consider relatively mild climate zones and focus on comfort temperatures and related health issues (Conceição & Lúcio, 2008; Su, 2017; Wang et al., 2017). In Quebec City, winter temperatures tend to oscillate between 0°C and -30°C for almost half the school year, i.e., between December and early April. This cold city also faces temperature swings between the seasons with outdoor temperatures varying between -30°C and 30°C throughout the school year (Figure 1.4). These thermal changes in the outdoor environment require buildings that can ensure occupant well-being in heating and cooling seasons.

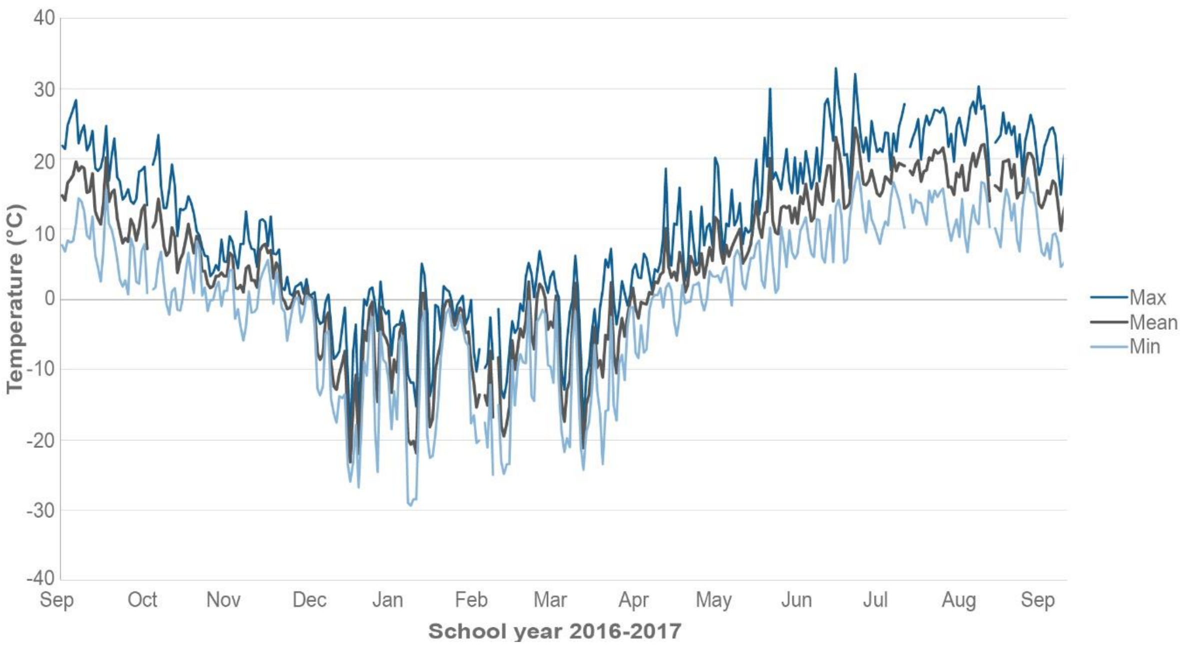

Figure 1.4 Daily outdoor temperatures during the school year in Quebec City, 2016-2017. Data from Environment and Climate Change Canada (2018b).

Children are more sensitive to higher temperature than adults (Teli et al., 2012), but can adapt to a wide variation in temperature. The higher metabolic rates in children probably explain why they are less sensitive to the cold (Fabbri, 2015). Trebilcock et al. (2017) observed comfortable temperature ranges for Chilean schoolchildren (ages 9-10) as low as 14.7°C-15.6°C in winter and 22.5°C-23.1°C in spring. Cooler temperature may therefore be advantageous in learning environments. A field intervention found that reducing the temperature from 25°C to 20°C improved students' (ages 10-12) performance on numerical and language tests (Wargocki & Wyon, 2007).

Even in cold climates, uncomfortably warm temperatures often occur in classrooms (Jauregui et al., 2019; Schola, 2019). This can be explained by the influence on thermal comfort of building type, outdoor conditions and the season (Frontczak & Wargocki, 2011). Buildings in Quebec also tend to have been designed for energy conservation by low wall-to-floor ratios instead of energy dissipation by high wall-to-floor ratios. Additionally, indoor temperatures in winter that are artificially maintained at high levels (e.g., at the upper limit or above the adaptive thermal comfort zone) by mechanical systems can represent a source of discomfort because occupants tend to expect indoor temperatures to reflect the variations present in the outdoor environment. In this sense, Baker and Steemers (2000) suggest that people "seem to be more tolerant of variations in the indoor climate provided they relate logically to outdoor conditions – i.e., people expect to feel hotter on a sunny day". The opportunity for people to adjust to conditions outside their thermal comfort zone can contribute to mitigating the effects of overheating, independently of season. Adaptive actions include personal and social elements, such as dress code working practices, as well as factors that influence the interaction between occupants and buildings, such as the ability to draw blinds or open windows (Nicol & Humphreys, 2002). However, relatively little research considers the biophilic potential of natural ventilation in schools in cold climates, especially during winter, when outdoor temperatures are much colder than adequate indoor temperatures.

During cold winter months when indoor spaces are heated, the difference between the desirable indoor temperature and the outdoor temperature limits the length of time windows can be opened. This occupant action aims in part to avoid heat loss and maintain energy efficiency, but is also influenced by occupants' comfort. Different literature values exist for the minimum outdoor temperature appropriate for natural ventilation. Duarte et al. (2017) studied appropriate temperatures for manual window airing of classrooms in Portugal. Their results indicate that natural ventilation is appropriate if the outdoor temperature is above 19°C and may also be appropriate between 16 and 19°C, depending on the indoor temperature. Givoni (1969, 1998) similarly recommends natural ventilation between 18 and 20°C. Bourgeois et al. (2000) suggest a lower limit of 12°C for natural ventilation during the day which is similar to the lower limit of 10°C reported by Causone (2016) based on practical design experience. Given the temperatures observed in cold climates, the possibility of using natural ventilation should consider the duration when windows are open and also weigh the negative aspects of thermal nuisances against their positive air quality or auditory aspects. A study of schools in the United Kingdom showed that high levels of outdoor noise resulted in the closure of windows which ultimately lead to overheating and poor indoor air quality (Montazami et al., 2012). Similar potential health and comfort risks seem plausible in cold climate schools when cold temperatures limit the use of open windows for ventilation.

Children require especially good ventilation because they breathe higher volumes of air in proportion to their body weights than adults (Mendell & Heath, 2005). Ventilating school buildings at adequate flow rates and filtration, as defined by ASHRAE 62.1-2010 (2010) or CIBSE AM10 (2005) for example, will remove or dilute contaminants that can be harmful in elevated concentrations. A review by Mendell and Heath (2005) indicated that there is evidence linking higher concentrations of indoor nitrogen dioxide (NO_2) to lower attendance at school. High exposure to ozone (O_3) and breathable particles (PM10) can also increase absenteeism (Gilliland et al., 2001). Carbon dioxide concentrations in classrooms can be used as indicators of ventilation rates and air quality. However, findings regarding the impact of carbon dioxide on the health of students appear inconclusive. In some studies (Bakó-Biró et al., 2012; Dorizas et al., 2015; Haverinen-Shaughnessy et al., 2011; Shendell et al., 2004; Simoni et al., 2010; Wargocki & Wyon, 2007), measurements of air exchange rates, carbon dioxide levels and relative humidity were associated with health effects or academic performance while other researchers found no significant correlation (Mendell et al., 2013; Smedje & Norbäck, 2000; Wargocki & Silva, 2015). Natural ventilation creates an unrestricted air exchange between indoors and outdoors and occupants lose the ability to control the quality of the air that enters the building. Yet contrary to mechanical ventilation, natural ventilation allows variations in airflow across the skin, air temperature and relative humidity that mimic natural environments (Browning et al., 2014).

To mediate between cold outdoor environments and warm indoor spaces, transition spaces can represent a sensible design solution (Pressman, 1995). This biophilic design principle creates a buffer zone between outside and inside that allows occupants to transition gradually from one to the other (Potvin, 2004). It also allows for the extension of occupants' contact with the outdoor environment and thereby could enhance their well-being while positively impacting the building's environmental performance (J. Li et al., 2018). Also, the conditions perceived as comfortable in these spaces may show a greater tolerance than in the regulated indoor building environment as they offer a greater connection to the outdoor environment. To achieve the full benefit from sensory variability, air or weather (Table 1.1), the design of biophilic schools should consider outdoor temperatures.

1.5.4 Variety in nature's colours, sounds and smells

The colours, sounds and smells that can be perceived from inside the classroom vary throughout the year. Seasonal changes affect the availability of nature in the outdoor environment which in turn influences the opportunities given to architects to bring nature into indoor spaces. If adequately considered, these sensory stimuli can enhance the experience of biophilic design. As Kellert (2008) suggests, "human satisfaction and well-being continue to be reliant on perceiving and responding to sensory variability, especially when this occurs in structured and organized ways within the built environment". Changes in vegetation, for instance, illustrate the structured and cyclic characteristics of stimuli in the natural environment that affect the experience of indoor spaces. During hot weather, tree foliage close to buildings offers a green nature view while acting as a natural shading device that blocks unwanted solar heat. The rustling of leaves and the fragrances of vegetation also provide auditory and olfactory stimuli into spaces that are naturally ventilated. The rich colours present in summer and autumn give way to colour monotony during the colder months that last for a large portion of the school year. However, during winter, this reduced foliage enables extended views and allows more sunlight to reach interior spaces. With the coming of spring, the rich colours, sounds and smells return.

The schoolyard offers the potential to optimise biophilia by providing children with a greater connection with nature, even in cold climates. In the cold Canadian climate zones, children spend approximately 25% of the school day in the playground, which is equivalent to about 110 minutes (Dyment et al., 2009). Several elements have been associated with a positive recreation experience such as the schoolyard's size (Arbogast et al., 2009), air quality (Gilliland et al., 2001) and the presence of vegetation (Dyment & Bell, 2007). Research indicates that natural school environments contribute to social well-being. They enable students to form supportive social groups and adopt pro-social behaviours (Brussoni et al., 2017; Chawla et al., 2014). The presence of nature in the schoolyard can also contribute to academic achievement (Kweon et al., 2017), students' perceived restorativeness of playground environments (Bagot et al., 2015) and enhanced psychological well-being and reduced stress levels (Kelz et al., 2015). Furthermore, a diversity of natural elements encourages physical activity in primary school children (Dyment & Bell, 2007) which can ultimately result in better health and well-being. However, large expanses of landscape, such as campus lawns, athletic fields and parking lots, have been negatively related to standardised test scores and college plans in high school students (Matsuoka, 2010). Therefore, schoolyard design and renovation projects should consider providing diverse natural environments for greater student well-being benefits.

Children may benefit from outdoor vegetation, even when they are in the classroom. In the context of elementary schools, the Heschong Mahone Group (2003) found that ample views from classroom windows including vegetation or human activity and distant objects were associated with higher standardised test scores. A study by Matsuoka (2010) analysing views of nature among 101 high schools revealed consistent and systematically positive relationships between nature exposure and student performance. Specifically, classrooms and cafeterias offering views with more vegetation were positively associated with student achievement (test scores, graduation rates, college plans). Likewise, a study of 94 students in five high schools investigated differences between classrooms with or without windows that opened onto a built space or a green space (D. Li & Sullivan, 2016). Results show that "classroom views to green landscapes cause significantly better performance on tests of attention and increase students' recovery from stressful experiences". Furthermore, Felsten (2009) positively related real and simulated views of nature to attention and perceived restorativeness in college campus settings. Therefore, it is important that quality views from inside schools are included in selecting school sites, designing buildings and renovating schoolyards.

Different types of sounds can influence the perceived biophilic qualities of indoor and outdoor spaces, yet in learning environments most studies have focused on noise-related issues for health and student achievement. Noise pollution represents a major environmental problem, which may interfere with cognitive performance, decrease motivation, cause annoyance and raise blood pressure (Goines & Hagler, 2007; Paunović et al., 2011; Shield

& Dockrell, 2008; Stansfeld & Matheson, 2003). In schools, the challenge intensifies because unfavourable listening conditions, including reverberation and noise, may impact children more than adults (Paunović et al., 2011). Primarily in naturally ventilated buildings with open windows, external noise penetrating the facades of buildings causes conflict between thermal comfort, air quality and noise control (Lee & Khew, 1992). In terms of health, aircraft and road-traffic noise exposure has been associated with an increase in children's blood pressure (Paunović et al., 2011). Children are also more easily distracted by irrelevant sounds than adults and therefore less able to focus on learning tasks in the presence of background noise (Doyle, 1973; Gumenyuk et al., 2004). Some studies have examined the detrimental influence of chronic noise pollution on the academic performance of children. Shield and Dockrell (2006) analysed the impact of environmental noise and noise generated within the classroom on the academic performance of London children aged 7 and 11. They found that children were impacted by internal classroom noise; background noise levels being negatively related to test scores. External noise also had a significant negative impact on performance, with a greater effect on the older children. Contrary to these findings, a study by Xie et al. (2011) showed that the environmental noise levels of 96 secondary schools in Greater London had almost no significant relationships with four academic achievement indicators, including absence. Similarly, a study among 158 children (grade 3) compared three noise conditions in classrooms: quiet, noise by children alone and noise by children plus environmental noise (Dockrell & Shield, 2006). Children in the condition with environmental noise performed significantly worse than those in other conditions on speed of processing tasks. In contrast, verbal task performance was only significantly worse in the noise by children setting. The source of the noise as well as the task being performed appears related.

Further studies in learning environments should investigate the influence of pleasant sounds, as opposed to noise pollution, on student performance. This aspect of biophilic architecture can contribute to restoration in adults (Payne, 2013; Ratcliffe et al., 2013). Shu and Ma (2018) obtained similar results when exposing children, aged eight to 12, to eight natural sounds and eight urban sounds. This study revealed that music-like sounds, such as singing and music, were perceived as the most attractive in both a classroom and urban park context, followed by natural sounds such as the rustling of trees, the singing of birds or falling rain. "The perceived restorative values of environmental sounds were found to be significantly influenced by their psychoacoustic parameters, children's personal information and visual contexts." Given the benefits of restorative settings (Berman et al., 2008; Hartig et al., 2014; S. Kaplan, 1995; Ulrich et al., 1991), introducing natural sounds into learning environments suggests potential benefits for the health and well-being of students and school staff. To achieve biophilic spaces that allow occupants to notice the variety in pleasant sounds throughout the seasons, occupied spaces should provide enough low levels of sound or silence to appreciate the noises of nature (Kellert et al., 2008).

In addition to the building envelope's key role to provide connections between the indoor and outdoor environments, it also affects environmental performance. In cold climates, buildings are often sealed tight during the winter to avoid heat loss. This means limited opportunities to open a window that in turn diminishes the thermal, auditory and olfactory contacts between indoors and outdoors. However, smells and sounds can be powerful triggers of pleasant experiences (Browning et al., 2014). Throughout the year, the school grounds offer a variety of smells and sounds, ranging from recently cut grass to freshly fallen snow and from birdsong to snow shovelling activities. The perceived intensity of these stimuli also varies.

Freshly fallen snow, and to a lesser extent compacted snow, have sound-absorbing properties that generate different experiences of the auditory environment in winter and summer (Maysenhölder et al., 2012). Fresh and fluffy snow absorbs sound waves at the snow surface, dampening sound. This snow type has acoustic absorption properties similar to glass wool whereas compact snow has absorption properties similar to a layer of glass beads with a diameter of 0.5 mm (Maysenhölder et al., 2012). As weather conditions change and snow melts and refreezes, the surface becomes smooth and hard which reflects sound waves, generating clearer sounds that can travel further. This has repercussions for the design of a biophilic schoolyard environment and of biophilic interior spaces. While it has yet to be quantified, a lower level of noise outdoors reduces the intrusion of exterior noise into indoor learning spaces and potentially lowers background noise levels in these spaces. In terms of thermal comfort, strategically located snowdrifts can block harsh winter winds, impact microclimates and enhance outdoor comfort, allowing children to spend more time outside rather than in indoor spaces with limited connections to the outdoor environments. Pleasant microclimates in the schoolyard can also facilitate outdoor learning. Outdoor classrooms offer many benefits such as the ability to vary teaching methods, to make learning tangible and to improve the well-being of students. The variability of colours, sounds and smells in nature showcases the influence of the biophilic design categories "natural features" and "patterns and processes" (Table 1.1) on the experience of the built environment.

1.6 Environmental diversity in cold climate schools

Cold climates present certain obstacles for biophilic design, but they also offer opportunities for environmental diversity that may be absent in milder climates. While the previous section presented separately the climate considerations affecting biophilic design, multiple synergies and conflicts exist among them. Moreover, to enhance biophilic experiences in learning environment, architects should consider both the availability of nature and the potential conflicts that arise from man-made visual, olfactory or auditory pollution. Designing school buildings as a filter between indoors and outdoors could enable the positive characteristics of nature to enter learning spaces, without overprotecting occupants from harsh outdoor conditions. From schoolyard design to the selection of natural materials for interior finishes, architectural decisions taken at different scales of the project can lead to benefits for students' well-being. Perhaps the most important principle of biophilic design is recognising that "the line between indoors and outdoors must be rethought; that indoor rooms must communicate with outdoor rooms; that windows must become doors" (Kellert et al., 2008). However in cold climates, this line often corresponds to a sealed building envelope, which is less than ideal for blurring the transition between indoor and outdoor spaces.

Providing teachers and students with the possibility of using natural ventilation when desired can be a positive classroom feature to connect indoor and outdoor settings. Natural ventilation generates thermal, olfactory and auditory connections with the outdoor environment and creates subtle changes in air temperature, relative humidity and surface temperature that mimic variations in natural environments. By controlling temperature, humidity and air quality, mechanical systems may flatten these subtle variations that naturally occur in the outdoor environment. Compared to mechanical airflow, natural ventilation produces different types of turbulence because airflow varies with meteorological conditions

(Bluyssen, 2009). The sensation of wind on the skin is integral to outdoor experiences of nature and the presence of windows permits this sensation to airflow indoors. Thermal and airflow variability generate spaces that feel refreshing, comfortable and invigorating while the absence of stimuli variability can result in boring and unexciting environments (Browning et al., 2014). Research indicates that teachers tend to express a preference for classrooms with operable windows in warm climates and increasing their ventilation is a high priority (Heschong, 1999). However, in order to present benefits for student health and academic achievement, the size of the window openings, building geometry and orientation must enable adequate natural ventilation. The potential for natural ventilation also depends on the outdoor microclimate. To seize this biophilic opportunity, careful consideration of sounds and odours in the outdoor environment is needed. The health and well-being benefits of auditory and olfactory connections with the outdoor environment apply to schools without disruptive influences nearby. Schools near airports, busy roads or odorous factories, for example, may introduce olfactory and auditory stimuli that occupants perceive as unpleasant. The pleasant stimuli in the natural environment, such as birdsong or plant fragrances, may pale in comparison. In considering sources of sound and noise from the outdoors, attention should also be given to sources of noise pollution, whether from the outdoor environment or from mechanical systems within the building. Figure 1.5 summarises the most critical climate principles that impact biophilic design in learning environments.

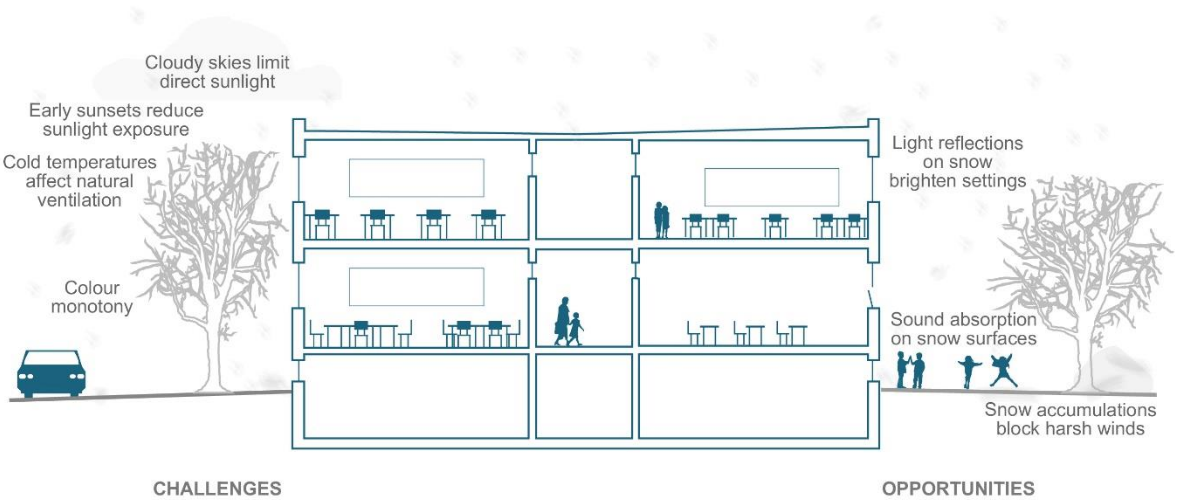

Figure 1.5 Challenges and opportunities provided by the climate for biophilic school design in cold climates.

Several challenges arise when rethinking the connection between indoors and outdoors in the aim of increasing the well-being of occupants without severely affecting energy performance. In summer, a prolonged and direct contact between indoor and outdoor spaces could result in undesirable settings such as excessive daylight and solar heat gain. In winter, an extended contact may cause heat loss. Figure 1.6 synthesises possible synergies, conflicts and challenges in cold climates that can arise when architects design for the well-being of occupants while also considering the energy performance of the building. In this sense, an integrated design process can lead to significant synergies between biophilic design and environmental performance (Wilson, 2008).

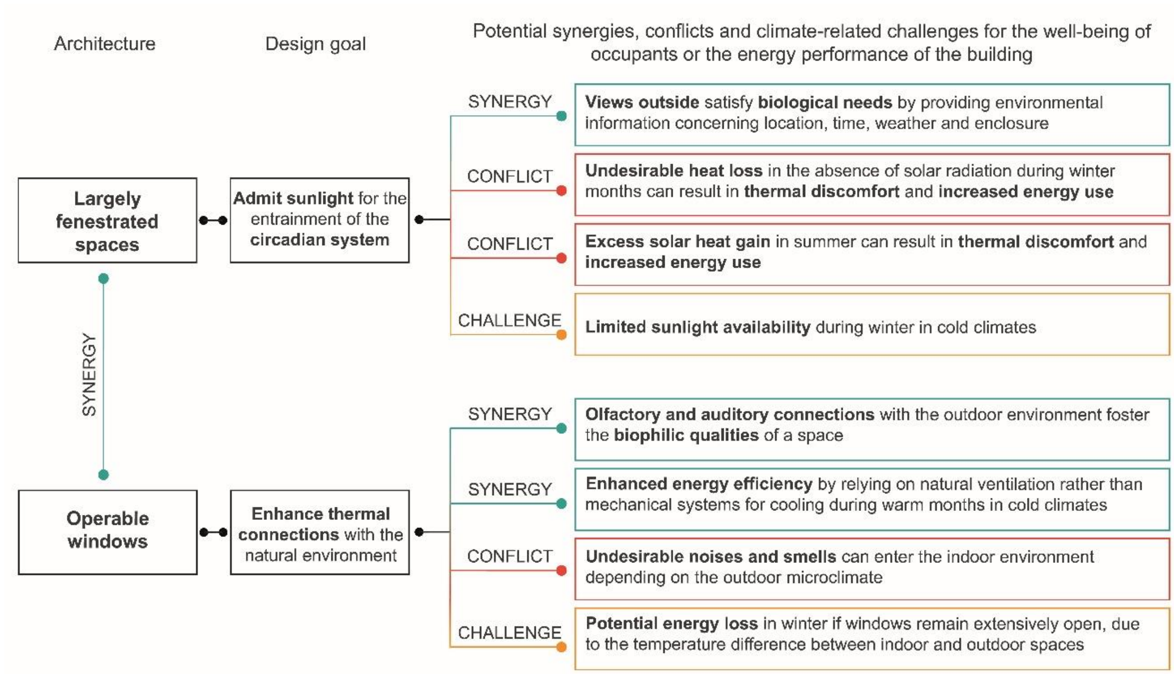

Figure 1.6 Example of synergies, conflicts and climate-related challenges for two architecture design decisions.

The interactions of students and teachers with buildings may contribute to enhancing the biophilic aspects of the design. Views to the outside and the presence of natural light in the classroom can only be achieved if building occupants adjust shading devices to daily and seasonal variations. Similarly, the thermal, olfactory and auditory benefits of opening windows become moot if windows remain closed. In order to offer teachers and students a satisfying experience of nature, school buildings should provide opportunities to adapt according to the availability or absence of outdoor nature. If a classroom has limited access to sunlight, students and teachers could be encouraged to use shared spaces, such as libraries, facing a different orientation for a portion of the day. Another possibility could involve migrating to outdoor teaching spaces for a daily dose of sunshine. This requires a holistic design approach to create a comfortable outdoor microclimate that considers available sunlight and the presence of windbreaks to create suitable settings for learning.

The use of complementary biophilic strategies to provide an indirect contact with nature could contribute to biophilic indoor settings. For example, indoor vegetation is increasingly recognised as having the potential to create attractive environments that contribute to cognitive performance (Fjeld, 2000; Han, 2018; van den Berg et al., 2017) and improve the quality of the indoor environment by purifying the air and reducing indoor pollutant levels (Pegas et al., 2012). Nonetheless, the benefits associated with indoor plants show heterogeneity depending on the research context (laboratory, photographic or field settings) and occupant characteristics (such as people focused on tasks or relaxing in a restorative setting) (Bringslimark et al., 2009). The use of natural construction materials represents another interior design element that could be considered when direct contacts with nature are limited. Numerous positive effects relating to the use of wood in various interior settings have been reported (Browning et al., 2014; Jafarian et al., 2017; Poirier et al., 2017; Watchman et al., 2017a) although few studies concern learning environments (Kelz et al., 2011). A holistic approach to biophilic design that considers indoor and outdoor nature appears advantageous in cold climates.

1.7 Conclusion

The evidence examined in this article makes a compelling case for school environments to offer greater connections with nature especially in cold climates. Research shows that biophilic design in learning environments can enhance the well-being of children and adults in the indoor environment and the schoolyard. Aspects of interest for indoor spaces comprise views of nature, daylight, variable lighting, natural ventilation and cool temperatures. The reported benefits include less stress, inattention and hyperactivity symptoms and absenteeism as well as increased physical activity, enhanced child development, better learning and achievement and improved social behaviour. However, only limited research has focused on these benefits in cold climates. Future research could expand this knowledge by further examining seasonal diversity and extreme climate conditions and its effects on biophilic experiences. The seasonal variations of cold climates highlight the necessity to adopt a climatic-based approach to biophilic architecture. In winter, reduced sunlight intensity and duration, cold outdoor temperatures and reduced variety in colour, sound and smell in nature presents challenges for a biophilic indoor environment. Thus, programming and designing learning spaces that accommodate the availability of nature throughout the year should be encouraged. Given the limited opportunities for a prolonged human contact with the outdoors during winter, a refined design of the components of the building envelope and the use of transitional spaces may increase the opportunities for maintaining a connection with nature throughout the year in different weather conditions. Bringing nature indoors via plants and natural materials such as wood could further create biophilic learning spaces when direct contacts with the outdoor environment are limited. The interactions of teachers and students with school buildings could also allow biophilic aspects of architecture to be enhanced. This could further maximise the architecture-climate-biophilia relationship and generate pleasant architectural experiences that enhance well-being.

Chapter 2 Biophilia in school buildings: Towards a simplified assessment method based on spatial geometry

The narrative review presented in the previous chapter revealed that the benefits of biophilic architecture have been investigated from perspectives such as physical and psychological well-being. It further highlighted how these benefits can pertain to children's learning environments. Some aspects of biophilic design are measurable while others are perceptual. Certain parameters of the built environment, such as light intensities, can be measured and related to well-being outcomes. Other parameters, such as those that relate to the appreciation of fragrances and sounds, are more subjective. The combination of these measurable and perceptual parameters contributes to the experience of nature in buildings. Given the complexity inherent to each category, the present chapter focuses on measurable architectural parameters that could inform architects' understanding of the biophilic qualities in existing spaces. Elements that relate to people's subjective experiences in these spaces are discussed in later chapters of this thesis.

Understanding the potential experiences of nature in existing spaces could help to foster multisensory experiences in architecture. To assist architects renovating school buildings, it appears useful to first detect areas of a building where positive nature experiences may currently occur as well as those areas where they may be more difficult to achieve. In this sense, this chapter aims to provide the knowledge tools necessary to understand the spatial geometry of primary schools to establish an architectural diagnosis and to guide design solutions based on quantitative assessments.

The diagnostic tool proposed in this chapter builds on the relationships between principles of biophilic design and well-being discussed in Chapter 1. It specifically focuses on measurable elements in architectural drawings that relate to the geometry of buildings and rooms and the building envelope. During the development of this assessment method, additional criteria and components of the built environment were evaluated. Appendix C details the components *site*, *circulation* and *materiality* that, while omitted from the article presented in this chapter for conciseness, further contribute to the understanding of biophilic characteristics of school buildings. The decision to focus on the geometry of rooms and buildings as well as the building envelope is supported by the abundant design literature that covers these themes. Moreover, building geometry and envelope are deemed essential components for designers to consider in post-occupancy evaluations as well as in the early design stages. The method draws inspiration from parameters used in building certification standards (such as WELL) and the limited research that has considered the spatial geometry of buildings to analyse biophilic design (Roös et al., 2016; Terrapin Bright Green, 2019). The assessment method was used on three primary schools in the Quebec City area. The schools were chosen to be representative of primary schools in the province based on criteria such as their construction date and their spatial configuration. The location of these schools was also considered as repeated visits to these same schools were anticipated for later stages of the research.

The quantitative approach presented in this portion of the research allows architects, before site visits, to identify which indoor environmental parameters may fall below the recommended thresholds and the areas of the schools in which they may occur. It therefore provides a preliminary diagnosis of people's potential experiences of natural elements such as light, air and vegetation. The objective data that is obtained allows architects and building managers to discuss the current state of schools against certification criteria that are oriented towards the health and well-being of occupants.

The diagnostic criteria presented in Chapter 2 further contributed to the development of an ensemble of diagnostic tools in the project Schola. The document "*Fascicule B: Bien diagnostiquer. L'école à rénover et ses enjeux"* developed by members of the Schola project brings together an ensemble of diagnostic tools making it possible to collect the information necessary to evaluate of a school building. Each tool refers to specific sections of the document "*Fascicule A: Apprendre. Les écoles primaires publiques du Québec*" which characterises primary schools in the province. The analysis of this information makes it possible to position a school building, and spaces in that school, in relation to the provincial sample of schools and to identify the specific issues and challenges associated with its renovation. The *Fascicule B* distinguishes analyses that designers can perform before site visits from those that are conducted during and after site visits. The assessment method presented in this chapter uses the same approach. The intention is for architects to work with readily available information, such as floor plans, to identify schools and issues that require more in-depth investigations. While not specifically investigated in this chapter, architects could employ this assessment method in the early design stages to compare design alternatives rapidly. This would enable them to select the design proposal that answers most successfully the biophilic issues of their project while also considering the particularities of their project.

This chapter presents the article “Biophilia in school buildings: Towards a simplified assessment method based on spatial geometry” by Mélanie Watchman, Claude M. H. Demers and André Potvin. The article was submitted to *Architectural Engineering and Design Management* and published in July 2021 (DOI: 10.1080/17452007.2021.1956419).

2.1 Résumé

La rénovation des bâtiments scolaires offre la possibilité d’améliorer le bien-être visuel, thermique et auditif des élèves et du personnel grâce au design biophilique. Un diagnostic des interfaces entre les environnements intérieurs et extérieurs pourrait aider les architectes à comprendre les défis et opportunités pour optimiser les connexions avec la nature. La présente étude discute d’explorations méthodologiques pour diagnostiquer les potentielles qualités biophiliques des écoles existantes. Elle découle d’une étude de trois écoles primaires canadiennes. L’article analyse de manière critique des plans, coupes et élévations en fonction de principes biophiliques identifiés dans les critères de certification des bâtiments et les principes de design bioclimatique. Cette exploration offre un processus reproductible pour décrire les caractéristiques de l’architecture biophilique. Les résultats soulignent les zones des écoles avec des qualités biophiliques et les opportunités pour un contact accru avec la nature. Cela illustre l’importance des dimensions mesurables et perceptibles de la nature.

2.2 Abstract

Renovating school buildings offers the potential to increase the visual, thermal and auditory well-being of students and school staff through biophilic design. Biophilic design guidelines generally describe the natural features in buildings and the intended experiences for occupants. As limited guidelines specify measurable architectural characteristics, this study discusses methodological explorations to identify potential biophilic qualities of buildings in the early stages of renovation projects, before in-depth post-occupancy evaluations and site

visits. This research critically analyses plans, sections and elevations based on building certification standards and bioclimatic design principles. The simplicity of the assessment method aims to facilitate a preliminary evaluation of numerous and diverse schools in Quebec, Canada. The results from a case study of three primary schools showed that the quantitative information in architectural drawings can serve to identify challenges and opportunities for direct experiences of natural features, such as sunlight, outdoor views and fresh air. This exploration illustrates a replicable process to capture measurable architectural parameters with the potential to foster experiences of nature.

2.3 Introduction

Children generally spend over a third of their day at school, where most of their learning activities occur indoors. In Quebec, Canada, 3333 public buildings are used for teaching purposes, of which 2111 are primary school buildings (Schola, 2021). Two thirds of primary schools were built between 1948 and 1978. These buildings have reached the end of a first life cycle estimated at 50 years; they require renovations to ensure a quality learning environment that meets current and future needs and practices (Després et al., 2017). Their renovation should consider the impacts of aspects such as daylight, temperature, ventilation and sounds, because they can increase well-being and academic success (Barrett et al., 2015; Heschong-Mahone Group, 2003). Furthermore, diverse and sustained experiences of natural processes during childhood impact people's emotional, intellectual and evaluative development (Kellert, 2005). This paper proposes an architectural assessment method as an initial step to understand potential biophilic qualities of buildings before conducting in-depth post-occupancy evaluations and site visits. Its value emerges from the efficient and rapid assessment of numerous buildings in the early stages of renovation projects using available architecture drawings.

Evaluating buildings using architectural drawings often constitutes an initial step in preliminary design studies and renovation projects. The originality of the proposed method using spatial geometry lies in the addition of analysis criteria potentially fostering biophilic experiences. The research argues that certain building typologies and measurable aspects in plans, sections and elevations could allow architects renovating schools to better prepare and complete site visits by identifying environmental parameters and spaces presenting greater challenges for direct experiences of nature. A combination of biophilic design guidelines, bioclimatic design principles and building certification standards offers a graphical and numerical representation of these quantitative parameters in architectural drawings.

To understand space, architectural theory and history uses two broad models (G. Baird, 1995; G. H. Baker, 1989; Giedion, 1954). *Lived space* focuses on emotional perception and is necessarily subjective. *Geometric space* uses universal and repeatable metrics to understand the physical ontology of space. While biophilic design comprises subjective qualities that influence nature experiences in buildings, it is argued that objective and measurable architectural elements, such as room proportions and window sizes, which describe typologies could contribute to a preliminary diagnosis that highlights the challenges and opportunities for fostering nature experiences. This paper focuses on spatial geometries to help designers understand in the early stages of renovation projects the conditions for potential nature experiences in school buildings. The proposed assessment method considers building characteristics that may foster positive visual, thermal, olfactory or auditory experiences of nature.

2.4 Background

Providing children and adults with daily opportunities to experience nature can positively impact their physical and psychological health and well-being (Barbiero & Berto, 2016; Browning & Ryan, 2020; Chawla, 2015). Particularly in children's environments, nature experiences can have lasting benefits as the relationship and responsibility for human and natural communities developed during childhood can lead to pro-environmental attitudes and behaviours in adulthood (Evans et al., 2018; Kellert, 2005). These benefits can be connected to biophilia - people's innate affinity for life and lifelike processes (Kellert & Wilson, 1993). "Biophilia is not a single instinct but a complex of learning rules that can be teased apart and analysed individually" (E. O. Wilson, 1993, p. 31). As biophilic values are a weak biological tendency, their development relies on learning, experience and sociocultural support (Kellert et al., 2008). Thus, understanding biophilia and the various nature experiences people may have in buildings supports a more complete analysis and design of biophilic architecture.

Assessing people's relationship with nature in architecture can be challenging due to multiple definitions of nature and different perspectives concerning the amount of nature people should be exposed to daily (Browning et al., 2014; R. Kaplan & Kaplan, 1989). Evaluating biophilic design typically focuses on two main elements: people's exposure to nature and the possible outcomes in terms of human well-being (Watchman et al., 2021a). Stress Recovery Theory (Ulrich et al., 1991) and Attention Restoration Theory (S. Kaplan, 1995) have documented the benefits of experiencing nature in indoor and outdoor environments. In turn, biophilic design guidelines encouraging practitioners to promote positive interactions between people and nature have been regrouped in three broad categories: direct experiences of nature, indirect or representational experiences of nature and common spatial experiences in nature (Browning & Ryan, 2020; Kellert, 2018). Biophilic buildings exceed the notion of connecting indoor and outdoor spaces as the outdoor environment may be perceived as unpleasant. For example, certain indoor spaces with abundant natural light, natural materials and diverse vegetation suggest potential biophilic experiences that outdoor spaces dominated by busy roads or odorous factories may not offer. *Nature*, in this article, refers to the elements of sun, air, water, and earth, and to living things such as plants and animals. The notion of well-being in buildings includes a heterogeneity of conceptual approaches (Hanc et al., 2019). Therefore, the notion of *experience* or *connection* with nature focuses in this paper on people's immediate, physical experience when they view, touch, smell or hear nature.

It is acknowledged that this framing of *nature* and *connection with nature* omits certain aspects of biophilic design (e.g., natural materials and organic forms) and simplifies experiences of nature (e.g., cultural and ecological attachment to place). For example, views through windows enable students to experience changing sky conditions, vegetation and the overall outdoor ecosystem which may foster an ecological attachment to place. Thus, by focusing on direct sensory experiences of natural forces and living organisms within the immediate ecosystem of a building, it becomes possible to examine architectural characteristics as assets or barriers to these experiences in a simplified manner that is sufficient in the early stages of assessing multiple buildings. Complementary analyses, such as site visits and occupant surveys, considering other biophilic design guidelines, would be beneficial in later stages of renovation interventions to inform design decisions.

2.4.1 Architectural characteristics of biophilic design

Few biophilic design guidelines specify geometric characteristics regarding the architectural settings that foster experiences of nature. Biophilic design guidelines generally describe the natural features to include in buildings and the intended experience for occupants. For example, Kellert (2018) and Browning et al. (2014) discuss the manipulation of light intensity, its diffusion and shadows without associating these experiential qualities to architectural qualities. In the absence of measurable guidelines, design teams rely on measuring the effects of biophilic design in post-occupancy evaluations and precedent analysis is often used to justify biophilic design decisions.

Among the different research methods documenting the benefits of nature for people, those that describe building parameters or indoor environmental conditions appear to offer more guidance for architects. Questionnaire-oriented studies have analysed well-being outcomes based solely on participants' perception of contact with nature and their self-reported evaluations (e.g., Collado et al., 2015; Norðdahl & Einarsdóttir, 2015). Objective measurements of the quantity and quality of nature provided by the built environment are therefore limited or unavailable. Research that uses satellite data or cartographic datasets reveals associations between biophilia and urban design, but its focus is limited to the outdoor environment (e.g., Hodson & Sander, 2017; Kweon et al., 2017). Several intervention studies have compared architectural settings to determine which generate more favourable outcomes (e.g., D. Li & Sullivan, 2016; van den Berg et al., 2017). The outcomes for occupants are often measured in more detail than the architectural intervention variables, which tend to focus on modifying a single parameter (green walls, interior finishes, outdoor views, etc.). Research that involves site visits typically considers architectural variables such as building and room characteristics (e.g., dimensions, orientation) and repeated measures of environmental conditions (e.g., noise, temperature, and lighting levels) that are complemented by subjective evaluations either by occupants or researchers. Although the objectives pursued may not directly relate to biophilic design, studies by the Heschong Mahone Group (2003) and Barrett et al. (2015) in learning environments provide insights into the architectural variables that could measure certain aspects of biophilic design, such as classroom and window characteristics. Nonetheless, these methods can be labour intensive and time-consuming and access to learning environments can be difficult to obtain without disrupting teaching activities.

Limited research has considered the spatial geometry of buildings to analyse biophilic design. Roös et al. (2016), for example, visually located biophilic design strategies on the floor plan of a railway station project, but omitted an analysis of the measurable physical data, such as building proportions and window ratios. Similarly, Terrapin Bright Green (2019) used floor plans and project section drawings to provide the visual locations of biophilic elements in case studies. These examples allow a visual and qualitative assessment of the location of natural elements in the building or on the site. An analysis of geometric space could contribute to a more objective, although simplified, evaluation of potential direct experiences of nature.

In contrast to the biophilic design literature, building certification criteria such as those included in the WELL Building Standard (2018) or the Living Building Challenge (2019) tend to describe measurable architectural characteristics that buildings should meet or exceed. Without necessarily specifying the links or associations with biophilia, some requirements embody fundamental components of a connection with nature, such as operable windows in each regularly occupied space to provide occupants with a thermal, olfactory and auditory connection with the outdoor environment. Although these requirements may be insufficient to determine if buildings stimulate the development of a deep and meaningful attachment to nature, these design parameters are the basics of any project and as such, could provide insight during the early stages of building assessments.

Bioclimatic design principles may also offer insights as to geometric qualities that foster experiences of nature. Certain quantitative guidelines and rules of thumb present in the bioclimatic design literature inform occupants' potential to experience natural elements (such as daylight and thermal variability), although bioclimatic design is not always biophilic and biophilic design is not always bioclimatic. By relying on resources in the surrounding environment, bioclimatic literature can enhance designers', and ultimately occupants', awareness of natural elements and processes. "Designers seeking to produce net-zero and peak-zero, net-positive energy buildings require an understanding of what causes buildings to use energy as well as how to harness the energy design process by integrating multiple design strategies" (DeKay & Brown, 2014, p. 51). Viewing climate as a resource elevates sun, wind, water and living things to key components in the design process. For instance, the petal "beauty" of the Living Building Challenge (2019) encourages good design that uplifts the human spirit by connecting people to nature, place and climate. The geometry of buildings, rooms and architectural components, such as windows, that manifest the integration of natural features further serves as a teaching tool. As David Orr notes, "buildings have their own hidden curriculum that teaches as effectively as any course taught in them" (1993, p. 226).

Biophilic design guidelines, building certification criteria and bioclimatic design principles offer different insights as to geometric characteristics that foster experience of nature (Figure 2.1). While biophilic design literature generally describes the natural features that offer direct experiences of nature, bioclimatic design guidelines and certification standards often include measurable parameters that could be transposed to assessments of biophilic experiences (Table 2.1). While nature experiences can be analysed at different scales, from building elements to urban design, the proposed assessment method focuses on measurable elements in architectural drawings that relate to the geometry of buildings and rooms, and the building envelope.

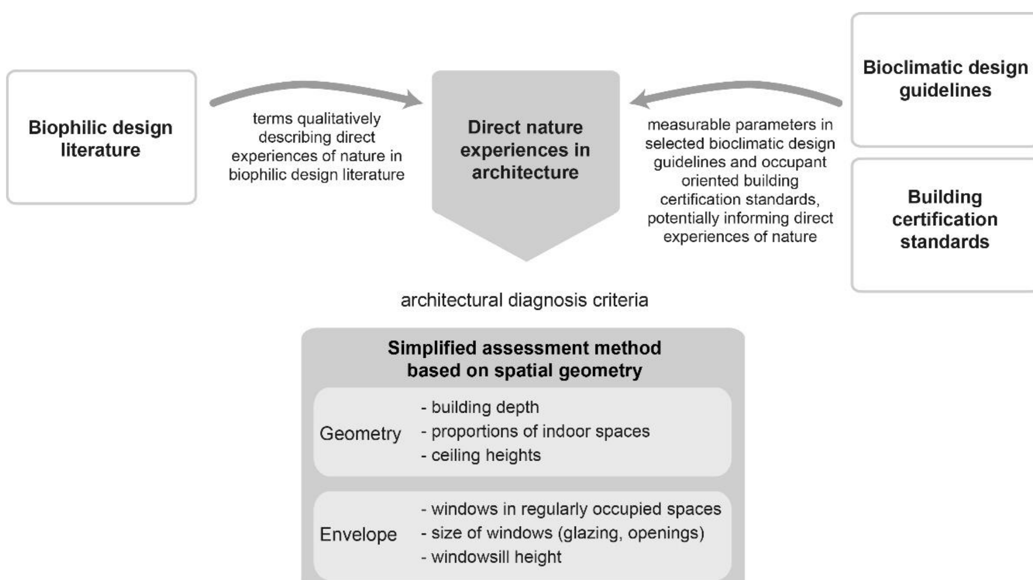

Figure 2.1 Research lens informing biophilic architecture diagnosis criteria.

Table 2.1 Literature and research lens informing biophilic architecture diagnosis criteria.

		Direct experiences of nature								Geometry				Envelope		
		Air	Animals	Fire	Landscapes	Light	Plants	Weather	Water	Building depth	Proportions of indoor spaces	Ceiling heights	Windows regularly occupied spaces	Size of windows (glazing)	Size of windows (openings)	Windowsill height
Biophilic design	Kellert (2018)	●	●	●	●		●	●	●							
	Beatley (2011)		●		●	●	●									
	Kellert & Calabrese (2015)	●	●	●	●	●	●	●	●							
	Browning et al. (2014)	●	●		●	●	●	●	●							
	Kellert et al. (2008)	●	●	●	●	●	●									
Certifications	Living Building Challenge	●	●		●	●	●						09, 10			
	WELL Building Standard	●			●	●	●		●	L01, L05			A07	L01, L05	A07, T08	T08
Bioclimatic design	Grondzik & Kwok (2015)	●				●				●						
	DeKay & Brown (2014)	●				●				35	35, 57	68		68, 70, 84, 85	86	68
	IES (2011)					●				14.7				14,7		

2.4.2 Geometry: compactness, room depth and ceiling height

Building geometry can reveal challenges and opportunities for biophilic connections with the outdoor environment. “At its simplest, form can be reduced to questions of tall or short, thick or thin”(Grondzik & Kwok, 2015). Thin buildings maximise exterior wall area, thereby preserving good light and fresh air in interior spaces (DeKay & Brown, 2014). In thicker buildings, floor area tends to be far from outdoor influences (Grondzik & Kwok, 2015). While arguments about energy performance often influence the design of more compact building forms, Montenegro et al. (2012) observed that certain linear geometries are similar or surpass the performance of compact geometries in a cold climate, like Quebec.

Room depth resulting in students’ desks positioned further from the window facade can limit their access to outdoor views, natural light and natural air movements. Proximity to windows enables occupants to experience dynamic lighting conditions which mimics natural environments (Browning et al., 2014). By generating offsets of the building perimeter, architects can identify the building zones which may have a higher opportunity for daylight. The portions of the floor exceeding this zone would in turn offer a more limited connection with the outdoor environment and require a higher reliance on mechanical systems. In the bioclimatic literature, the completely daylit zone generally corresponds to a 4.5 metre wide perimeter zone. The next 4.5 to 9 metres generate a partially daylit zone. Floor area exceeding nine metres from the facade will be electrically lit (Grondzik & Kwok, 2015). Criteria in the WELL Building Standard (2019) suggest that less than 70% of the floor area should be more than six metres from the facade and less than 30% of the floor area should exceed seven metres from the building edge.

Variations in ceiling heights throughout the school evoke the biophilic design attribute of complimentary contrasts (Kellert et al., 2008). While modifying the patterns of daylight, they can also engender experiences of high and low, open and enclosed, which impact thermal and auditory sensations. High windows and ceilings contribute to a greater interior daylight penetration (DeKay & Brown, 2014). Furthermore, rooms with a higher ceiling tend to be regarded as more beautiful and they also activate structures involved in visuospatial exploration (Vartanian et al., 2015). In a series of experiments, Baird et al. (1978) demonstrated that preference increased as ceiling heights increased from 1.83 m and reached a peak at 3.04 m before decreasing. This sensory variability created by variations in ceiling heights appears positive when moving from a distributive (corridor) to a functional space. However, lower classroom ceilings should never be positive unless they define a zone within a room.

2.4.3 Building envelope: glazing areas and position, window openings and views

The presence of windows in regularly occupied spaces could perhaps represent the simplest indicator of a contact by students and school staff with the outdoor environment. Windows represent a key element in the design of biophilic buildings because of their multiple benefits on the well-being of occupants. People prefer spaces with windows and tend to be happier, healthier and perform tasks more efficiently than people in windowless spaces (Farley & Veitch, 2001; Vásquez et al., 2019). The size of the window glazing area influences the contrast of light and shadow and the perceived boundary between inside and outside (Guzowski, 2000).

Window glazing areas can enhance the potential for views and natural light indoors; two important dimensions of biophilic design that positively impact well-being. The size of windows directly relates to the daylight intensity at a location in a space (N. Baker & Steemers, 2000, p. 43). For basic daylighting levels, the size of glazing area should represent 10-15% of the floor area while glazing ratios between 15 and 25% provide more adequate daylighting levels (DeKay & Brown, 2014). Glazing ratios under 10% and exceeding 25% suggest that monitoring should take place to verify that adequate daylighting levels can be obtained. Glazing performance impacts the severity of heat loss in the absence of solar radiation at night and during winter and overheating due to direct solar gain in summer. As architectural drawings for most schools in Quebec rarely include this information, window sizes serve as an indicator of potential challenges and opportunities for experiences of daylight and natural ventilation before conducting site visits and more detailed analyses of schools with pressing renovation issues.

Although several biophilic design strategies appeal to visual experiences, others highlight the importance of sensory variability and non-visual connections with nature. Inoperable windows limit the biophilic qualities of the space since they exclude thermal, olfactory and auditory exchanges with the outdoor environment. Based on the WELL Building Standard (2018), the operable window area should represent at least 4% of the net occupiable floor area of a space or floor plate. A lack of natural ventilation can result in overheating and indoor air pollution (Camacho-Montano et al., 2019). Moreover, a lack of diverse sensory experiences can generate boring and unsatisfying environments which ultimately affect people's health, mood and task performance (Clements-Croome, 2005). However, in learning environments, excessive sensory stimulation may distract students and negatively impact their concentration. As the naturalness, individuality and stimulation conceptual model shows (Barrett et al., 2015), the intended use of the building should determine the appropriate level of stimulation.

Views and vistas represent a key biophilic design element as they inform occupants on location, time, and weather (Kellert et al., 2008; Lam, 1992). Prospect-refuge theory (Appleton, 1975) shows that unobstructed views over a distance tend to characterise preferred views. Window height informs the reach of natural light deep into building interiors. Placing windows high on a wall creates a more uniform distribution of daylight and allows it to penetrate deeper into a space (Grondzik & Kwok, 2015). As a rule of thumb, daylight enters a space along the building perimeter to an approximate depth of 1.5 to 2 times the window head height (Illuminating Engineering Society [IES], 2011). Additionally, windowsill heights determine the view children and school staff have towards the outdoor environment. The field of view varies with building depth and students seated further from the facade will have more limited views to the sky and may have less exposure to melanopic light, a good indicator of circadian rhythm, provided by the sun (Carrier et al., 2019). Moreover, research shows that the view distance, the number of view layers, the quality of the landscape or elements and the composition of the view best predict view quality (Matusiak & Klöckner, 2016). From a bioclimatic standpoint, placing trees closer to the facade reduces solar heat gain during summer while enabling the winter sun to enter indoor spaces when the leaves have fallen. In terms of biophilia, it enables children to experience the seasonal rhythms of vegetation growth and change.

Experiences of nature fluctuate over time, particularly in a cold climate. "These fluctuations may be more or less wild, more or less sudden, depending on such issues as the nature of the space, its occupancy pattern, the form of construction and the climate" (Steemers & Steane, 2004, p. 9). Dynamic and variable season-related issues, such as sun paths, wind patterns and plant cycles, affect occupants' contact with nature and therefore require a careful interpretation of the geometric characteristics of buildings.

2.5 Method

A simplified assessment method based on the geometric characteristics of buildings was developed to identify quickly and efficiently the primary schools in Quebec that present the most pressing issues in terms of daylight, temperature, air quality and auditory conditions. Three school environments in Quebec City were chosen for this investigation.

2.5.1 Analysis criteria

The biophilic design guidelines, bioclimatic design principles and building certification criteria discussed above served to establish quantitative criteria to evaluate the connection with nature in the selected schools using architectural drawings. Previous studies investigated the expression of biophilic design guidelines in building certification criteria (Jiang et al., 2020; Xue et al., 2019). The originality of the proposed assessment method lies in the visual representation of these quantitative parameters in architectural drawings to identify the potential to enhance experiences of nature in existing buildings. The building geometry and envelope (Figure 2.1, Table 2.1) were chosen for the analysis because sufficient information is available in architectural drawings to offer a preliminary assessment of buildings. Additional indoor-outdoor connections may exist at other schools and further biophilic design characteristics could be considered, such as green areas near the site or the colours and textures of materials. Fundamental to the analysis is the concurrent assessment of the impact of design features on natural light, thermal variations, airflow, smells, sounds, views, and vegetation (Table 2.2). As with comfort, providing various biophilic opportunities that stimulate different senses gives occupants the freedom to choose based on their desired experience.

Table 2.2 Summary of the diagnosis criteria and the corresponding type of nature and contact

Diagnosis criteria	Nature					Contact			
	Sun	Air	Water	Plants	Animals	See	Touch	Smell	Hear
Geometry									
Building compactness	•	•				•	•	•	•
Building depth	•	•				•	•	•	•
Proportions of indoor spaces	•	•				•	•	•	•
Ceiling heights	•	•				•			
Envelope									
Windows in regularly occupied spaces	•	•	•	•	•	•	•	•	•
Size of windows (glazing, opening)	•	•	•	•	•	•	•	•	•
Windowsill height	•			•		•			

2.5.2 Case studies

The proposed assessment method contributes to the decision-making process for school renovations and aims to understand the state of the numerous and diverse school buildings in Quebec. Spatial configurations for primary schools in Quebec commonly include linear volumes (e.g., classrooms distributed on each side of a central corridor) or more compact volumes (e.g., classrooms encircling a gymnasium) (Schola, 2020). Additions tend to generate multiple linear volumes or combinations of linear and compact volumes. The schools chosen for the study included this diversity and captured a variety of indoor-outdoor connections making it possible to explore the application of biophilic design to three common spatial organisations: L-shaped, T-shaped and compact school layouts (Figure 2.2).

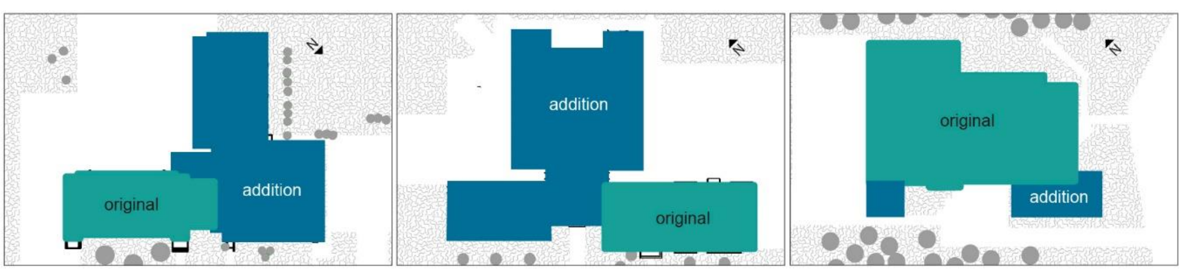

Figure 2.2 Spatial configuration of School L (left), School T (middle) and School C (right).

The selected schools are also representative of construction periods in the province. The three schools selected to explore this biophilic assessment method were built or enlarged between 1949 and 1997 and are in residential neighbourhoods of the Quebec City area. The three schools cater for children from kindergarten (4-5 years old) to 6th grade (12 years old) (Table 2.3).

Table 2.3 General characteristics of the selected primary school buildings

	School L	School T	School C
Spatial configuration	Linear - L	Linear and Compact - T	Compact - C
Date of construction	1949	1961	1983
Date of building addition	1968	1966	1997
Area			
All floors	5 442 m^2	6 811 m^2	6038 m^2
Ground floor	1 858 m^2	2 462 m^2	2 110 m^2
Schoolyard	16 739 m^2	12 754 m^2	16 563 m2
Students			
Kindergarten	40	55	60
Primary (1^{st}-6^{th} grade)	157	291	316

2.5.3 Evaluation process

Within the research project Schola.ca (2020), school boards provided architectural drawings for a random sample of primary schools in Quebec. This information was imported via AutoCAD into Archidata (2019), a space management digital platform enabling plans to be analysed with other data sources (e.g., construction data, school population, situated survey responses) in later stages of post-occupancy evaluations.

Quantitative information, such as dimensions of buildings, rooms and windows, was measured using AutoCAD. This data was processed in Excel to obtain values, such as window to floor area ratios (Figure 2.3). This data was then compared to threshold values and was analysed in relation to graphical representations superimposed on architectural drawings to situate the parameters presented in Figure 2.1. This analysis helps to visualise and measure issues associated with renovating a school building in relation to the provincial building stock.

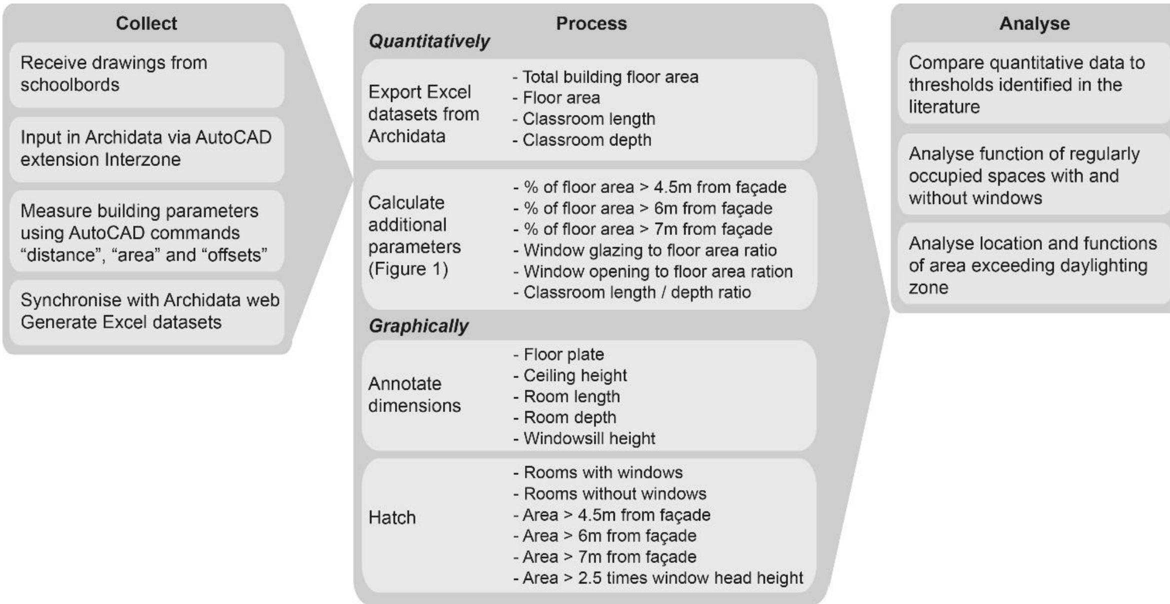

Figure 2.3 Evaluation process of architectural drawings.

2.6 Results

Using objective criteria and measurements revealed the relative differences among the schools in terms of potential biophilic qualities and potential challenges for occupant well-being. The analysis of the building and room proportions and the window glazing and openings highlighted these challenges and opportunities.

2.6.1 Geometry – building and room proportions

Based on floor plate dimensions, Schools L and T present a higher potential than School C for multisensory nature experiences. Portions of Schools L and T share geometric characteristics that differ from School C. The rectangular original construction of School L (Figure 2.4) has a length to depth ratio of 2.69. School T was initially 2.37 times longer than deep. In both schools, the gymnasiums, added when the buildings were enlarged, create broader floor plates. School C offers a thick floor plate, with the narrowest portion of the school containing multiple layers of rooms and circulation spaces.

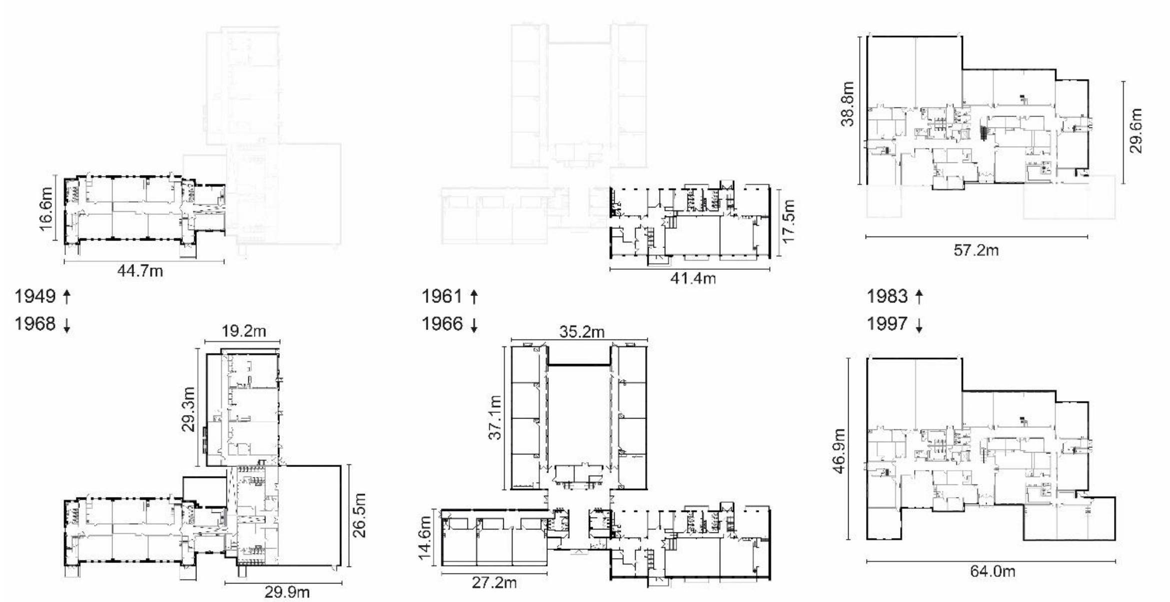

Figure 2.4 Geometry of the ground floors of School L (left), School T (middle), and School C (right) when originally constructed (top) and enlarged (bottom).

The classrooms in the three schools present different opportunities for daylighting, natural ventilation and outdoor views. The three schools are compared (Figure 2.5) using the percentage of floor area that exceeds the daylighting rule of thumb distances and those considered by the WELL Building Standard (2018). Using the general rule of thumb, the ground floor of School L shows the largest task daylighting zone (58.1%) whereas the ground floor of School C shows the smallest task daylighting zone (46.3%). Percentages of floor area more than six metres from the facade vary between 24.4 and 41.3%. Only School C (34.1%) slightly exceeds the WELL threshold for floor area exceeding seven meters (30%) from the facade because of its compact layout. The circulation spaces and gymnasiums in the three schools may have limited opportunities for nature experiences. The amount of time people spend in these spaces would help determine the importance of this issue.

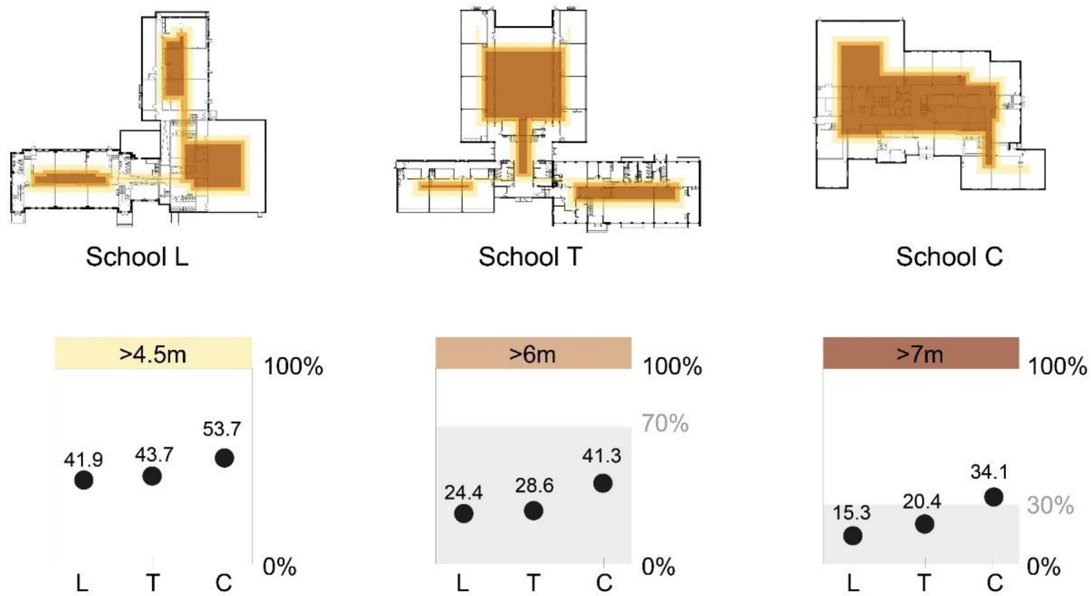

Figure 2.5 Percentages of ground floor area exceeding defined distances from the facade.

Classrooms that are longer than deep present the potential for increasing multisensory experiences of the outdoor environment, provided that windows cover the length of the facade such as in the classroom in the School T addition which has a length to depth ratio of 1.3 (Figure 2.6). On the contrary, classrooms that are deeper than wide, such as in School C (calculated ratios of 0.8 and 0.9), may present inequalities because students seated near the windows have more opportunities to experience the outdoor environment than the students seated towards the back of the room.

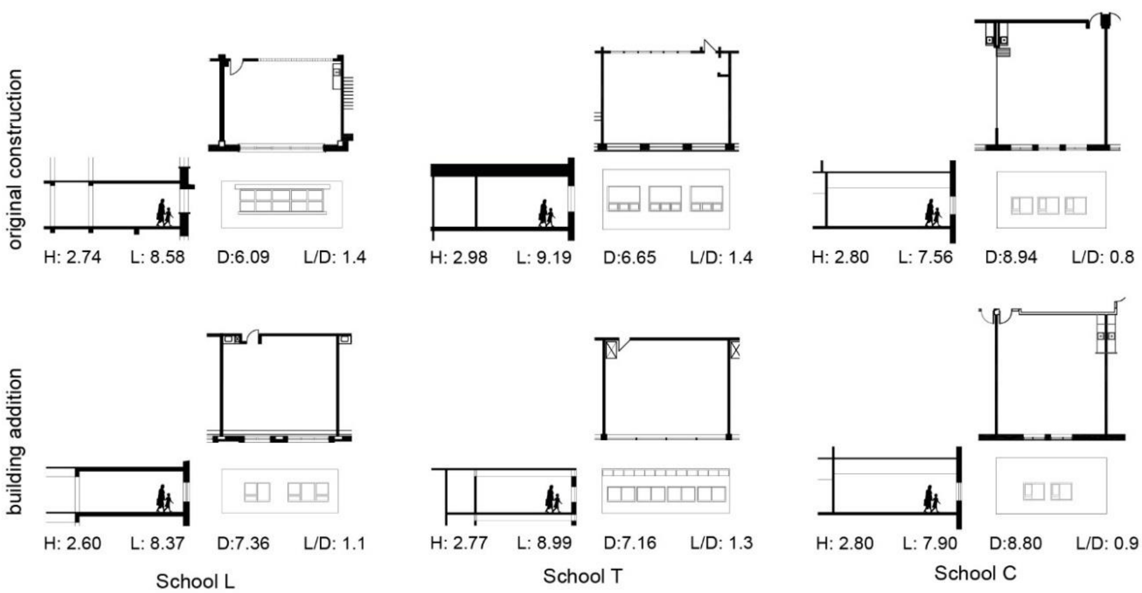

Figure 2.6 Classroom ceiling heights (H), lengths (L), depths (D) and length to depth ratios (L/D).

Ceiling heights vary in Schools L and T based on the construction date, while in School C original classrooms and additions share the same ceiling height (2.80 m). The floor-to-ceiling heights in classrooms of the three schools vary between 2.60 m and 2.98 m (Figure 2.6). The floor-to-ceiling heights in the building additions of Schools L and T are smaller than in the original constructions. In School L, a typical classroom built in 1968 has a ceiling height 5.1% smaller than in a classroom built in 1949. In School T, a classroom built in 1966 has a ceiling height 7.0% smaller than in a classroom built in 1961.

2.6.2 Envelope – window glazing and openings

More regularly occupied spaces with windows exist in Schools L and T than in School C. Given the longevity of school buildings, regularly occupied spaces included rooms in which children or staff could spend most of their school day, such as classrooms, gymnasiums, libraries, child-service offices and administrative offices. The use of school spaces tends to change annually depending on the number of students and their needs. A meeting room occasionally used one year could become a speech therapist's office, for example. Rooms not considered as regularly occupied spaces include toilettes, storage rooms, and mechanical areas.

In School L, 44 of the 50 (88.0%) regularly occupied rooms have windows towards outdoor spaces. All the rooms without windows are small offices in the school addition (Figure 2.7). These offices are occupied by the physical education teacher, the librarian, and child-service professionals such as psychologists and speech therapists. In School T, 44 of the 46 (95.6%) regularly occupied spaces have windows. The gymnasium and the office of the physical education teacher lack windows. In School C, 28 of the 42 (66.6%) regularly used rooms have windows. The rooms without windows include the offices for child services, the physical education teacher's office, the library, the teachers' lounge and a meeting room. Schools L and T exceed the Living Building Challenge 4.0 (2019) and WELL Building Standard (2018) criteria for healthy indoor environments by providing windows in more than 75% of regularly occupied spaces. School C falls below this threshold, further highlighting a challenge for nature experiences. In the original construction of School L (built 1949) and School T (built 1961), 100% of regularly occupied spaces have windows. The spaces without windows emerge in the building additions of 1968 and 1966. School C built in 1983 has several rooms without windows due to its thicker floor plate than Schools L and T. The building addition of School C in 1997 did not generate additional rooms without windows (Figure 2.4).

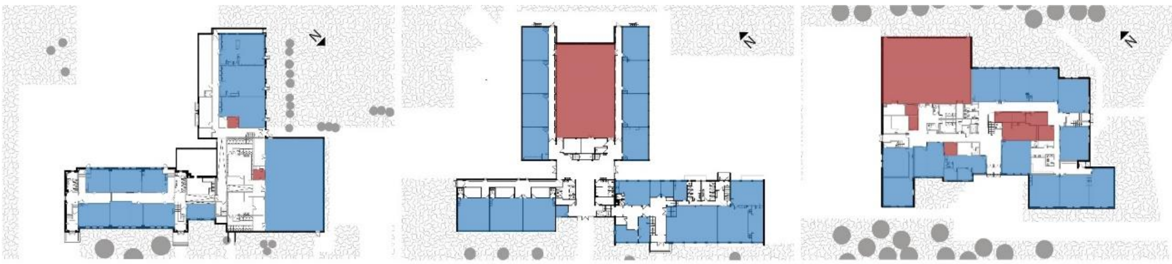

Figure 2.7 Regularly occupied spaces with windows (blue) and without windows (red) on the ground floors.

The comparison of window glazing to floor area ratios in Schools L, T and C reveals a diversity of facade transparency among the schools, and among types of spaces (Figure 2.8). School C offers the lowest glazing to floor area ratios, suggesting more limited visual connections to the schoolyard. Most classrooms in the three schools offer glazing ratios between 10 and 25% (as suggested in DeKay & Brown, 2014). The glazing ratio in the gymnasiums of the three schools approaches zero. Other space types present a greater diversity of glazing ratios. For example, administrative spaces have glazing ratios between 0% and 41%. Five spaces in School L and four spaces in School T have glazing ratios over 25%, suggesting a need for on-site monitoring.

Window opening to floor area ratios are highest in School L and vary between 0% and 21% depending on the function of the space (Figure 2.8). WELL (2018) considers an openable window area above 4% of the occupiable floor area. School C faces the most challenges for thermal, olfactory and auditory exchanges between indoor and outdoor spaces because it offers the lowest window opening to floor area ratios (only three spaces above 5% ratios).

Figure 2.8 Diversity of window glazing and window opening to floor area ratios per regularly occupied room type in each school.

The original construction of School L and School T offer the smallest non-daylit zones (Figure 2.9). School C and the addition to School T present larger non-daylit spaces. In the School T addition, windows in the upper portion of the wall extend the daylit zone. When superimposed on the non-daylight zones estimated from three offsets of the school perimeter (shown in plan in Figure 2.5), the offset distance of four and a half metres is also within the rule of thumb calculation. The only exception is the gymnasium of School C without windows or skylights. In three of the six building sections analysed, the rule of thumb calculation creates a smaller non-daylit zone than the zone created from an offset of seven metres from the building perimeter. The six-metre offset is equal to the rule of thumb calculation for two of the six sections. Provided there are windows in the space, the six-metre offset distance appears to allow a quick estimation of the daylight zone. As Figure 2.9 demonstrates, considering window heights adds finesse to the evaluation.

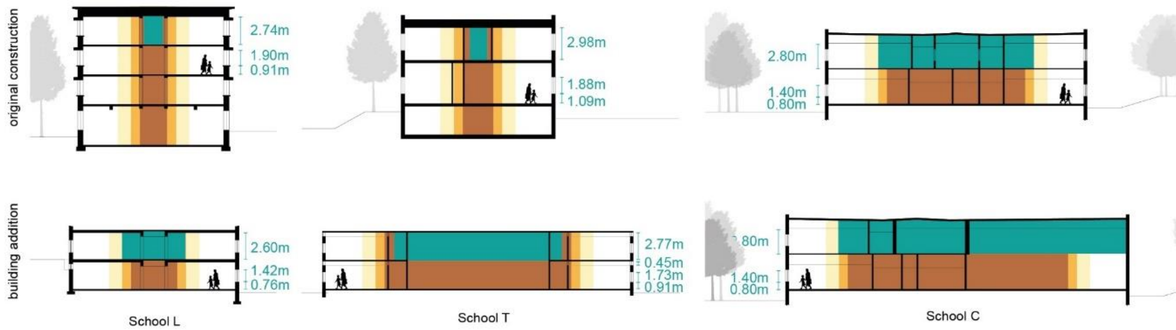

Figure 2.9 Differences between non-daylit zones based on window heights (blue) and zones exceeding defined distances from the facade (shown in plan in Figure 2.5).

Windowsill heights measured in classrooms of the three schools vary from 0.76 m to 1.09 m (Figure 2.9). The typical eye height of seated primary school children approximates one metre, meaning that young children may only have views to the sky in some of these classrooms. In Schools L and T, certain classrooms facing the street have mature trees which limit the view distance while enriching the biophilic experience of the rooms. Classrooms in School C also have views to outdoor vegetation, yet the trees are positioned further from the facade thereby increasing the field of view.

2.6.3 Biophilic challenges and potential opportunities

Potential challenges for biophilic experiences in buildings become identifiable when superimposing the following criteria: regularly occupied spaces without windows, spaces with glazing to floor area ratios below 10% and the zones more than 4.5 m, 6 m and 7 m from the facade (Figure 2.10). Superimposing these layers creates darker zones on the floor plans and sections which highlight potentially problematic areas of the schools.

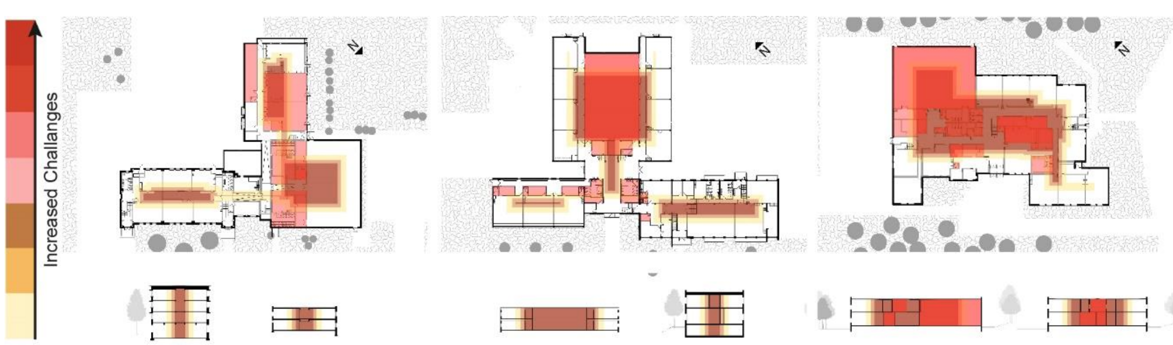

Figure 2.10 Situating challenges for biophilic design in School L (left), School T (middle) and School C (right).

The building zones with opportunities for experiences of nature become identifiable when superimposing the regularly occupied spaces with windows, spaces with glazing to floor area ratios above 15%, the areas offering a direct physical connection to the outdoors and the spaces without windows to which windows could be added because they have an exterior wall (Figure 2.11).

Figure 2.11 Situating opportunities for biophilic design in School L (left), School T (middle) and School C (right).

The quantitative physical data (Figure 2.12) further contributes to the diagnosis of potential biophilic qualities in buildings. A relative comparison between the schools is achieved by positioning the values obtained for each criterion on a scale. The limits of the scale and their position in the figure reflect the relationship with nature that can be created. The thresholds recommended by building certification systems are also included to position the current state of typical spaces in these buildings.

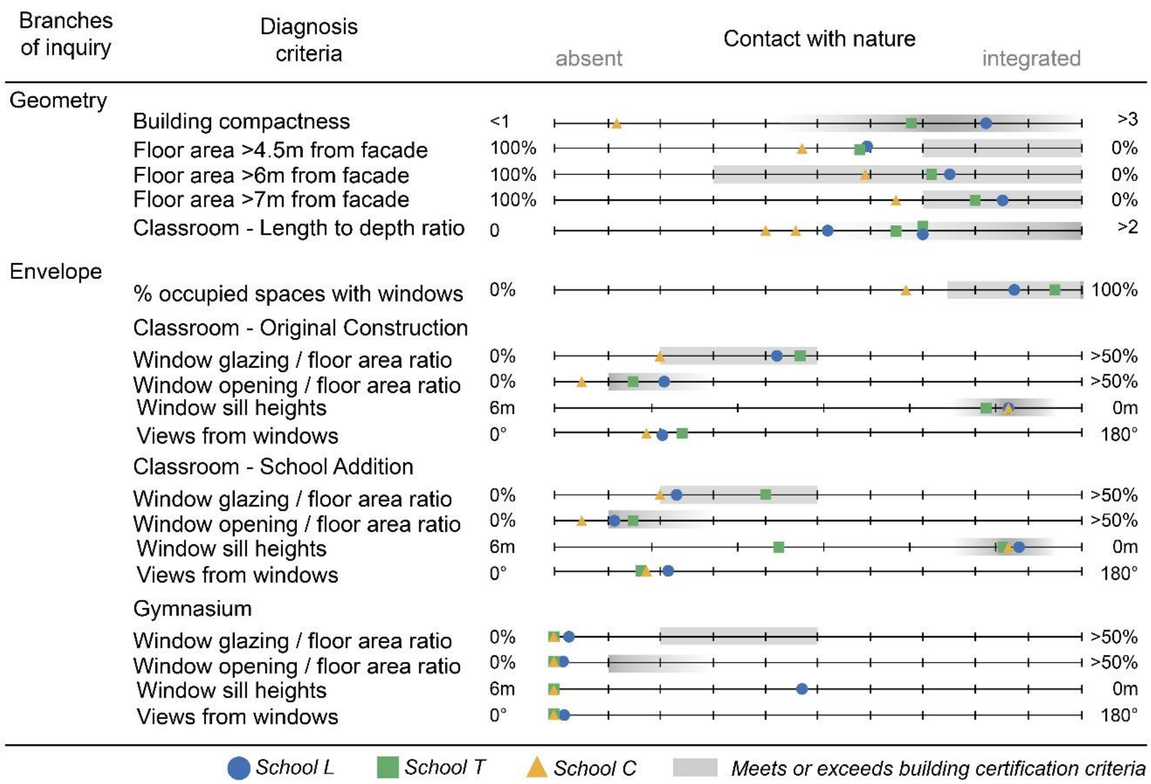

Figure 2.12 Biophilic architecture diagnosis tool evaluating three schools against building certification recommendations.

2.7 Discussion

This paper shows that architectural plans, elevations and sections can be considered valuable documents during the early stages of renovation projects to assess challenges and potential opportunities for improving students' and school staff's contact with nature in schools. Their analysis highlights the importance of the building envelope. The size and placement of windows served as an indicator of current direct experiences of sunlight, fresh air, outdoor vegetation and weather. In a renovation project, their replacement therefore offers the opportunity of enhancing both occupants' experiences of nature and the environmental performance of a building, as long as occupants' adaptive actions are also considered to improve the indoor environmental quality (Carlos, 2017). Window orientation and shading devices further inform the biophilic qualities of space. For example, shading provided by trees near windows (see School L) incorporates natural elements in the field of view of students and school staff while offering other benefits such as enhancing biodiversity in the schoolyard and improving air quality. In comparison to studies investigating impacts of outdoor vegetation on students (for example D. Li & Sullivan, 2016; Matsuoka, 2010), this study helps designers to quantitatively assess architectural characteristics (e.g., window heights and glazing to floor area ratios) that enable or hinder views of these natural elements in schoolyards. Thus, while previous research in cognitive disciplines has investigated impacts of nature on people, this assessment method provides architects with quantitative criteria to evaluate buildings that enable or prevent occupants from experiencing nature.

The value of this assessment method using spatial geometry also lies in the efficiency provided by its simplicity to use. Contrary to time-consuming occupant surveys and *in situ* measurements (e.g., Cochran Hameen et al., 2020; Hassanain et al., 2016) or simulation approaches (e.g., Carlos, 2017) which provide an in-depth diagnosis of buildings, the proposed method enables architects to rapidly assess numerous buildings and identify those offering limited direct experiences of nature (e.g., daylight, natural ventilation and outdoor views including vegetation). The case studies showed that quantitative information contained in architectural drawings enables a relative comparison of a sample of schools and a comparison with criteria in the literature. This allows architects, before site visits, to identify which environmental parameters may fall below recommended thresholds and the spaces (e.g., gymnasium) or characteristics (e.g., window performance) requiring a detailed investigation using post-occupancy evaluation tools.

This analysis highlights architectural opportunities that could be considered during renovation projects. Based on their floor plate dimensions, Schools L and T present a higher potential than School C for multisensory experiences of the outdoor environment. In a thick building like School C, design opportunities include installing skylights or creating atrium spaces to bring daylight and sky views into the core of the building. Additionally, the gymnasiums in Schools T and C offer the opportunity to improve visual and physical access to the outdoors. Gymnasiums represent important gathering spaces that can also serve as dining spaces so installing windows and doors to exterior walls would be highly beneficial. In contrast, offices located at the core of the building present more complex architectural challenges. Inviting occupants to migrate from rooms without windows to shared rooms with windows or to better designed outdoor spaces represents an occupant-centred adaptation strategy that could contribute to overcoming this architectural challenge (DeKay & Brown, 2014; Demers & Potvin, 2016).

2.7.1 Limits and outlook

Using measurable components of architectural drawings in relation to building certification criteria and bioclimatic design principles constitutes an initial step to evaluate architectural opportunities fostering people's well-being. The selected components assist designers in understanding the conditions for potential nature experiences to arise, although they cannot guarantee effective biophilic experiences. Biophilic architecture includes characteristics other than those identified in the proposed assessment method which could be explored in future research. Examples include the relationship between buildings and their immediate landscape and design considerations such as materiality. As Kellert (2018) remarks, "most of our most successful building and landscape designs often respond to a wide range of biophilic values". Moreover, occupant actions can influence to what extent the building features become an opportunity or an obstacle for direct nature experiences. Indoor shading devices, for example, provide occupants with a greater control of sunlight, yet their sustained use limits visual connections with the outdoors.

Buildings offering indirect or representational experiences of nature, that are excluded from the simplified assessment method based on spatial geometry, would be prioritised for site visits in the following stages of the diagnosis. During building walkthroughs, additional biophilic design strategies could be identified and the evaluation of the building would be adjusted to reflect opportunities and challenges provided by these biophilic design solutions. Therefore, a diagnostic approach incorporating this assessment method with other post-occupancy evaluation methods (e.g., surveys and *in situ* measurements) enables a more complete evaluation of buildings based on their geometry (typology) and envelope. Examples of *in situ* assessment methods emphasising biophilic qualities include the Biophilic Design Matrix (McGee et al., 2019) and the Biophilic Experience Representation Tool (Watchman et al., 2021b).

This paper simplifies nature experiences and offers a first step to encourage architects to address biophilic design during building renovations. To seize the opportunities identified with the assessment method, design teams explore beyond these simplified quantitative indicators and adopt an interdisciplinary approach. Communicating the findings of building assessments to occupants could bring awareness to opportunities currently available before vast architectural renovations. Encouraging occupants to participate in the next stages of the diagnosis and renovation of their school could further inform design decisions by considering their current and future needs and activities. As Browning and Ryan (2020, p. 26) suggest, "the inspiration, activities and resulting design solutions will expectedly vary in accordance with architectural processes, the characteristics unique to each project and site, and the priorities of the people engaged to make it all happen". Combining architectural practice with fields such as environmental psychology could ensure that projects also consider qualitative indicators relevant to experiences of nature, such as symbolic references and people's awareness and understanding of natural processes.

2.8 Conclusion

Assessing school architecture contributes to identifying the opportunities and challenges for enhancing students' and staff's direct experiences of nature and their multisensory well-being. This study of three Quebec schools explores an approach based on architectural drawings. It demonstrates the applicability of evaluating spatial organisations common in Quebec schools: L-shaped, T-shaped and compact buildings.

This exploratory study reveals that measurable elements in architectural drawings can provide a preliminary diagnosis of people's potential experiences of natural elements such as light, air and vegetation. The illustration in plan, elevation and section drawings is combined with the positioning of quantifiable data on a scale that allows the current state of school buildings to be discussed against certification criteria that are oriented towards the health and well-being of occupants.

Analysing architectural drawings provides a description of the geometry and sensory attributes of buildings that align with bioclimatic design principles and that can foster the emergence of experience of space and the creation of a sense of place. Extended site visits, occupant surveys and building simulations complement the preliminary analysis proposed.

An analysis of spatial geometry during the design stage would also benefit architects by providing them with a rapid comparison of design alternatives. The evaluation criteria would then generate real-time integration of biophilic issues and opportunities for architects intervening in renovation projects from the early assessment of a building, through site visits, and in the design development process.

The novelty of this assessment method lies in the rapid evaluation of numerous buildings to identify those to prioritise for renovation interventions as they may present challenges for occupant well-being and experiences of nature. This study shows that measurable elements, such as building proportions, contained in architectural drawings, can serve to situate a school building in relation to biophilic, bioclimatic and certification guidelines while identifying issues associated with its renovation.

Chapter 3 Sensory experiences and biophilia: walkthrough observations and field measurements

In situ measurements provide a novel approach in environmental surveys for gathering multisensory information about positive experiences of nature that influence considerations of bioclimatic and biophilic design. This chapter aims to discuss how natural elements such as daylight, wind, snow and vegetation, influence sensory experiences during site visits to schools in cold climate. It draws on measuring tools and methods that exist to assess the quality of the indoor environment from the perspective of building occupants (such as Candido et al., 2016; Cochran Hameen et al., 2020; Heinzerling et al., 2013). Walkthrough observations and field measurements of environmental parameters were recorded to document how architectural configurations foster biophilic experiences. What are the roles and influences of natural light, thermal variability and auditory stimuli on people's experiences in indoor and outdoor spaces? Complementary to the analysis of Schools L, T and C in Chapter 2, visits to these three schools took place during different seasons to observe and measure light, temperature and sound conditions. The findings assist in defining the challenges and opportunities in relation to spatial geometry identified in Chapter 2. The parameters are selected contributing factors to affecting indoor environmental quality and potential biophilic qualities of the existing spaces.

3.1 Introduction

Sensory experiences — visual, thermal, olfactory or auditory — that relate to natural elements, patterns or processes can foster pleasant architectural settings for building occupants (Browning & Ryan, 2020). It has been argued that "the design and construction of the built environment generally deals with infrastructure systems and specialities whose impact falls roughly into the original five categories of touch, taste, hearing, sight and smell" (Erwine, 2017, p. 26). Describing, measuring and representing sensory experiences raise many questions in terms of people's affiliation with nature; this chapter discusses how architectural configurations of indoor and outdoor spaces influence people's sensory experiences of nature.

In the context of renovating primary schools in Quebec, the investigation focused on sensory experiences within biophilic and bioclimatic design frameworks. The aim was to identify design opportunities capable of enhancing people's sensory experiences and well-being. This was achieved by a combination of walkthrough observations and indoor environmental quality (IEQ) measurements for each sensory experience. In a post-occupancy framework, this approach showcases how each level of investigation (Mallory-Hill & Gorgolewski, 2018) contributes to the assessment of buildings. This reflection is inspired from and contributes to the development of diagnostic tools within the research project Schola.ca (2021) to help design professionals assess and renovate learning environments in Quebec.[6] Site visits are proposed to discuss spatial types in terms of sensory biophilic experiences. This chapter raises the following questions:

- how can field measurements serve to discuss biophilic experiences?
- how can measurements of light, temperature and sound conditions reveal potential opportunities or challenges in existing buildings to connect people with nature?
- what are the limitations of site visits in assessing people's experience of nature?

Real-time measurements and observations of lived space offer the opportunity to complement the assessment of architectural drawings (presented in Chapter 2) by experiencing these school settings. As Demers and Potvin (2016) explain, "existing spaces offer the advantage to experience actual ambiences in real time, enabling to assess quantitative parameters as well as qualitative ones". While post-occupancy evaluations often include *in situ* measurements, the novelty of the approach proposed is to discuss environmental surveys in relation to positive multisensory experiences of nature. The findings presented in this chapter integrate photographs and physical data in relation to illuminance, equivalent melanopic lux, air and surface temperatures and sound levels, and provide the basis for representing and discussing sensory experiences of nature in learning environments. The discussion focuses on biophilic experiences in three space types offering

[6] The document "*Fascicule B: Bien diagnostiquer. L'école à rénover et ses enjeux*" developed by the project Schola brings together an ensemble of diagnostic tools making it possible to collect the information necessary to evaluate of a school building. Each tool refers to specific sections of the document "*Fascicule A: Apprendre. Les écoles primaires publiques du Québec*". The analysis of this information positions a school building in relation to the provincial sample of schools and identifies the specific issues and challenges associated with its renovation.

different connections between indoor and outdoor spaces: sheltered building entrances, interior corridors and classrooms.

3.2 Background

Previous studies of primary schools in Quebec reveal the importance of indoor environmental quality measurements on building occupants and stimulate innovative renovation proposals. Between 2014 and 2017, primary schools in Quebec were investigated as part of the project "*Ensemble pour des contextes de repas plus conviviaux*".[7] These investigations into the environmental quality of Quebec schools highlighted the inadequate visual, thermal, olfactory and auditory conditions affecting activities of students. The scope of this previous research omitted to address the biophilic qualities of these schools and how students and school staff experience nature throughout the year.

Biophilic design seeks to establish and enhance positive connections between people and nature, rather than examine or create settings that do not make people sick or unwell (Kellert et al., 2008). Various methodological approaches can be used to measure the benefits of nature on the health and well-being of children.[8] In post-occupancy evaluation studies of school settings, multiple measuring tools and procedures are used to examine indoor environmental quality (IEQ) parameters such as light, noise, temperature and humidity. The systematic and rigorous manner of evaluating buildings reveals the consequences of past design decisions and the resulting building performance (Preiser et al., 1988). Methodological approaches include surveys to document occupants' satisfaction and perception of buildings (Sadick & Issa, 2017; Schola, 2018), detailed and repeated objective measurements of environmental conditions (Carrier et al., 2019; Duarte et al., 2017; Secchi et al., 2017) and the combination of surveys and IEQ measurements (Cochran Hameen et al.,

[7] This research project was given to the *Groupe interdisciplinaire de recherche sur les banlieues* (GIRBa) by the *Association québécoise de la garde scolaire* (AQGS). It included the following activities: (1) site visits of six existing, one recently renovated and four newly constructed primary schools, (2) in-depth diagnostic and renovation scenarios for six primary schools in the Quebec City area, based on scientific evidence, *in situ* observations and measurements and the consultation of a multisectoral and multidisciplinary committee of experts and (3) the architectural assessment of three schools in the province using staff surveys and *in situ* measurements of the visual, thermal, auditory and olfactory conditions during lunch.

[8] A review by Chawla (2015) shows that research in children's environments has included ethnographic research methods (such as interviews, observations as well as drawings, photographs and diaries by children), naturalistic experiments and correlational designs (such as investigations of schoolyard renovation interventions or different outdoor views to grow the evidence base with quantitative findings). More recently, experimental, quasi-experimental and correlational studies have followed a medical model that compares exposure to nature with a medication to investigate how access to nature can contribute to the absence of disease or infirmity.

2020; Kim & de Dear, 2018). Nonetheless, investigating the impacts of the indoor environment on building occupants tends to focus on identifying and correcting features leading to uncomfortable or unhealthy situations (Bluyssen, 2009). Overheating during summer, excessive noise, and high concentrations of indoor contaminants represent examples of unpleasant situations often discovered in IEQ assessments. Field measurements provide tangible evidence of the relationships between indoor conditions and thresholds known to boost people's comfort in buildings and during transitions between indoors and outdoors. Measuring the amount and distribution of natural light, natural ventilation and sound conditions could additionally offer insights into the positive characteristics of nature people may experience.

By modulating environmental conditions during the passage between inside and outside, transitional spaces at the building edge can promote pleasant sensory experiences for occupants. Presented as an attribute of the biophilic design element "natural patterns and processes", Kellert et al. (2008) suggest that transitional spaces include thresholds, portals, doors, bridges and fenestrations. The careful design of these spaces between interior and exterior environments favours environmental diversity (Potvin, 1996) which can contribute to the visual and thermal comfort and delight of occupants. For example, Araji et al. (2007) showed that key elements for promoting visual comfort in transitional spaces include gradual variation in light levels and providing sufficient time for visual adjustments. Gradual thermal transitions also improve people's adaptation to an indoor environment. Vargas et al. (2017) studied the thermal perceptions of students walking through transitional spaces to their classroom in comparison to a group of students walking directly inside. They observed that gradual and even multiple abrupt changes in the same thermal direction can lead to a more positive thermal adaptation than a single sudden change in temperature between the exterior and the interior. Given the benefits of experiencing nature in schools (see Chapter 1), this chapter focuses on documenting and evaluating the potential biophilic qualities present in a selection of transitional spaces.

Overlapping sensory experiences connect people and their environment and thus require a systemic assessment. Humphreys et al. (2016) argue that an occupant's response to an environmental stimulus can be affected by its interaction with other stimuli. Heschong (1979, p. 29) addresses this simultaneity as follows:

> Since each sense contributes a slightly different perception of the world, the more senses involved in a particular experience, the fuller, the rounder, the experience becomes. If sight allows for a three-dimensional world, then each other sense contributes at least one, if not more, additional dimensions. The most vivid, most powerful experiences are those involving all of the senses at once.

Some environmental stimuli creating sensory experiences can be quantified and measured, such as light quantities, temperatures and sound levels. However, other sensory experiences allude to the subjective experience of space. In terms of auditory stimuli, for example, biophilic design is more directly informed by the perception and appreciation of sound than by building acoustics and considerations such as reverberation time. Thus, although the observations and field measurements discussed in this chapter aim to address multiple sensory experiences, measurements of environmental conditions only capture certain dimensions of multisensory experiences in architectural spaces and indoor-outdoor transitions.

Excellent light does not refer strictly to the quantity of light, but also includes its quality, which may be even more important (Rasmussen, 1964). Lam (1992, p. 14) argues that "the real objectives of lighting design [are] to provide a comfortable, pleasant, reassuring, interesting, and functional space for the people who will inhabit it". Beyond ensuring specific levels of illumination for people's activities, the luminous environment should satisfy biological needs (via environmental information such as time, location and weather). In a biophilic design framework, a useful metric to complete these observations and to assess daylighting performance is the daylight factor (DF). This metric characterises the ratio between light levels inside and outside of a building.[9] The DF can be calculated for a specific location in a room or as an average value for a room. Considering the latitude of Quebec City (46.8°), the target daylight factor range for classrooms is 3.05-8.10% (DeKay & Brown, 2014, p. E310). Since high DF values suggest enough light for reading and writing activities without electric lighting (CIBSE, 2015), this metric could serve as an indicator of potential

[9] In comparison, daylight autonomy (DA) expresses the percentage of the year during which electric lighting is not needed to obtain specific illuminance levels in indoor spaces. Depending on the climatic context of a building, this may be complex to achive.

experiences of daylight in relation to outdoor conditions. When designing for optimal visual experiences, the non-visual effects of light also deserve attention. The length duration and diurnal and seasonal extent of exposure to light affect the regulation of the circadian system (Boyce, 2003). In northern latitudes during winter, lack of sunlight can induce negative moods and seasonal affective disorder (SAD). The spectral compositions of artificial light differ from natural light and can enhance the effects of SAD (Malnar & Vodvarka, 2004). The biological effects of light can be measured in equivalent melanopic lux (EML), an alternative metric to lux that considers intrinsically photosensitive retinal ganglion cells (ipRGCs) (Brown, 2020; R. J. Lucas et al., 2014). Members of the Schola research project have investigated the non-visual effects of light in Quebec primary schools. The spatialisation of this lighting data collected during site visits in Schools L, T and C is explored by Carrier (Forthcoming) to assess the quality of outdoor views and to compare the performance of a space with lighting and well-being standards.

Indicators characterising thermal experiences can include the quantity and quality of warmth a space receives from direct sunlight and the ability to control heating and cooling systems. In terms of measurable indoor conditions during winter, ASHRAE (2019) recommends classroom temperatures between 21.8 °C and 26.2 °C depending on relative humidity; CIBSE (2015) recommends temperatures between 19 °C and 21 °C to generate comfortable conditions. During summer, these recommended thresholds increase to 23.8 °C and 27.5 °C (ASHRAE, 2019) and 21 °C and 23 °C (CIBSE, 2015). Acknowledging that steady-state thermal environments prevail in many public buildings in the United States, Heschong (1979) suggests that “such uniformity is extremely unnatural and therefore requires a great deal of effort, and energy, to maintain”. Similarly, Baker and Steemers (2002) state that comfort issues are important to building design, but not “an obsessive application of narrow ‘optimised’ environmental parameters”. They stress the importance of variable conditions and the ability for occupants to choose and modify these conditions if desired. Similarly, biophilic design encourages thermal and airflow variability (Browning et al., 2014). In addition to comfort considerations, temperature measurements could be used to determine whether building occupants would experience thermal variability within a space or across several areas in a building. Thermal imaging performed during site visits reveals the invisible physical phenomenon people experience while localising potential thermal singularities.

Using different colour gradients, thermographs locate the coldest and hottest surfaces in a space or reveal homogeneous thermal environments. Incorporating people in these thermal images could further help to discuss the temperature of space in relation to the experiences of its occupants.

The sources of desirable sound or disturbing noise, its distribution and perception determine the quality of auditory experiences in indoor spaces (Bluyssen, 2009). Biophilic design guidelines mostly refer to the subjective nature of natural sounds and offer little guidance as to useful metrics for the design and evaluation of an auditory experience. For example, the literature recommends that architects prioritise nature sounds (e.g., songbirds, flowing water) over urban sounds (Browning & Walker, 2018). Also recommended is the minimisation of noise pollution and enhancement of natural sounds in the outdoor environment (Kellert et al., 2008). When measuring sound levels, dBa often serves as an indicator for human (and subjective) responses to noise across the range of audible frequencies (CIBSE, 2015). For classrooms, ASHRAE recommends a maximum background noise level of 35 dBa while CIBSE (2015) allows a maximum range varying between 25 and 35 dBa. The upper threshold corresponds to the maximum noise generated by the mechanical services of the building. While quiet or loud spaces are not necessarily biophilic, it is possible to suggest that quiet spaces make it easier for building occupants to hear the pleasant sounds that nature has to offer (such as birds or rain).

It is important to acknowledge that absolute measurements of light levels, equivalent melanopic lux, temperatures and sound levels do not necessarily relate to biophilic experiences such as a sense of exhilaration and curiosity towards nature (Browning et al., 2014) or “engagement and immersion in natural features and processes” (Kellert, 2018, p. 19). Yet, designers can “orchestrate the occurrence and shape of the sensory inputs to create the possibility of experience” (Erwine, 2017, p. 38). Therefore, this chapter argues that relative measurements of temperatures, light and sound levels among interior and exterior spaces could help to discuss sensory experiences of natural forces and organisms. These sensations may be understood as a fundamental level of biophilic experiences (see the model developed in Appendix E presenting sensations, affect, understanding and affiliation with nature as nested levels). In this sense, relative measurements of environmental conditions reveal potential opportunities for students to learn in naturally lit instead of artificially lit classrooms, to experience variable rather than uniform thermal conditions and to hear pleasant sounds rather than noise from building systems or noisy sites.

3.3 Method

The methodological approach for the site visits presented in this chapter concerns the first two levels of investigation in a building performance evaluation (BPE) framework proposed by Mallory-Hill and Gorgolewski (2018). They identify observations during building walkthroughs as one of the methods used during the first level of investigation. This method corresponds to the desired level of detail in the *Fascicule B* developed by the research project Schola (2021). Field measurements of the indoor environmental quality (IEQ) recorded during the second level of investigation provide detailed information about the physical settings to complement walkthrough observations. The following sections present the tools used, school spaces experienced and site visit procedure for Schools L, T and C.

3.3.1 Measurements

People experiencing these settings is key to the appreciation and understanding of biophilic buildings. Therefore, this approach draws on measurements of environmental conditions taken by stationary and moving pedestrians (Boiné et al., 2018; Demers & Potvin, 2021) to provide spatiotemporal representations of multisensory phenomena. Instrumental measurements and photographic surveys of the interior and exterior environment were recorded at three schools.

Specific tools were employed to record lighting, temperature and sound conditions in each space. A multimeter (Environmental Meter EN100, Extech Instruments by FLIR Systems) measured illuminance, temperature and humidity data. A calibrated radiometer (ILT5000 Research Radiometer, International Light Technologies) with a sensor head equipped with a melanopic optical diffuser recorded melanopic illuminance. An infrared laser thermometer (IR Thermometer 62max+, FLUKE) captured the temperatures of walls, floors and ceilings. A sonometer (Sound Level Meter NL-22/NL-32, RION) documented sound levels with “A” frequency weighting. Both the radiometer and sonometer also captured environmental conditions during a walk between the schoolyards and classrooms.

Combining photographs and instrumental measurements aimed at contextualising the quantitative information collected. Photographic surveys constitute an inexpensive and unobtrusive method to document physical traces (such as the use of windows and shading devices) that could influence visual, thermal, olfactory and auditory experiences. Observing these physical traces can help researchers and designers understand how people use and feel about their surroundings and how specific settings meet the needs of the users (Ziesel, 1984, p. 89). Photographic surveys were undertaken using two different instruments. A Nikon D5200 was used to photograph the visual appearance of the indoor and outdoor settings. The entire field of view was documented with a Photolux digital photoluminancemeter from Soft Energy fitted with a 180° fisheye lens. High Dynamic Range (HDR) images were transformed into a greyscale image in Adobe Photoshop and applied to study the distribution of light on chosen surfaces within the selected spaces. Such visual representations assist in discussing these multisensory phenomena in relation to architectural space.

3.3.2 Case study schools and space types

The site visits in three educational buildings documented the multisensory experiences created by the spaces and architectural features, such as windows, circulation spaces and sheltered building entrances, separating classrooms from each other and from the outdoor environment. The three primary schools analysed in Chapter 2 capture a variety of indoor-outdoor spaces making it possible to explore biophilic experiences in three common spatial organisations: L-shaped, T-shaped and compact school layouts. The analysis based on spatial geometry showed that Schools L and T present a higher potential than School C for visual, thermal, olfactory and auditory experiences of nature (Table 3.1). The method proposed in this chapter makes it possible to further explore the challenges and opportunities for biophilic experiences identified using architectural drawings alone. It also becomes possible to observe how occupants adapt these settings and to what extent the building features become an opportunity or an obstacle for direct nature experiences. Considering the numerous primary schools in Quebec potentially requiring renovations, the diagnostic approach developed in Chapter 2 helps architects and school boards to identify quickly, among the 2111 buildings in the province, those to prioritise for site visits in subsequent stages of their diagnostic. This chapter shows how instrumental measurements and photographs taken during such site visits serve to discuss sensory experiences of nature.

Table 3.1 General characteristics of the selected primary school buildings

	School L	School T	School C
Spatial configuration	Linear - L	Linear and Compact - T	Compact - C
Date of construction	1949	1961	1983
Date of building addition	1968	1966	1997
Students Kindergarten Primary (1st-6th grade)	 40 157	 55 291	 60 316
Opportunities*	• Elongated building geometry • Large daylighting zone • Occupied spaces with windows • Physical access to outside	• Elongated geometry of original construction • Elongated classroom geometry • Occupied spaces with windows	
Challenges*		• Compact building addition	• Building compactness • Small daylighting zone • Occupied spaces without windows

** Main opportunities and challenges for multisensory experiences of nature identified using the simplified assessment method based on spatial geometry (Chapter 2).*

Measurements and photographs were taken in the schoolyards, circulation spaces, certain classrooms, the gymnasium and library of each school. These spaces were selected based on their availability so as not to disrupt learning activities. This chapter presents the findings related to the research questions concerning sheltered entrances, corridors and classrooms at the three schools (Figure 3.1). Appendix D presents additional field measurements and photographs used to document other spaces. The entrances investigated face the street in front of the school or the schoolyard, opening the space to road traffic or children playing outdoors. They are all enclosed overhead, sheltering people from the sun and falling rain as they enter or exit a building. Some spaces are delimited by a wall on one or both sides of the space which limits the field of view while protecting people from harsh winter winds. The corridors selected for study are located either in the original construction or the building addition to investigate the impact of different spatial configurations on environmental settings. Most corridors have a window to the outside and transoms that connect these spaces to classrooms. The classrooms differ in their solar orientations, room proportions and glazing characteristics and these attributes may influence an occupant's relationship to the outdoor settings.

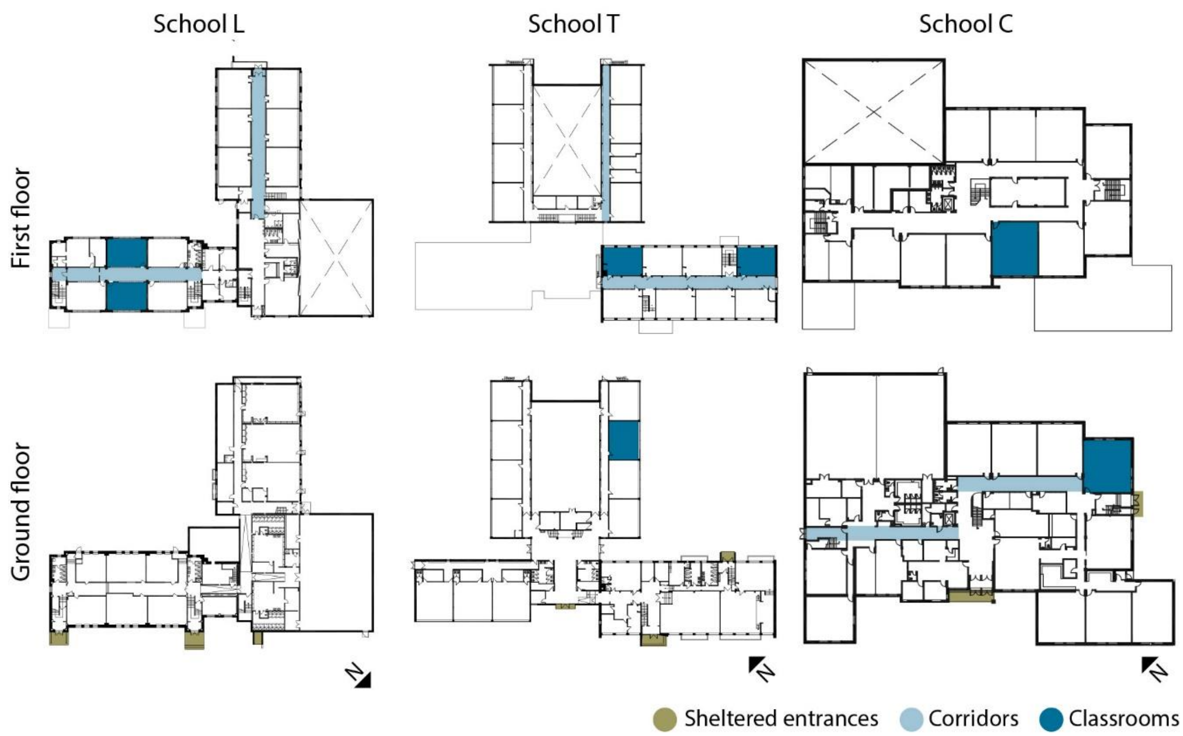

Figure 3.1 Locations of space types selected for discussion in each school.

3.3.3 Procedure

Site visits took place over different seasons to capture a variety of sky, temperature, precipitation, vegetation and occupancy conditions. In the cold climate of Quebec, the distinct seasons present great variety and variability of nature (Chapter 1). Visiting three schools during summer, autumn and winter enabled the gathering of information under conditions of overcast and clear skies, rain and snow, and foliated and leafless vegetation (Figure 3.2).

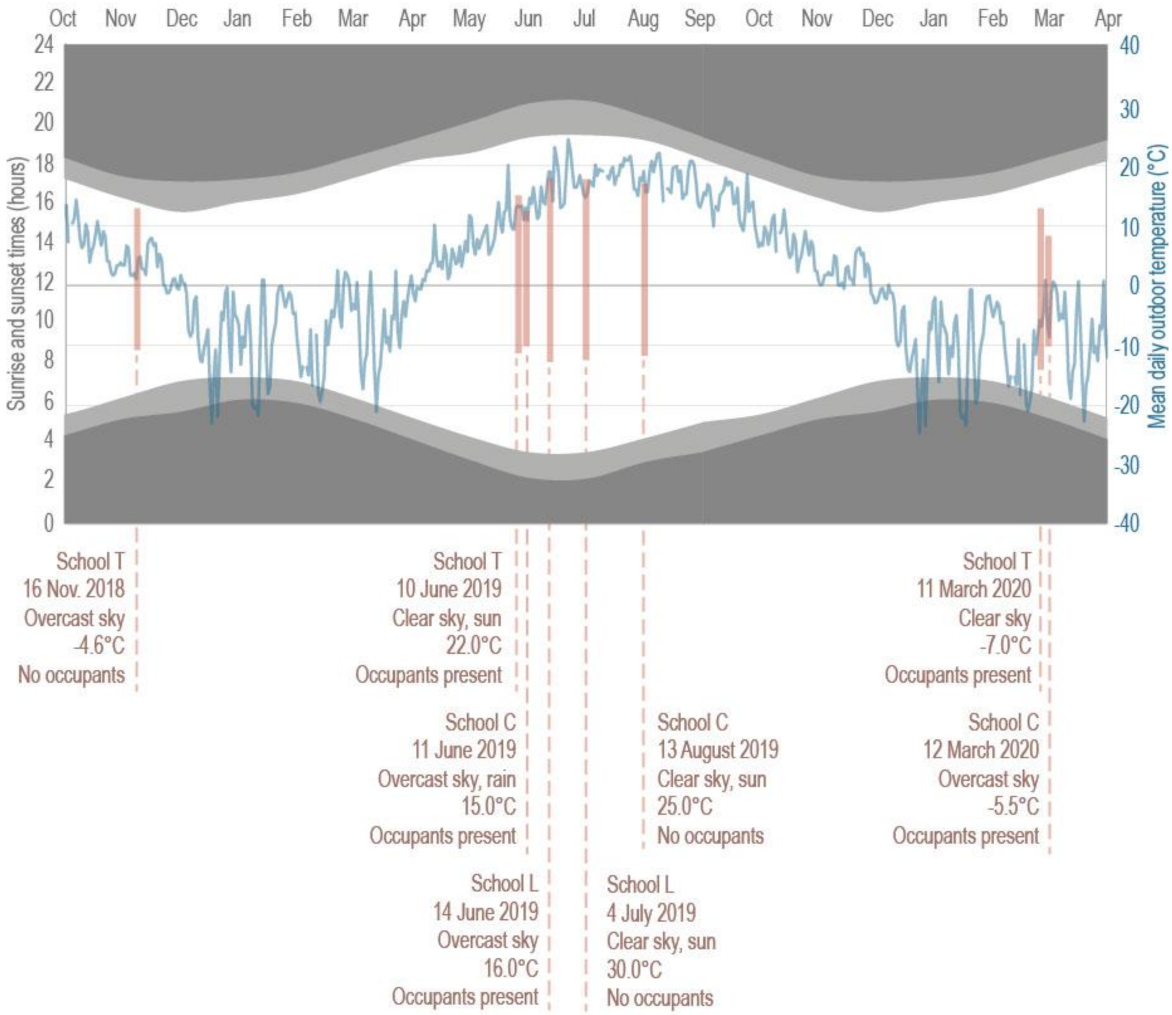

Figure 3.2 Site visits in the three schools over different seasons and weather conditions.

To evaluate sensory experiences at different distances from windows and various view angles to the outdoors, five locations were chosen in classrooms. Measurements were made of illuminance, temperature, humidity and sound levels (Figure 3.3). Photographs taken at these locations were used illustrate the range of distributions of light and exterior views as well as to document the nature of the materials in the space and the occupancy conditions. The extremities and midpoints of corridors were selected for study whereas the limited sizes of building entrances restricted the observations to a single point. Measurements and photographs taken at several locations in the schoolyard enabled the calculation of outdoor environmental values and provided data relevant for discussing indoor and outdoor sensory experiences.

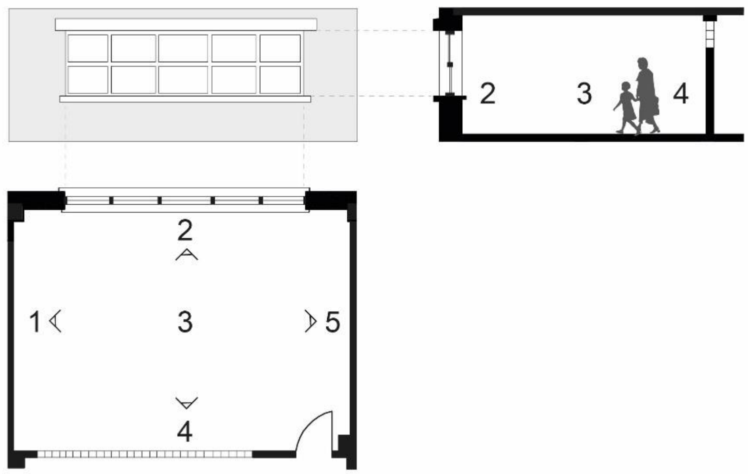

Figure 3.3 Typical measurement locations of environmental conditions and camera view angles in classrooms.

Repeating photographs and measurements at specific times proved challenging and required a research procedure that could be adapted based on the availability of teaching spaces and weather conditions. For instance, during the June visit to School C continual heavy precipitation resulted in children spending both recesses and lunch in their classrooms. Consequently, fewer photographs and measurements were taken in these regularly occupied interior spaces than during subsequent visits. The second visit to School L was planned during the summer holidays in order to document the spaces without occupants. As this visit coincided with summer cleaning and maintenance, some spaces were inaccessible while others were devoid of furniture. While these inconveniences impacted the possibility to compare spaces, it revealed the inherent qualities of empty spaces without reflections and absorption provided by furniture, which changes based on the use of the classroom. Moreover, it was impossible to visit School L during winter because of the public health measures in effect in 2020 and 2021. Contrary to comparative field studies (e.g., Watchman et al., 2017b) or studies requiring extensive measurements in specific conditions (to comply with standards such as ASHRAE), this research favoured instrumental measurements in an exploratory approach to discuss sensory experiences in a variety of spaces in different seasons. This approach also reflects the sporadic visits that are expected to be made by building managers to identify issues to address during renovation interventions.

3.4 Findings and discussion

The findings of sensory experiences in three architectural configurations from the site visits are presented below. Sheltered building entrances, interior circulation spaces and classrooms generate different connections between indoor and outdoor spaces and influence people's experiences of natural light, thermal variability and auditory stimuli from a bioclimatic and biophilic standpoint. A longitudinal visualisation of sensory experiences in these spaces offers an informative sensory narrative as people transition from outdoor to indoor settings.

3.4.1 Sheltered building entrances

Sheltered building entrances of different dimensions and orientations are present in School L, School T and School C. These CANOPY PLACES (concept further described in Chapter 5) enclose overhead, creating a refuge with a view or garden connection. Certain building entrances are delimited by a wall on one or both sides, further enclosing the space. Figure 3.4 organises digital and thermal photographs to show the views and distribution of light and temperature at each building edge. These images present the environment from the perspective of a pedestrian approaching the building from the street or the schoolyard and entering the building from different locations. The second series of images reflects views obtained by a pedestrian walking in the opposite direction, exiting the building and observing the surrounding context. These sheltered entrances are discussed within a spatial sequence, because "the experience of space in architecture is dynamic with periodic or constant movement between areas of a building or between inside and outside" (Potvin, 2004). Particularly in schools, children walk in and out of the building multiple times throughout the day for morning and afternoon recess, during the lunch break, and occasionally, for physical education classes.

Thermal photographs illustrate how these sheltered spaces reduce temperature contrasts to facilitate the thermal transition between interior and exterior spaces. In the three schools, cooler temperatures were recorded during the summer visits because the overhead canopy limits exposure to the sun (Figure 3.4). While the experience of such transitional spaces may be brief, as students enter from recess for example, they offer the possibility of enhancing pleasant experiences as the body adapts to a new thermal environment. When exiting the building, all the locations provide views of vegetation. However, entrances facing the street enabled views of more vegetation than the asphalt-dominated schoolyards.[10] The distribution of natural and artificial surfaces and the presence of trees in the immediate field of view reduce temperatures at the perimeter of the building, further reducing thermal contrasts.

Each door connecting indoor and outdoor spaces in Figure 3.4 contains glazing, enabling occupants who are circulating within the building to appreciate outdoor views. Yet, entry sequences including a vestibule reduce the amount of natural light illuminating the indoor entry. Only the main entrance of School T offers a direct line of sight through the building, given the thin building plan and absence of opaque indoor walls. Despite the proximity of the entries to the outdoors, artificial light was necessary to illuminate these spaces.

Built and natural elements in the field of view also contextualise the auditory experience of these architectural spaces. Blesser and Salter (2007) illustrate the connections created by open doors and windows with the notion of an “acoustic arena”. Defined as an “experience of social spatiality, where a listener is connected to the sound-producing activities of other individuals”, acoustic arenas do not respect the visual and social markers that delineate a transition between two spaces. While the physical boundaries of these entrances protect from direct sun and light, they remain experientially connected to road noises in front of the buildings or to potentially more biophilic sounds, such as birds, rain and children playing in the schoolyard.

[10] The distribution of natural and artificial surfaces and the presence of trees on the site of the schools is further analysed based on architectural drawings in Appendix C.

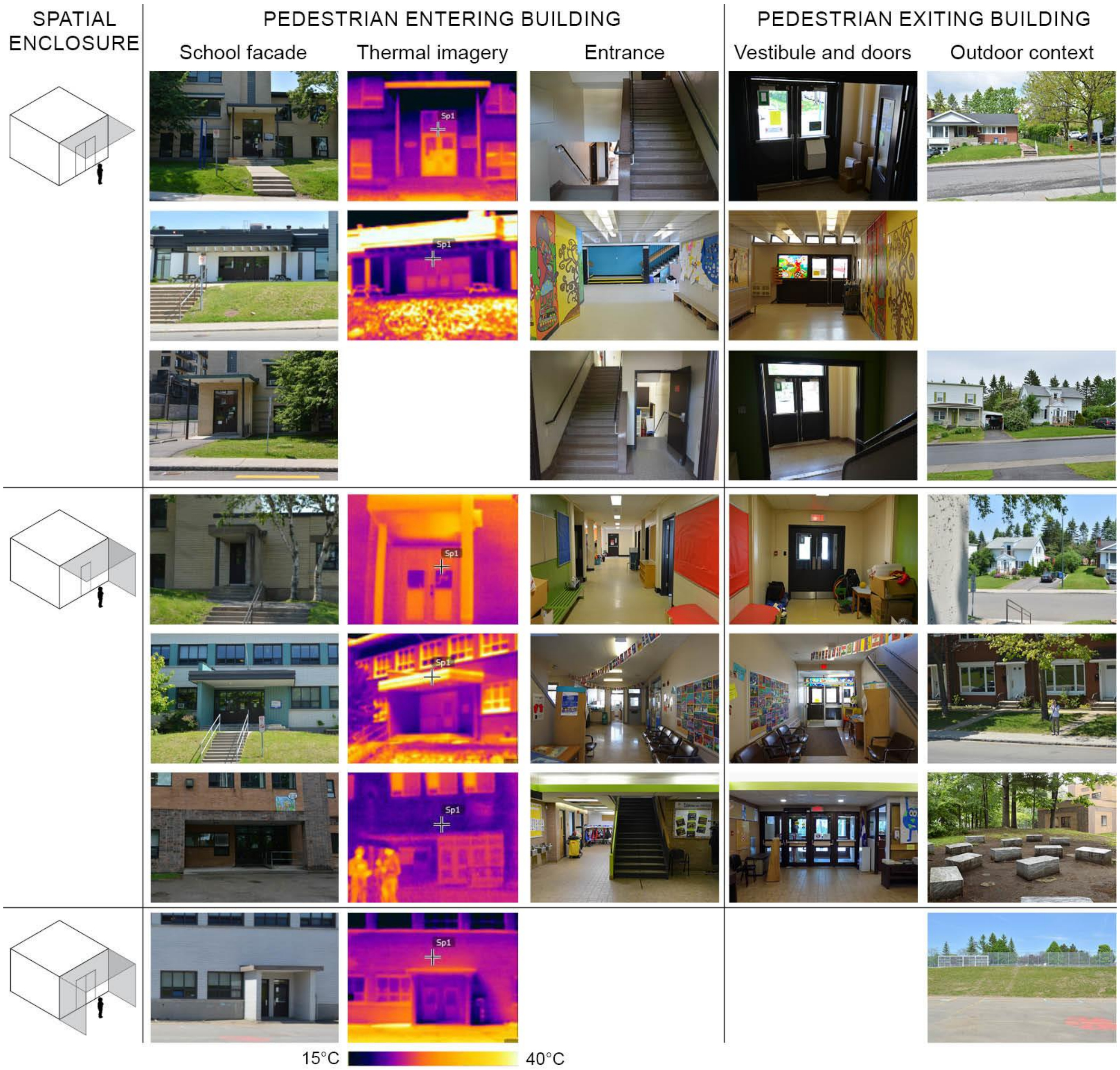

Figure 3.4 Views and distribution of light and temperatures in sheltered building entrances photographed entering and exiting three schools during summer visits.

The presence of two sets of doors delimiting a vestibule at several entrances represents an additional physical separation with the outdoor environment. The photographs of the vestibule taken from the main entrance hall of School T during winter illustrate the thermal difference between these two sets of doors (Figure 3.5). The entrance hall and interior doors of the vestibule appear in warm yellow-orange hues. Because the interior door on the left is open, it becomes possible to observe the cooler temperature of the exterior door, shown in purple. The photograph taken as a parent and student enter this space shows that this vestibule is warmer than the sheltered outdoor entrance. These changes in the same thermal direction as people enter the building could result in a positive thermal adaptation, as found by Vargas et al. (2017). While a vestibule is present at the main entrance of School T, the doors generally used by students during recess had neither a vestibule nor a sheltered outdoor entrance. In Figure 3.5, photographs document students entering from the schoolyard after recess during winter. The door remained open for several minutes as numerous students entered, suggesting that even if a vestibule were present, both sets of doors would be opened after recess to facilitate students' entrance. This temporarily let cool and fresh air into the building, informing indoor occupants, who were not outside during recess, on outdoor conditions.

Figure 3.5 Thermal events as students enter School T during winter.

These sheltered entrances can therefore be considered as transitional spaces, not only in terms of their spatial configuration and function, but also in terms of sensory stimuli. The distribution of light and temperature and connections to auditory events reveal the capability of entrances to create comfortable transitions between indoor and outdoor spaces. The limited size of these sheltered entrances nonetheless makes it difficult to linger in these spaces and appreciate the outdoor conditions. While they may foster comfortable transitions when students enter or exit the school for recess, they cannot be used by groups of students during outdoor learning activities. In the three schools, these were the only outdoor spaces offering some protection from the sun and rain. In their current configuration, these sheltered entrances suggest design interventions during renovation projects to increase the amount of time students and staff can spend outside, even during rainy days or cold periods of the year.

3.4.2 Corridors offering indirect experiences of outdoor conditions.

Circulation spaces in the three schools were generally far from exterior influences, offering students and staff indirect experiences of outdoor conditions. Classroom doors and transoms assisted in creating an INDOOR VIEW (concept further described in Chapter 5), bridging spatial boundaries via layers of frames and transparency degrees. The transom window above the classroom doors in the original construction of School T could open, enabling thermal exchanges between classrooms on either side of the central corridor. The narrow floor plate of this portion of School T allows naturally occurring air currents to cool classrooms during warmer months and to distribute heat during cooler months. During winter visits, indoor temperatures were expected to be relatively uniform due to the use of heating systems. As Figure 3.6 shows, at one end of the corridor, a heater located below the window warms the space at child height. Students and staff can modulate thermal exchanges with the corridor by opening the classroom door and transom above it. This can also help reduce thermal asymmetries between classrooms with different solar orientations. The efficiency of cross ventilation would increase in this portion of School T if all the transoms between the classroom and corridor could open. In doing so, this would further expand the acoustic arena of the classroom to include sounds from the corridor and other learning spaces. While pleasant sounds contribute to positive sensory experiences, noisy sites or nearby rooms can generate conflicts between quiet environments for learning activities and the control of the temperature provided by the opening of doors, transoms and windows. As shown in the provincial survey *Renseignez-nous!* (Schola, 2018), noise associated with student activities and inadequate natural ventilation are the most frequent sources of discomfort encountered every day by teachers. This reflects the importance of investigating occupants' experiences in a multisensory approach.

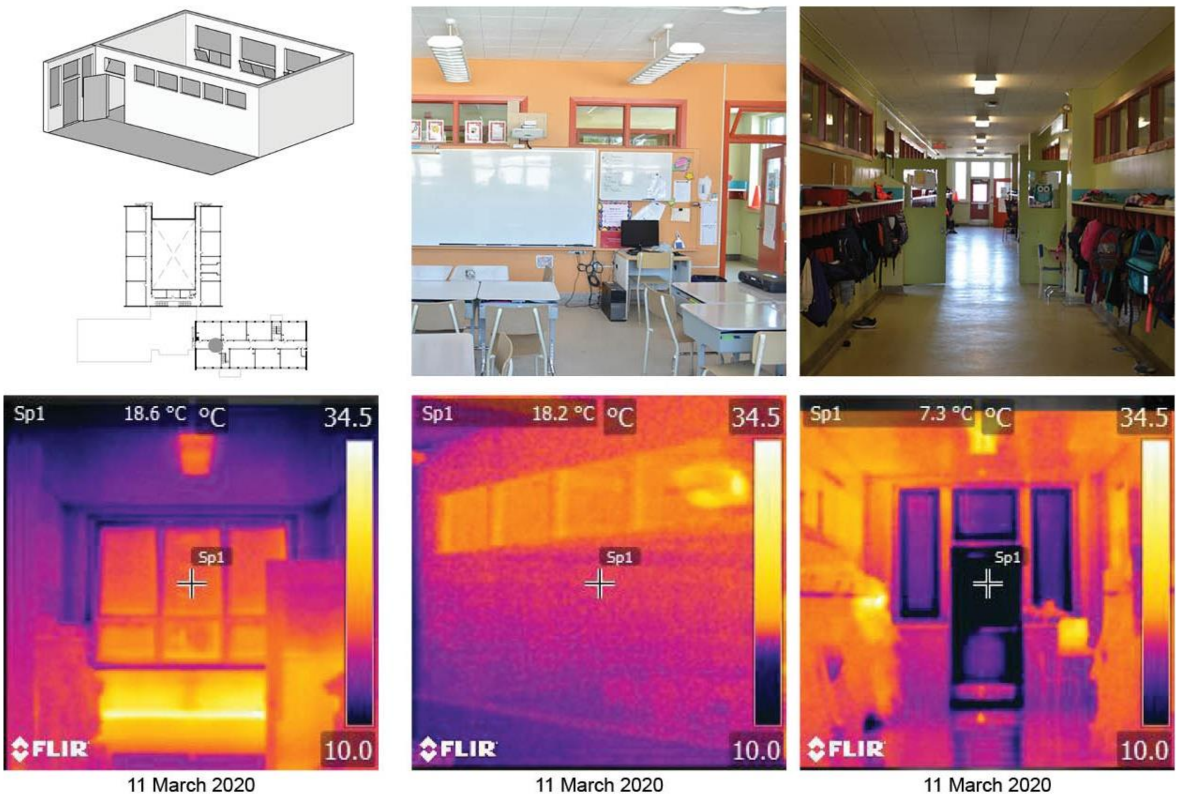

Figure 3.6 Temperature gradients during winter near windows to the outside and classroom transoms in the original construction of School T.

The transom windows in the building addition of School T are located between the structural elements of the classroom ceiling. Because these transoms do not open, only the classroom door enables thermal and auditory exchanges with the corridor (Figure 3.7). Moreover, since the gymnasium is located at the core of this portion of the building, cross ventilation is not possible on warmer days at the beginning and the end of the school year. The presence of a researcher in the thermal photograph taken in November 2018 (Figure 3.7) highlights the thermal uniformity of this classroom. In the neighbouring corridor, thermal photographs of a window reveal the influence of outdoor conditions on this circulation space. During the June 2019 visit, the area closest to the window, shown in yellow in the image, is heated by the sun, while the corridor is represented in cooler purple colour tones (Figure 3.7). The photograph from the March 2020 visit reveals the opposite thermal pattern. These subtle seasonally changing thermal distributions suggest the importance of windows to the outside, even in circulation spaces, to connect building occupants to seasonal rhythms.

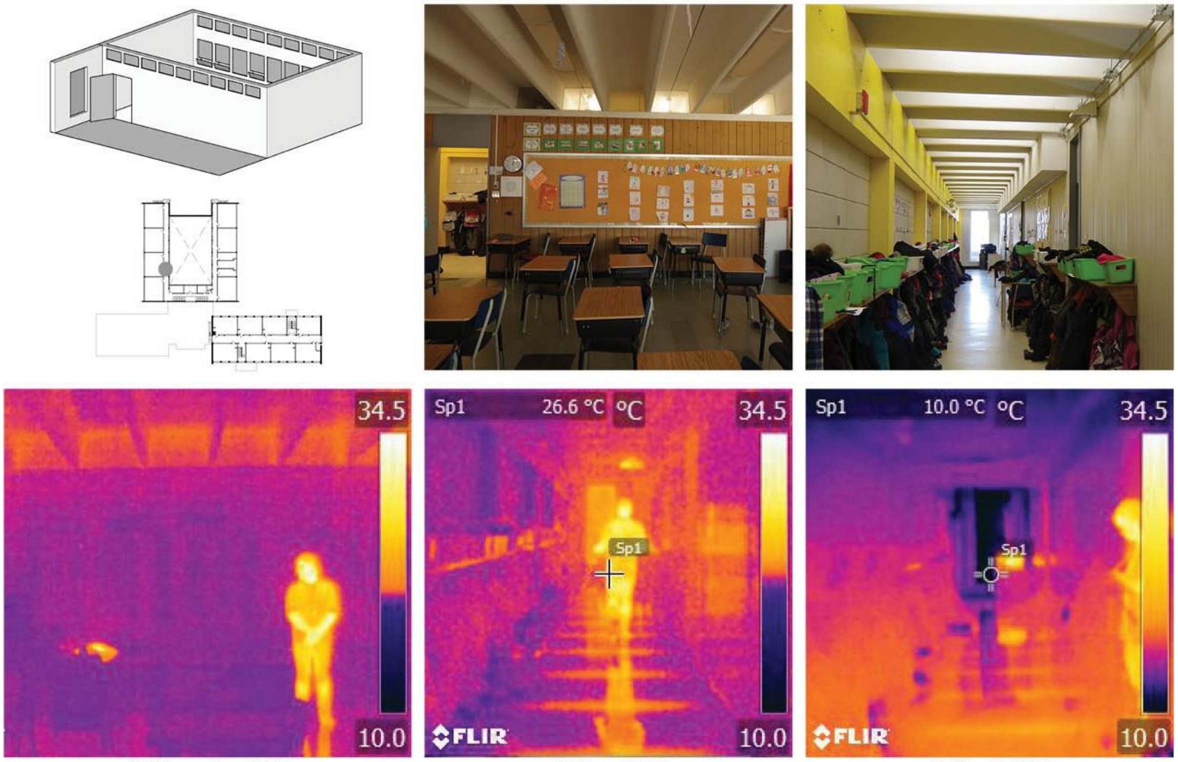

Figure 3.7 Temperature gradients in autumn, summer and winter near windows to the outside and classroom transoms in the building addition of School T.

The presence of transoms provided corridors with borrowed light from the classrooms, although the thermal and auditory exchanges among the spaces were often limited. The presence of windows at both extremities of the original corridor further increased the naturally daylit zone, enabled a visual connection to the outside and increased thermal variability. Assessing the distribution of light within the corridors of School T was done by using calibrated high dynamic range (HDR), grey scale, and false colour images (Figure 3.8). Where floor areas are affected by sun patches at the extremity of the corridors, lighter areas are visible on the grey scale images. Similarly, the thermal photographs in Figure 3.6 and Figure 3.7 illustrate decreasing thermal gradients with increasing distance from the facade. In the absence of electric lighting, illuminance values in the corridor of the original construction exceeded the values in the building addition. This suggests that the natural light present in this space informs occupants on environmental information such as outdoor weather conditions. The corridor in the building addition had an opaque emergency exit at one extremity and a window at the other. When walking away from the window, this spatial configuration reduced the availability of direct experiences of natural light, outdoor temperatures and sounds. The low illuminance values also necessitated the use by occupants of electric lighting while circulating in the corridor. However, people may find an indoor space has sufficient light if they transition through a slightly darker corridor, as the human eye adapts to lower illuminances. This could mean occupants not feeling the need to turn on artificial light when they enter their room. In a review of factors influencing occupants' behaviours in buildings, Stazi et al. (2017) found that the highest frequency of turning on lights is on arrival; when people enter a room the first time in the day. People rarely turn on lights at other times of the day. Once the lights are on, their status usually remains unchanged. Corridors responding well to occupation patterns are likely to decrease the need for artificial light during the day.

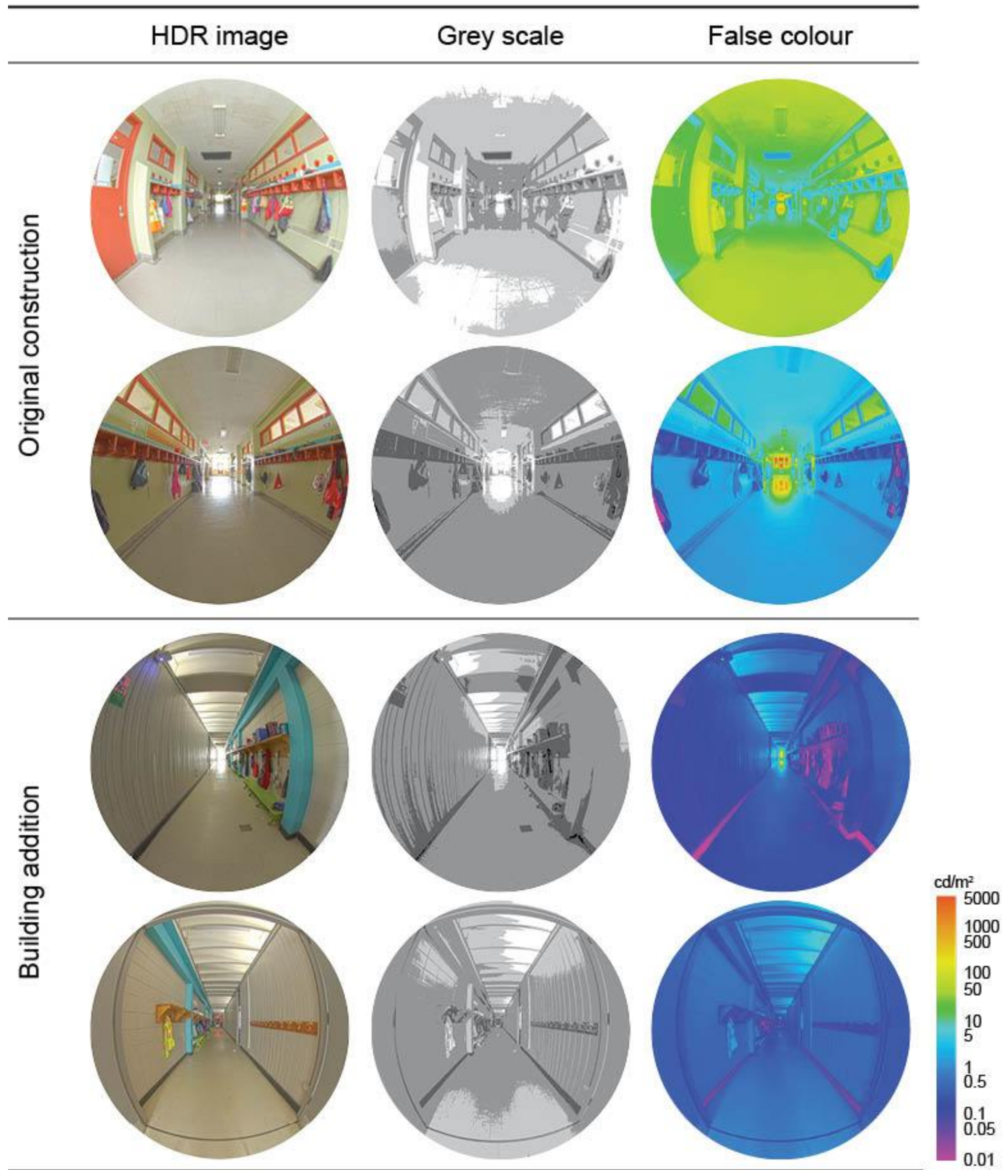

Figure 3.8 Visual results from Photolux photoluminance metre analysis in two corridors in School T, 16 November 2018: high dynamic range (HDR), grey-scale mode, and false colour images.

3.4.3 Classroom windows

The arrangement of classroom windows both low for children and higher for adults influences views and nature engagement (see PRIMARY FACADE, Chapter 5). As Figure 3.9 illustrates, the window arrangement of classrooms in the original construction of School T and the subsequent building addition offer different distributions of natural light and outdoor views. The walls and ceiling of the classroom in the original construction provide a more uniform distribution of natural light, as shown by the grey-scale images. These surfaces reflect and redistribute daylight, providing a good distribution throughout the room. The complexity of the exposed structure of the ceiling in the other classroom creates a dynamic daylighting pattern due to variations in light levels. This illustrates the biophilic design pattern *dynamic and diffuse light*.[11] As the false colour images indicate, the areas in blue show that students seated furthest from the windows in the building addition benefit less from natural light. Moreover, the continuous horizontal arrangement of windows and the low windowsill height of 0.91 m in the building addition offers seated children outdoor views (see Chapter 2). In comparison, taller windows in the original construction with higher windowsills (1.09 m) enable natural light to enter deep into the classroom. However, when students are seated, the higher sill height results in outlooks predominately of the sky (shown in orange in the false colour images, Figure 3.9), suggesting a better daylighting performance, and limited views of tall outdoor vegetation. In both types of classrooms, the lower portions of the windows can be opened easily to enable children and adults to adjust the temperature and flow of fresh air. In terms of auditory experiences, the opportunity to close doors, transoms and windows to outside noises impacts how pleasant people find particular sounds. For example, an open classroom window allows its occupants into the acoustic arena of children playing in the schoolyard. As also noted for the interior corridors, the ability to control whether or not the acoustic arena of the classroom includes outdoor events constitutes a potential adaptive action. Such opportunities could increase people's auditory comfort zone and positively contribute to their appreciation of sensory experiences.

[11] Browning and Ryan (2020, p. 5) define this pattern of biophilic design as "varying intensities and colour of light and shadow that change over time to create conditions similar to those that occur in nature".

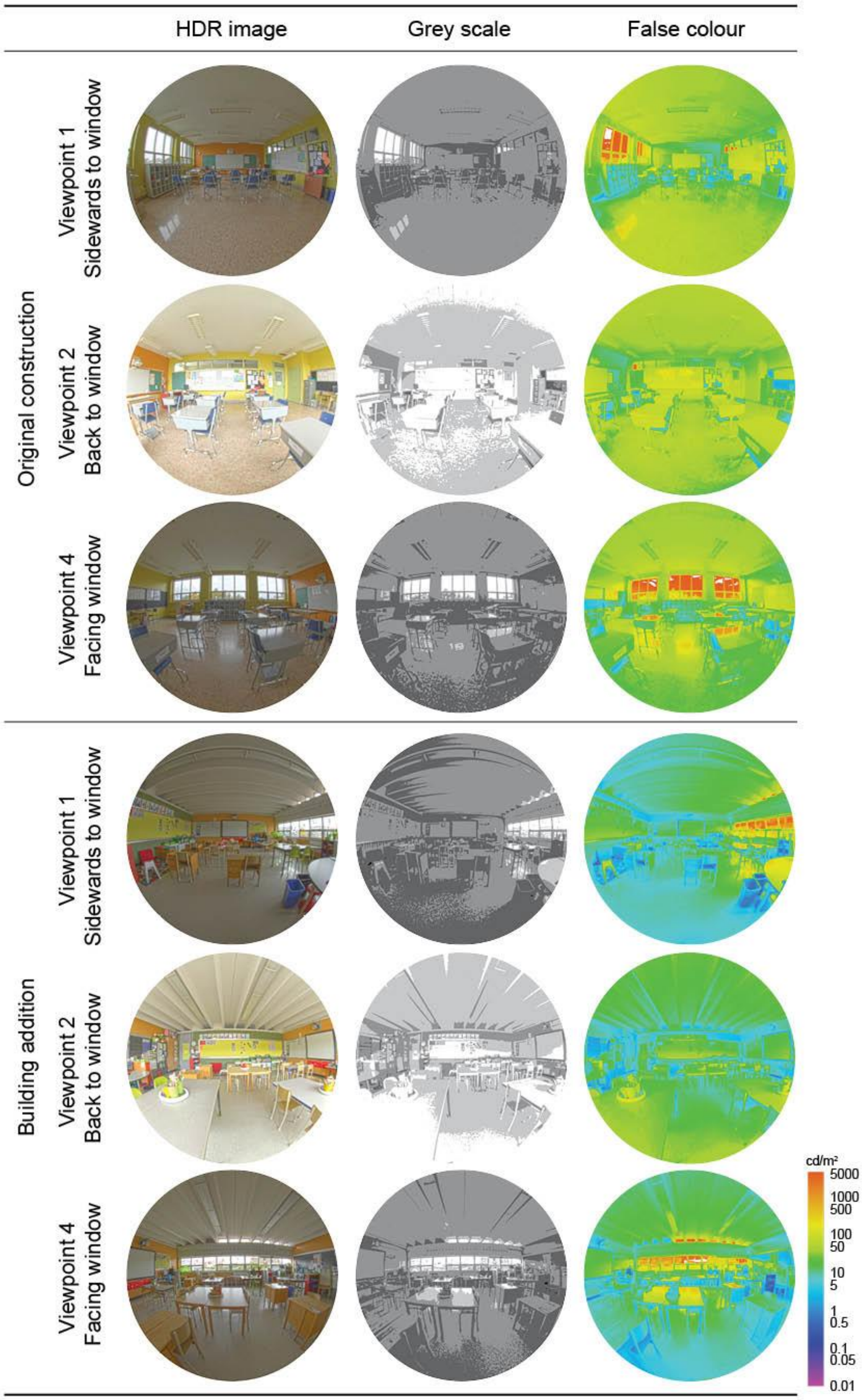

Figure 3.9 Visual results from Photolux photoluminance metre analysis in two classrooms in School T, overcast sky, 16 November 2018: high dynamic range (HDR), grey-scale mode, and false colour images.

Daylight offers a richness of hues and variability. Considering light levels in learning spaces in relation to outdoor levels identifies classrooms where students may experience these natural lighting patterns throughout the day. As previously discussed, elevated daylight factor values could indicate spaces with enough daylight for learning activities, without the need for electric lighting. The calculation of daylight factors in the three schools considered the average hourly global horizontal illumination in Quebec City for the month of each visit.[12] The daylight factor calculated in classrooms in the three schools generally met or fell below the target range of 3.05-8.10% for reading and writing activities at the latitude of Quebec City (Figure 3.10). In School T, the daylight factor values align with the results obtained with the false colour images. Despite the presence of windows near the ceiling in the building addition, students seated furthest from the windows benefit less from natural light. As primary school children spend most of their day in the same classroom, ensuring they can learn in a naturally lit space offers them the opportunity to experience daily and seasonal rhythms of daylight that artificial light sources cannot match.

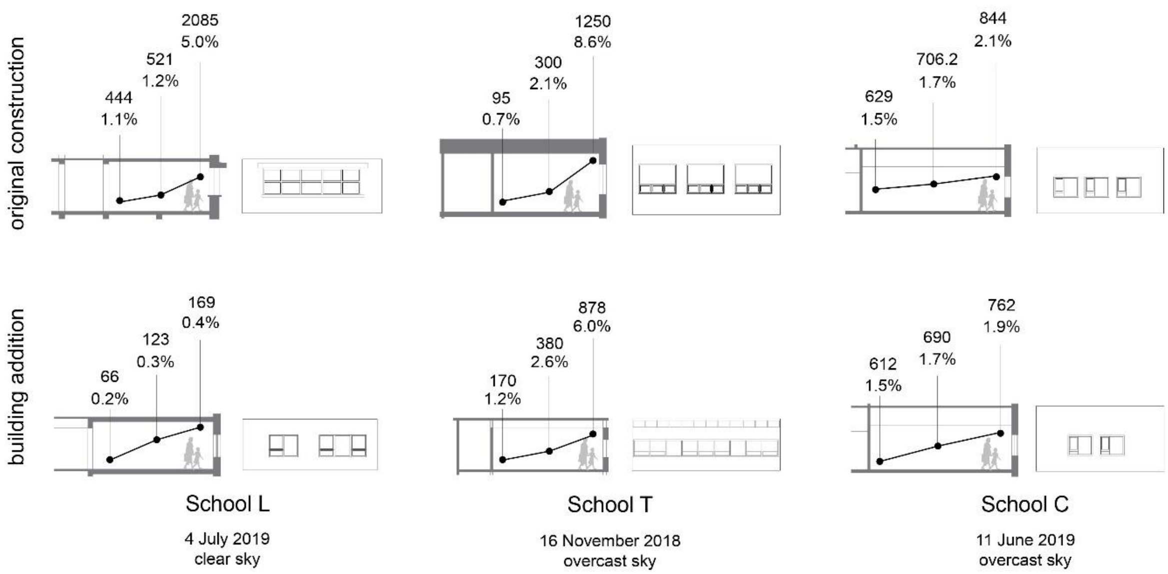

Figure 3.10 Illuminance levels (lux) and daylight factors (%) by room depth superimposed on classroom sections in the three schools.

In the building addition of School T, the site visits revealed a different model of classroom windows than those specified in the architectural drawings. While the glazing to floor area

[12] In Quebec City, the average hourly global horizontal illumination is 40,656 lux in June, 41,976 lux in July and 14,567 lux in November (Energy Design Tools, 2020).

ratio remains similar in most classrooms, reducing the ratio of window opening to floor area influences the bioclimatic and biophilic qualities of the space. The reduction in the size of window opening reduces the efficiency of natural ventilation and the thermal, olfactory and auditory exchanges between indoor and outdoor spaces (Darvishi Alamdari, Forthcoming). While relative humidity measurements for classrooms in the original construction and building addition were the same, slightly higher temperatures were measured in the building addition (Appendix D). Specifically, the architectural drawing specified eight sliding windows with an opening to floor area ratio of 7.5% (Figure 3.11). The site visit revealed nine windows, including seven hopper windows, offering a glazing to floor area ratio of 3.2%. This ratio should exceed 5% to permit efficient natural ventilation. These observations demonstrate the importance of validating the assessment of potential nature experiences using architectural drawings to accurately inform renovation decisions.

Figure 3.11 Window replacement reducing thermal and auditory exchanges between classrooms and schoolyard. (a) Elevation of the original construction (b) Exterior facade in June 2019 (c) Classroom in June 2019.

During site visits, observations were also made of physical traces (Ziesel, 1984) indicating how building occupants modify their settings and how their actions influence potential visual, thermal and auditory experiences of nature. Occupants seemed to prefer adaptations that reflected their teaching styles and increased the functionality of their learning, despite the negative impacts on bioclimatic and biophilic opportunities of the space. For example, in several spaces, storage units in front of the windows and items on the windowsills restricted the opening of windows (Figure 3.12a). In other classrooms, closed sunshades covered open windows, reducing the efficiency of natural ventilation and experiences of thermal variability (Figure 3.12b). Moreover, the presence on multiple walls of abundant teaching material, student artwork and decorations reduced the distribution of natural light. While in some classrooms these were limited to specific surfaces, this material often overflowed onto other wall surfaces (Figure 3.10c). In several classrooms, the presence of teaching material on transoms affected the amount of borrowed light in the corridors (Figure 3.10d). These observations resemble the considerable visual density reported by Schola (2020). In that study an analysis of 18 classrooms in as many schools, communication material and decorations occupied 68% of the walls, indicating the importance to the occupants of classroom personalisation.

The orientation of seated students in relation to classroom windows also influences their experience of natural light and outdoor views (Carrier et al., 2019). In 13 of the 22 classrooms visited (59%) in the three schools at the end of the 2018–2019 academic year, students' desks were perpendicular to the windows (Figure 3.12e). This observation is higher than the responses from school staff in the survey Renseignez-nous! (Schola, 2018) where 47.7% stated children were generally seated perpendicular to the windows (see Appendix B). In three classrooms, students sat with their backs to the window when facing the main teaching area. In two classrooms, some students' chairs faced the windows while others turned their backs away from the windows (Figure 3.12f). These situations can result in uncomfortable conditions because they either offer too much or too little natural light for reading and writing activities. Thus, the classrooms studied provided the opportunity to experience natural light, exterior views, thermal variability and pleasant natural sounds. Countering the biophilic opportunities of the spaces were the arrangement of the furniture and the placement of whiteboards, reflecting teaching styles. In the early stages of a renovation project, these observations and photographs are useful in identifying the design challenges and opportunities so that occupants can positively experience nature throughout the year. Follow-up surveys or interviews with building occupants could help to further understand these adaptations and interactions with the built environments.

Figure 3.12 Physical traces of occupants' adaptive behaviour revealing their control of natural light, electric lighting, outdoor views and natural ventilation. (a) Storage unit making opening windows more difficult (b) Shades reducing solar gain, yet preventing efficient natural ventilation (c) Teaching material influencing surface reflectance (d) Teaching material on transoms affecting borrowed light in corridor (e) Organisation of students' desks enabling outdoor views (f) Organisation of students' desks with their backs to or facing the window.

3.4.4 Synthesising sensory experiences during spatial transitions

Longitudinal representations of environmental conditions in different spaces offer a history of sensory experiences. Figure 3.13 illustrates a walk from the snow-covered schoolyard of School C, through the sheltered entrance and the entrance hall, up the stairs at the core of the building and ends in a classroom. While the previous sections discussed visual, thermal and auditory experiences in three space types common to Schools L, T and C, continuous recordings of equivalent melanopic illuminance (EML) and sound levels offer a quantitative history of the stimuli experienced. The high levels of EML outdoors gradually decrease in the entrance as the walk progresses towards the staircase and interior corridors. These levels remain low in the staircase area at the core of the building, illustrating its disconnection with natural light in the outdoor environment. In the classroom, measured light levels remained below the threshold of 136 EML in the WELL Building Standard[13], except upon first entering and looking directly at the windows. Annotations of auditory events facilitate the comprehension of the documented fluctuations. For example, outdoor sounds capture stochastic winter winds and the familiar sound of snow creaking and crunching as people walk towards the school entrance. Grey scale images of the four spaces illustrate the predominance of artificial light in the main entrance hall and staircase area. Meanwhile, natural light is reflected on the ceiling and furniture of the classroom. Similarly, the circulation areas at the building core illustrate fewer thermal gradients than the entrance and classroom spaces where windows and doors to the outside present cooler zones. As people cross spatial boundaries every day to move from one building zone to another and between the interior and exterior environment, this longitudinal visualisation of sensory experiences offers an informative sensory narrative.

[13] The WELL Building Standard threshold is of 150 EML when electric lighting is used and of 136 EML in naturally daylit spaces.

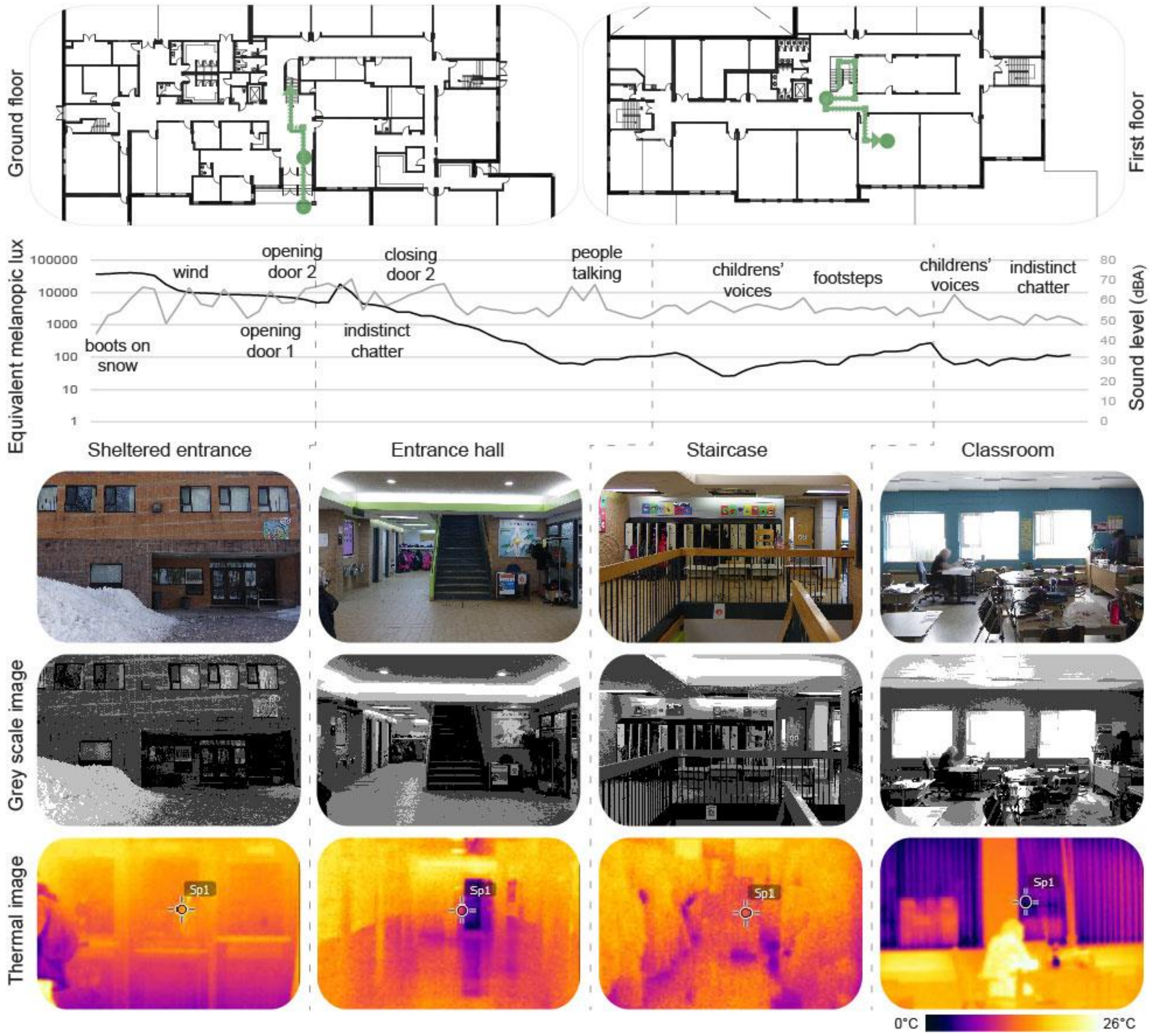

Figure 3.13 Combined representation of light, temperature and sound conditions during a walk from the schoolyard to a classroom in School C during winter.

Transitional elements are often overlooked in the design analysis and are rarely considered as anything other than functional components that connect spaces; yet, they are critical to the sensory experience of architecture and to movements through space (Malnar & Vodvarka, 2004). The experience of an intermediate space between inside and outside can create a gradual transition to a new environment. “The transitions between such spaces — whether gradual or sharp — will influence our perception of diversity and the opportunity to choose or anticipate contrasting conditions” (Steemers & Steane, 2004). By providing access from the built to the natural environment, transitional spaces within and between indoor and outdoor spaces often foster higher levels of comfort by offering less intense contrasts. Discomfort that could arise from an intense variation between two disparate spaces is avoided because of the progressive adaptation provided. Transitional spaces, either expressed as sheltered entrance, interior corridors or windows, further promote biophilic experiences. They enable people to have multisensory experiences of natural features, such as daylight, indoor temperatures reflecting outdoor conditions, precipitations or vegetation, and an extended acoustic arena.

The combined representation of architectural drawings, measurements and photographs presented in Figure 3.13 helps to identify biophilic design elements in existing buildings and to associate them to spatial characteristics. When instrumental equipment is unavailable to quantify these environmental conditions, photographs taken during site visits continue to offer a qualitative assessment of architectural space. Figure 3.14 illustrates how photographs of a staircase in School C during two visits enable a discussion of nature experiences. Including vegetation in the built environment is a biophilic design strategy that also reflects the amount of natural light present in a space. The presence of plants on the windowsill in this staircase indicates abundant light as vegetation typically requires a daylight factor of 20%. During the winter visit, natural light along the brick wall created a dynamic visual experience, informing occupants on sky conditions and solar paths. It further brought awareness to the textured surface of the wall and enticed a tactile and thermal experience of bricks warmed by the sun. A desk and chairs at the top of the staircase revealed that occupants consider this space as more than a circulation path. During both visits, pairs of students were observed completing schoolwork, chatting quietly. Additionally, the large window area provides an outdoor view that includes multiple components informing occupants on environmental conditions (such as snow on the ground, trees moving in the wind or cloud cover). In combination with view distance, the quality of the landscape and the composition of the view, this constitutes a characteristic of a pleasant view presented by Matusiak and Klöckner (2016). In terms of thermal variability and air quality, the strings attached to the upper portion of the two windows suggest an adaptation enabling students to open the windows in the space and let in fresh air. Opening the double doors on the ground floor in combination with these windows could enhance air circulation and the cooling of the space in warmer months. Together, these observations of environmental conditions and adaptations made by occupants enable an interpretation of the biophilic qualities of existing spaces. Such an interpretation complements and enhances other assessment methods, such as analyses of architectural drawings and of objective instrumental measurements.

Figure 3.14 Staircase in School C during rainy summer visit (left) and sunny winter visit (right).

3.5 Conclusion

Measuring and representing visual, thermal and auditory parameters during site visits in three primary schools enabled a discussion of architectural configurations connecting indoor and outdoor spaces. It further showed the rich sensory transitions at the building edge, in interior circulation spaces and windows in learning spaces. The representations of natural light and temperature made possible by grey scale images and thermal photographs illustrated areas of the schools that enable occupants to experience natural light and thermal variability. These conditions are potentially favourable for bioclimatic architecture and could also be beneficial for biophilic experiences.

Instrumental measurements offered insight into the positive characteristics of nature people may experience in these spaces. For example, measuring the daylight factor to document the amount of natural light present in indoor spaces could help determine whether building occupants will need electric lighting for reading and writing or circulating throughout the building. In this sense, the information gathered serves indirectly as an indicator of potential experiences of daylight. Similarly, temperature measurements establish whether building occupants can experience thermal variability in a space or across several spaces within a building. Moreover, windows, transoms and doors give occupants the ability to control the degree to which sounds are transmitted and received. This increases their appreciation of quiet spaces and enables them to hear pleasant sounds such as leaves rustling in the wind or rain falling.

As positive experiences of nature not only relate to the amount of nature available in a space, it remains difficult to assess positive experiences based solely on metrics such as the daylight factor, temperatures or sound levels. The photographic surveys made it possible to observe the circumstances under which building occupants seized opportunities to improve their biophilic experiences or overcome the challenges of experiencing nature. In this sense, photographic surveys document direct experiences of natural light and natural ventilation, for example via open sunshades and windows. Photographs are also useful in assessing indirect experiences of nature (e.g., natural materials, see Appendix D). Observing the use of sunshades and electric lighting indicates people's needs in relation to the amount and distribution of natural light for learning activities. Opportunities to open easily accessible windows inform the potential to ventilate indoor spaces naturally so occupants can experience thermal variability. This also reveals the possibility to control the extension of the acoustic arena to include sounds from other interior spaces or from the schoolyard. Therefore, the use of photographic surveys at the three schools provided a valuable, quick and non-intrusive method to investigate how occupants use or adapt the building to gain potential experiences of nature.

In the shift from the assessment of the quality of the indoor environment to potential biophilic experiences in school settings, each methodological approach has its own advantages and disadvantages. These methodological approaches can include an analysis based on architectural drawings (Chapter 2), *in situ* measurements and observations (Chapter 3), occupant surveys (Schola survey *Renseignez-nous!*, Appendix B), simulations (presented in master dissertations by architecture students in the Schola project) or experiential surveys (Chapter 4). Site visits are valuable because they complement the challenges and opportunities for biophilic experiences identified in Chapter 2 using architectural drawings. The following chapter refines the analysis of the biophilic qualities of these schools by developing a tool to represent people's subjective experiences of nature during building walkthroughs.

Chapter 4 Towards a Biophilic Experience Representation Tool (BERT) for architectural walkthroughs: a pilot study in two Canadian primary schools

The tools presented in the previous chapters of this thesis help architects and building managers to better understand biophilic experiences in existing school building by using architectural drawings and field measurements. The simplified assessment method based on spatial geometry developed in Chapter 2 focused on quantitative parameters and therefore could not evaluate experiential aspects of biophilia. Meanwhile, the observations and measurements presented in Chapter 3 described school spaces in different seasons and began to characterise sensory experiences as the fundamental level of biophilic experiences. The representation tool developed in this chapter focuses on people's subjective experiences. It aims to facilitate the assessment of biophilic experiences during building walkthroughs in the preliminary design stages of renovation projects.

To improve multisensory experiences in primary schools, this chapter elaborates a walkthrough tool to efficiently note multisensory experiences relating to environmental features. Because visual, thermal, olfactory and auditory experiences are currently reported as inadequate in many schools in Quebec (as discussed in the Introduction), it is hypothesised that a better understanding of existing experiences could help architects during renovation projects to make design decisions that foster positive experiences. It could ultimately help them to become more aware of their own biophilic experiences in architecture.

An architectural diagnostic tool was developed to assess biophilic experiences during building walkthroughs in the context of post-occupancy evaluations, as discussed in the Introduction and Chapter 3. This tool, the Biophilic Experience Representation Tool (BERT) also aims to assist designers in the preliminary design stages of renovation projects, which are further discussed in Chapter 5. BERT expands on the simplified assessment method based on measurable spatial geometry (Chapter 2) and a theoretical model of biophilic experiences (Appendix E) by representing subjective experiences of nature. The theoretical reflection explored a new way of understanding biophilic design with a focus on experiences in children's environments. It examines how children's developmental stages create an opportunity to better understand and describe experiences of nature. The assessment method presented in this chapter also draws inspiration from previous research (such as Demers & Potvin, 2021) that has investigated the potential of architectural representation to discuss measured field data. This enables a representation of the subjective aspects of biophilic experiences during building walkthroughs.

The methodological intention was to use the proposed representation tool during winter visits to the same three schools that are examined in the previous chapters. This aimed to complement the analysis of Schools L, T and C based on spatial geometry and field measurements in order to continue to refine the assessment of biophilic experiences in these settings. However, it became impossible to visit School L because of the public health measures in effect in 2020 and 2021. The results discussed in this chapter therefore focus on five spaces in Schools T and C visited during the winter of 2020. This analysis of these spaces was deemed sufficient to illustrate how BERT can assist architects during post-occupancy evaluations. Appendix F presents the results for additional spaces visited in these two schools that further detail the experiences documented during the walkthroughs.

A complementary activity was organised to explore other potential outcomes of BERT in a different context since it was only possible to use the tool during two walkthroughs. This aimed to explore the use of BERT as a pedagogical tool for architecture students, in addition to its intended use by practising architects. In the fall of 2020, a workshop was organised as part of a course in the Bachelor of Architecture programme at *Université Laval*. Exploring the use of BERT in a pedagogical context offered feedback into how future research could expand the use of the tool to other environmental features and building types. It further showed how this could lead to new and overlapping representations of biophilic experiences.

This chapter presents the article “Towards a Biophilic Experience Representation Tool (BERT) for architectural walkthroughs: a pilot study in two Canadian primary schools” by Mélanie Watchman, Claude M.H. Demers and André Potvin. The article was published in the journal *Intelligent Buildings International* and is available online since May 2021 (https://doi.org/10.1080/17508975.2021.1925209).

4.1 Résumé

Les architectes intègrent de plus en plus les principes du design biophilique pour favoriser les expériences de la nature dans des bâtiments régulièrement occupés, comme des écoles. Bien que des chercheurs mesurent des données objectives des bâtiments pour documenter la présence de la nature, peu d'outils aident les architectes à évaluer les expériences biophiliques subjectives lors des visites de bâtiments dans les étapes préliminaires de conception. Cet article présente les résultats d'un banc d'essai conçu pour aider à développer un outil diagnostique représentant les expériences d'éléments naturels tels que la lumière naturelle, le vent et la neige. L'*outil de représentation des expériences biophiliques* (BERT) a été testé lors de visites de deux écoles primaires canadiennes en hiver. Cela montre le potentiel de BERT pour représenter les dimensions subjectives de l'architecture biophilique. Il révèle également l'importance de la saisonnalité dans l'évaluation et la conception de bâtiments biophiliques dans les climats froids.

4.2 Abstract

Architects are increasingly integrating principles of biophilic design to foster experiences of nature in regularly occupied buildings such as schools. Although researchers often objectively measure building variables to document the presence of nature, few tools currently help architects assess subjective biophilic experiences during building walkthroughs in the preliminary design stages of renovation projects. This paper presents the results of a pilot study designed to assist the development of an architectural diagnostic tool that represents designers' experiences of natural elements such as sunlight, wind and snow. The Biophilic Experience Representation Tool (BERT) was used during site visits in two Canadian primary schools in winter. These post-occupancy evaluations with BERT highlight its potential to discuss subjective dimensions of biophilic architecture. It further reveals the importance of seasonality when assessing and designing biophilic buildings in cold climates.

4.3 Introduction

This paper develops an architectural diagnostic tool that subjectively represents experiences of nature during building walkthroughs in post-occupancy evaluations. Biophilic architecture shapes occupants' potential experiences and understanding of nature. These buildings attempt to translate people's innate *love of life* (E. O. Wilson, 1984) by encouraging “engagement and immersion in natural features and processes” (Kellert, 2018, p. 19). The health and well-being benefits of daily experiences of nature have been widely studied (e.g., Franco et al., 2017; Hartig et al., 2014). Moreover, childhood experiences of nature have received interest due to their long-term benefits such as pro-environmental behaviours in early adulthood (Evans et al., 2018) and active care for the environment in adulthood (Chawla, 2015). In Quebec, Canada, primary school children generally spend a third of their day at school. Most of their learning activities occur indoors, however, inadequate physical environments have been reported in numerous school buildings (Després et al., 2017). Given the potential well-being benefits of nature experiences during childhood, it would be advantageous for architects tasked with renovating schools in Quebec to identify and locate the biophilic potential in these buildings.

The proposed diagnostic tool, the Biophilic Experience Representation Tool (BERT), aims to assist architects complement their objective assessment of nature with subjective evaluations of diverse nature experiences in buildings. Building variables, such as window sizes, and indoor environmental parameters, such as illuminance and noise levels, are often objectively measured or simulated to document their well-being benefits for occupants; architects can use such variables to assess buildings. For example, McGee and Marshall-Baker (2015) developed the Biophilic Design Matrix (BDM) to help designers identify and quantify biophilic features during a visual inventory of interior spaces. However, incorporating nature in buildings also affects people’s feelings and appreciation of the space (for reviews in children’s environments, see Chawla, 2015; Korpela, 2002). Renovating learning environments to provide satisfying experiences of nature and enhance well-being could be advantageous for children and teachers, since children spend most of their day at school.

The results of a pilot study using BERT are discussed in this paper. Two types of pilot studies with different purposes can be identified in social science: (1) feasibility studies (smaller version of studies) and (2) pre-testing of research instruments (T. L. Baker, 1994; van Teijlingen & Hundley, 2001). The latter characterises this pilot study. It focuses on developing and employing BERT to document people’s nature experiences. Two key components form this tool: a rose representing the perceived quality of environmental features and four textual fields describing biophilic experiences. The summary of this information offers a multisensory representation of complex perceptual experiences of nature. Targeted at architects, using BERT during building walkthroughs aims to inform the development of renovation proposals by identifying spaces or issues that merit follow-up visits or more detailed assessments.

4.4 Background

Several environmental parameters reportedly influence people's experiences of nature. This section examines tools designed to document sensory perceptions that offer transferable components for the development of a tool assessing biophilic experiences. Including natural forces and living organisms in the built environment are key biophilic design strategies. For example, the "environmental features" proposed by Kellert et al. (2008) and later regrouped in the category "direct experience of nature" (Kellert, 2018; Kellert & Calabrese, 2015) include air, fire, light, water, weather, geology, animals and plants. Similarly, Browning et al. (2014) provide the following examples for patterns included in the category "nature in the space": airflow, fire, light, water, weather, geology, animals and vegetation. The benefits of these environmental features for the health and well-being of occupants have been widely reported (for a review, see Bluyssen, 2017; Chawla, 2015). This could explain why biophilic design strategies often refer to people's sensory response when exposed to natural forces and living organisms.

Insight into the assessment of such experiential qualities can be gained from notation systems developed by sensory researchers to document and represent sensory phenomena. Some systems focus on a specific sensory experience, such as thermal perceptions (Vasilikou & Nikolopoulou, 2015) or smellscapes (Henshaw, 2014). Other tools combine multisensory experiences and offer a more comprehensive assessment of indoor or outdoor spaces. Malnar and Vodvarka (2004) developed a set of Sensory Sliders that record sensory experiences for particular locations and times. Adapting these sliders, Mace (2014) proposed a Sensory Flow Diagram to compare sensory characteristics of five outdoor spaces in central London. The model developed by Woloszyn and Siret (1998) offers a homogeneous account of an atmosphere and the presence, proximity and significance of sensory phenomena in architectural configurations. The Physical Ambience Rose (PAR) developed by Demers et al. (2009) simultaneously illustrates the subjective perception of visual, thermal, olfactory and auditory experiences. It offers a graphical record of occupants' environmental satisfaction. The Sensory Notation Schema developed by Lucas and Romice (2010) depicts the relative importance, corroboration, and qualities of Gibson's (1966) six perceptual systems. It takes the evaluation further than other systems by developing a vocabulary of qualitative descriptors to accompany the concentric circles that represent the strength of sensory experiences. Nonetheless, people may have difficulty isolating sensory qualities given the subjective weighing process where a good feature can compensate for a poor feature (Humphreys, 2005). Moreover, the relative importance of environmental parameters can change with a person's satisfaction towards the physical environment (Frontczak & Wargocki, 2011). Thus, in addition to assessing people's immediate sensory response to biophilic spaces, it appears important to document their feelings and understanding of nature.

Biophilic experiences, besides affecting people's sensory perception of the environment, affect people's emotions and mood. For instance, natural settings have been shown to impact happiness (Nisbet & Zelenski, 2011) and overall positive affect (McMahan & Estes, 2015). Mood improvements have also been reported across seasons, indicating that nature contacts are not only beneficial during summer (Brooks et al., 2017). Understanding people's individual and subjective experiences in biophilic architecture can be enriched by considering feelings and thoughts, knowledge and understanding and affiliation with nature (Watchman et al., 2020). In documenting biophilic experiences, sensations can be considered as the immediate response to environmental stimuli (such as warm, noisy, or bright). Feelings about these sensations can include terms such as comfortable, delightful, safe or exposed to the elements. Understanding natural forces and processes relates to an awareness, a knowledge of processes such as water cycles or sun movements. Affiliation is associated with the deep and meaningful relationship with nature that can become manifest as place attachment or a sense of community (Gifford, 2014). This reflects the dynamic relationships among environmental stimuli while illustrating that immediate physical sensations only capture a portion of nature experiences. It further highlights the importance of assessing environmental features that architects can shape to foster subjective biophilic experiences.

4.4.1 Aims and Scope of the Pilot Study

Three aims were established for this diagnostic tool relative to (1) multisensory experiences, (2) their representation and (3) seasonality. Firstly, the study aimed to elaborate a walkthrough tool to efficiently note multisensory experiences relating to environmental features. Most research has focused on visual aspects of nature experiences, although people are multisensory (Franco et al., 2017). For instance, olfaction directly impacts emotions and memories, yet the sense of smell remains little explored in terms of nature experiences (M.-X. Truong et al., 2020). Moreover, as Kaplan and Kaplan (1989, p. 5) remark, "Humans judge situations with such facility that they are often not aware of the fact that such an evaluation is occurring". It can thus be difficult for people to express the environmental features that contribute to their experience of nature. By presenting a selection of natural forces and living organisms, the intention was to bring awareness to these components and facilitate their individual assessment by architects. Secondly, the pilot study aimed to develop a novel representation tool to integrate subjective experiences of nature in buildings. Multiple measuring tools and methods exist to assess spatial experiences and the quality of the indoor environment from the perspective of occupants (such as Candido et al., 2016; Cochran Hameen et al., 2020; Heinzerling et al., 2013). Previous research has also investigated the potential of architectural representation and storyboards to discuss simulated or measured field data and assist in the recollection of spaces (e.g., Demers & Potvin, 2021; Hua et al., 2014; Jakubiec et al., 2017). The representation tool proposed in this article expands on this knowledge by proposing the representation of subjective aspects of biophilic experiences in an architectural representation tool. Thirdly, the study aimed to draw attention to and include seasonal experiences in the assessment of spaces. Schools in cold climates, like in Quebec, are mostly occupied during winter, but this season is often overlooked in the biophilic design literature (Watchman et al., 2021a). Environmental features susceptible to seasonal changes were included in BERT to bring awareness to these seasonal rhythms.

As part of the research project Schola.ca (2021), BERT aims to assist project managers and architects diagnose and renovate schools in the province. Two primary schools in Quebec within the random sample of buildings used by Schola were selected for this study. Based on a preliminary analysis of architectural drawings (Watchman et al., 2021c), School T offers more enjoyable biophilic experiences than School C. The linear volumes of School T are on a mineral site with few trees. The more compact School C is on a site with mature trees (see Method section). The pilot study tests the hypothesis that School T offers more biophilic experiences than School C due to objective differences observed using spatial geometry, such as its higher envelope to volume ratio affording students and school staff more opportunities for natural light, natural ventilation and outside views.

Since the 2018 provincial-wide survey *Renseignez-nous!* (Schola, 2018) identified daily routines and satisfaction levels of over a thousand teachers, in-school childcare educators, maintenance workers, administrators and principals from 200 primary schools, BERT focuses on documenting designers' experiences during building walkthroughs in early stages of school renovations. Although this paper focuses on experiences documented during two site visits, further development of the notation system as a pedagogical tool is presented in the discussion of this paper as part of a follow-up workshop with architecture students.

Documenting children's experiences of nature exceeds the current scope of this tool. While some research has assessed children's perception and definition of nature, more studies are needed to better understand children's perceptions of nature (Bolzan-de-Campos et al., 2018). Nonetheless, the ease of tool use could lead to the involvement of building occupants and other stakeholders during walkthroughs. Such avenues for future research with BERT are presented in the discussion of this paper.

4.5 Method

The proposed Biophilic Experience Representation Tool (BERT) combines subjective aspects of nature experiences in site visits. During building walkthroughs, designers complete the rose assessing the perceived quality of a selection of environmental features and four textual fields describing biophilic experiences while also taking photographs. Afterwards, photographs and descriptions noted by each person are overlaid to summarise the experiences. The following section presents the rose and the textual fields as well as the schools selected and procedure.

4.5.1 Architectural Diagnostic Tool

The rose in BERT documents designers' experiences of ten environmental features. The environmental features in the rose originate from recurring biophilic design principles discussed above, selected from the literature to cover both natural forces and living organisms: sun, light, wind, air, earth, natural materials, snow, rain, vegetation, and animals (Figure 4.1, top left). A brief description of each environmental feature is included on the back side of BERT (Figure 4.1, top right). For example, sun refers to thermal experiences of direct rays of sun, while light appeals to visual qualities of natural light. Wind connotes the movement of air. Earth was chosen to evoke the notion of geology used by Kellert (2018), Kellert and Calabrese (2015) and Browning et al. (2014). Distinguishing snow and rain provides additional precision to seasonal experiences of water in mixed climates, either on the ground or as it precipitates. Drawing on stimuli scores in the Physical Ambiance Rose (Demers et al., 2009) and scales used in the Flourish wheel (Clements-Croome et al., 2019) which offers a framework to assess design considerations for workplaces where occupants thrive, the BERT scale varies from detrimental (-3) to exceptional (+3) experiences of environmental features with a neutral midpoint (0) (neither positively nor negatively experienced). When an environmental feature is absent, no marking is made.

The hand-drawn notations on the roses completed during the pilot study can be represented either for individuals or groups. Similarly to the Physical Ambience Rose (Demers et al., 2009), they can be superimposed and mapped for each space or across several spaces. The examples in Figure 4.2 present different hypothesis to illustrate possible polarisations based on environmental settings. The thick black line represents notations made during site visits. Additional lines can be superimposed when several people participate in walkthroughs. The top left rose evokes a noisy urban mineral site in the shade and exposed to the wind during winter. Thus, sun, vegetation and animals are absent and no markings are made on their respective axis. The appreciation of snow accumulations and reflected natural light is positive (+2), the wind is perceived as very detrimental (-3) because it is undesired during the winter visit and the air quality is deemed detrimental because of noise and pollution (-2). The top right rose typifies a more comfortable outdoor space in autumn. In this scenario, abundant vegetation and animals are deemed exceptional (+3) as is filtered light descending through the trees. No form of precipitation is present while experiences of a gentle breeze and the diverse site topography are pleasant (+1.5). The roses on the bottom row offer examples of detrimental and exceptional indoor spaces. On the bottom left, natural light entering the space is limited yet glaring while snow accumulations in front of windows limit the field of view.

A cold winter breeze is continuously entering the space through an open window and a bad smell remains present. Meanwhile, the bottom right rose typifies an indoor space with exceptional biophilic qualities. Large windows let in fresh air as well as sounds of birds and an outdoor water feature. The facade filters solar gains while creating daylight patterns on interior wooden finishes. Comparing the rose for these four examples shows that both the diversity of environmental features present in a space and their perceived quality are represented. These simplified examples illustrate how the rose allows and invites a diversity of experiences to be documented.

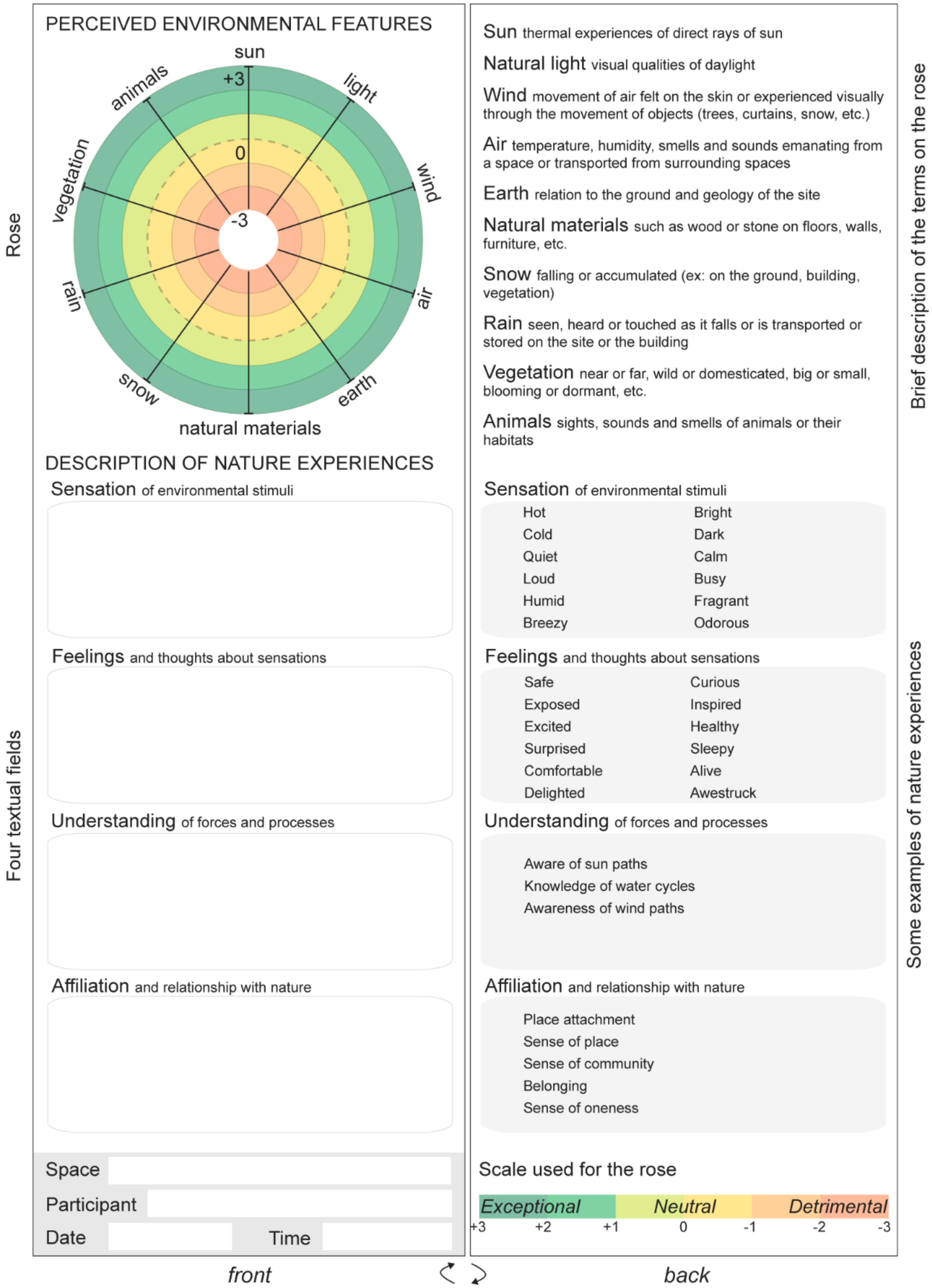

Figure 4.1 Biophilic Experience Representation Tool (front) with definitions and examples of textual descriptions (back).

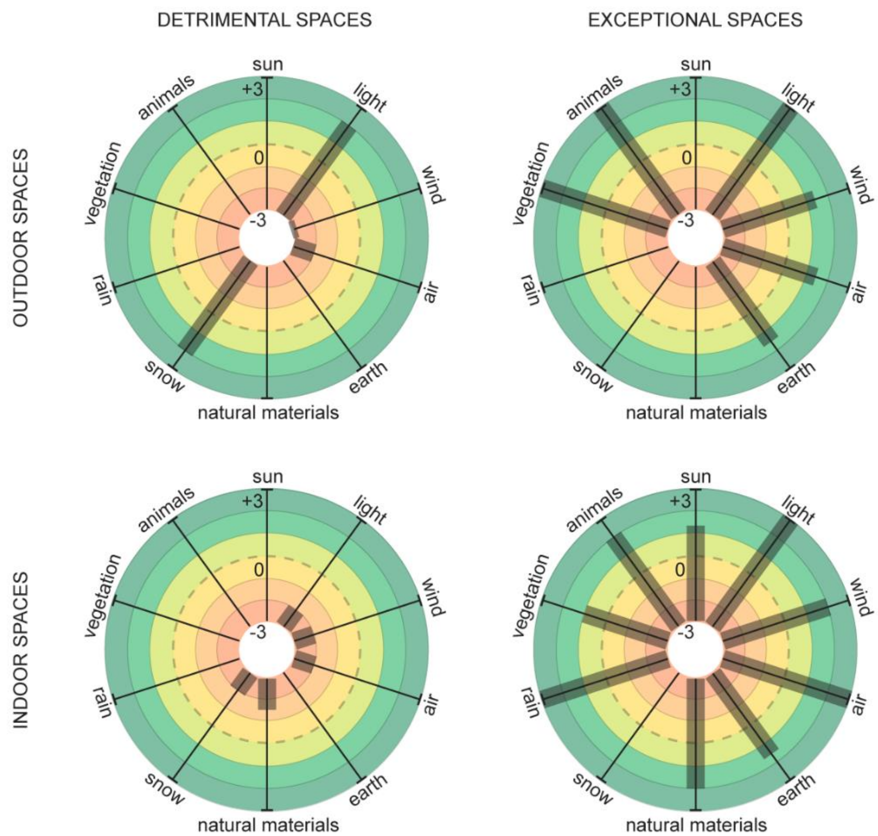

Figure 4.2 Possible polarisations of the rose hypothesised for detrimental and exceptional outdoor and indoor spaces.

The textual fields in BERT characterise experiences of nature based on people’s sensations, feelings, understandings and affiliations (Figure 4.1). It adapts a theoretical model of biophilic experiences (Watchman et al., 2020) into fields documenting on-site experiences. Contrary to the Sensory Notation Schema (R. Lucas & Romice, 2010) that includes a set list of sensory descriptions, any word can be used in the textual fields to describe nature experiences; the back side of BERT offers some examples. This enables users to describe sensations, feelings, understanding and affiliation with nature in their own words and offers the flexibility to note other issues or biophilic design elements (such as textures and patterns or geothermal heating strategies) than those included in the rose.

Photographs taken while designers complete the rose and textual fields are important for two main reasons: (1) to document the environmental settings and (2) to calibrate and clarify individual ratings upon analysis of each BERT. The photographs document the spatial qualities, textures and views to other spaces or the outdoor environment.

4.5.2 School Settings

Two primary schools in the Quebec City area were selected to discuss biophilic experiences in thin and thick plan buildings. Access to these buildings and consent had been obtained before this study due to their participation in a larger research project studying school environments (Schola, 2021). The chosen schools represent common construction periods and spatial organisations for learning environments in need of renovation. Primary schools in Quebec commonly include linear volumes with classrooms distributed on each side of a central corridor or more compact volumes where rooms at the core of the building lack windows and physical access to outdoor spaces. Based on measurable aspects of biophilic design in architectural drawings (Watchman et al., 2021c), the hypothesis for this study is that School T, labelled based on its built form, offers more enjoyable biophilic experiences than School C. Built in 1961 and enlarged in 1966, School T has a 0.55 envelop/volume ratio while School C has a more compact building (0.36 envelop/volume ratio) constructed in 1983. Both schools cater for children from kindergarten to sixth grade (4-12 years old). Theoretically, School T should score higher than School C due to its higher envelope to volume ratio affording more opportunities for natural light, outside views and natural ventilation (Figure 4.3, Figure 4.4).

Figure 4.3 School T (left) and School C (right) photographed from the street and the schoolyard.

Figure 4.4 Locations from which spaces were assessed in School T (left) and School C (right).

4.5.3 Research Team

Architects tasked with assessing and renovating school environments are the intended users of BERT given the current renovation of schools in Quebec and the aims of the research project Schola. Field studies in school buildings involved four graduate researchers from the Schola project. Each researcher provided feedback during the elaboration of the diagnostic tool and completed both school visits. Further development of the notation system as a pedagogical tool was made possible by a workshop organised in the fall of 2020. As part of a lighting course in the Bachelor of Architecture programme at *Université Laval*, BERT was explained to 33 third-year architecture students who used the tool to assess nature experiences in their home-office environment. Group discussions enabled students to share their assessments and feedback on BERT, which are included in the discussion.

4.5.4 Procedure

Building walkthroughs are among research activities in the first of three levels of investigation in building performance evaluation (Mallory-Hill & Gorgolewski, 2018). The term walkthrough is used to describe the space-by-space early assessment of nature experiences in buildings. Walkthroughs offer a quick, easy, and cost-effective way of assessing a building's performance, particularly when focusing on a few issues (Preiser et al., 1988). During one-day visits, BERT was used in six types of school spaces to capture a variety of settings that may or may not foster experiences of nature. In each school, the semi-enclosed main entrance, three hall spaces, three corridors, three classrooms, the gymnasium and the schoolyard were studied (Figure 4.4). Photographs documented spatial qualities, textures and views to other spaces or the outdoor environment.

Site visits were organised to evaluate how BERT supports assessments of winter experiences (aim three of the study, presented above). School T was visited on 11 March 2020, under clear to overcast sky conditions with temperatures between -9.0 C and -5.5 C. School C was visited the next day under clear sky conditions with temperatures between -9.5 C and -3.1 C. Students and school staff were present to provide a more authentic experience of environmental conditions, such as children's outdoor clothing hanging in corridors that contributes to visual and olfactory experiences. The modulation of lighting and shading devices further affects visual experiences while learning activities influence auditory conditions. The selection of spaces was adjusted on-site based on their availability to avoid disrupting learning activities.

4.6 Results

The main contribution of this research lies in the provision of a novel tool to integrate subjective experiences of nature in the built environment. Descriptions collected during walkthroughs in School C and School T illustrate the application of BERT and its potential to support a diagnosis of buildings in post-occupancy evaluations. The space-by-space representation facilitates comparisons of similar space types in different buildings, seasons or occupancy conditions. Through an ensemble of outdoor and indoor spaces which are regularly occupied (e.g., classrooms or gymnasiums) or only transitioned through (e.g., corridors), the representation tool connects subjective assessments of the perceived environment with specific architectural settings. The representation includes a plan, photographs and the rose and four textual fields describing people's subjective experiences. With most information being subjective, architectural plans and photographs offer a complementary representation of the spaces.

4.6.1 Experiences in School C

Figure 4.5 offers an example of nature experiences that can be analysed in five spaces in School C using the output of BERT. Even if responses are subjective and limited in number, it is possible to observe that graduate researchers perceived more *exceptional* environmental features in the sheltered entrance and in the classroom of School C. In both spaces, the roses indicate that nature was mostly experienced via natural light, air, snow and vegetation. In contrast, in the entrance hall and staircase area of the same school, the markings are constricted and closer to the centre. Although variations exist in markings made in these spaces, their superposition reveals a tendency which can inform school renovation decisions.

The content of the textual fields further serves to analyse multisensory experiences of nature. Words and expressions noted in each field can be coded thematically based on environmental features present in the rose (see Figure 4.5 colour legend). In this example, the text size illustrates repetitions of a term by several people. In School C, many sensations relate to sounds, temperature and light. While sounds in the schoolyard evoke “birds” and “branches moving in the wind”, the transition to interior spaces shifts sensations to people’s conversations. Particularly in circulation spaces and the gymnasium, “mechanical ventilation noise” becomes the main source of auditory stimuli noted. In the gymnasium, most environmental features on the rose were absent or perceived as detrimental. Feelings expressed include disconnection, disorientation and imprisonment. In the entrance hall, one researcher expressed that there are “no real biophilic qualities inside, except views to the exterior”.

Overall, sensations recorded in the textual fields in School C concern light, air, wind and animals. For example, light was most often expressed using terms such as “bright” and “artificial”. Sensations related to elements absent from BERT were also noted. These descriptions concerned architectural features (such as textures and colours) and building systems (such as artificial light and mechanical ventilation). In the entrance hall and staircase, for example, the presence of “lots of materials” and “hard textures” left some researchers feeling “overstimulated”. Artificial light was experienced in the entrance hall, the staircase and the gymnasium which have few or no windows to the outside. Thus, while the outdoor space and the classroom foster an understanding of multiple natural processes and an affiliation with nature, the circulation spaces and the gymnasium in School C created a sense of disconnection from nature.

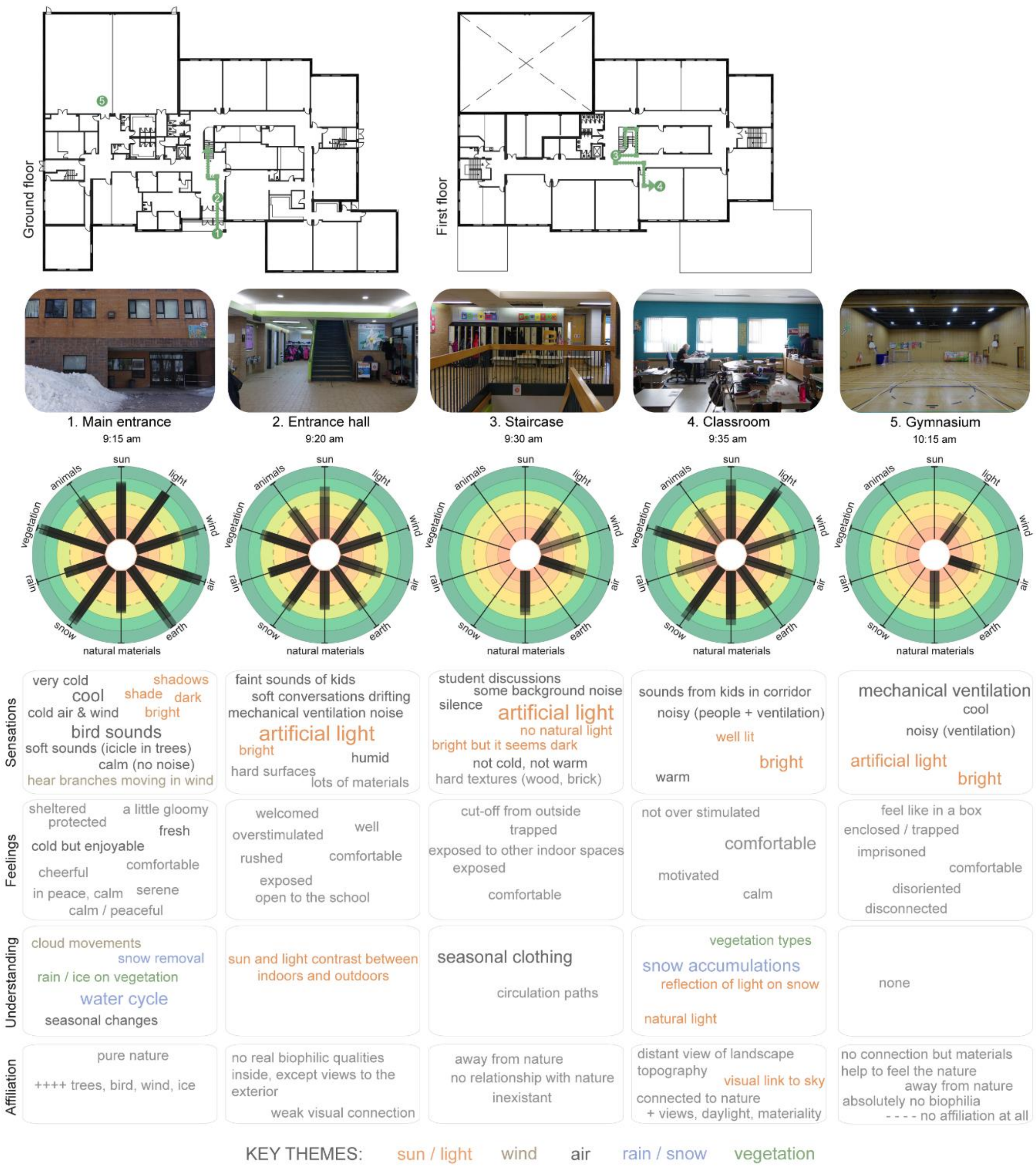

Figure 4.5 BERT summarising perceived experiences during a walk from the main entrance to a classroom and the gymnasium in School C.

4.6.2 Experiences in School T

Figure 4.6 offers an example of the researchers' responses in similar space types to the five spaces presented above. As in School C, the roses for the main entrance and the classroom revealed the most *exceptional* biophilic qualities. In these spaces, vegetation, snow and light obtained the highest scores.

The roses for the entrance hall and corridor in School T were predominantly polarised for the environmental features light and air, although they were deemed less exceptional than in the outdoor space and the classroom. The rose for the gymnasium showed an absence of most natural environmental features. Only "light" and "air" were deemed slightly positive or negative by certain researchers. Among these five spaces in School T, the content of the textual field *understanding* was most diverse in the main entrance and in the classroom where an understanding of daylight, vegetation and snow phenomenon was expressed.

The sensation of warmth noted in the entrance hall contrasted with outdoor thermal sensations. This was echoed by feelings that were "slightly uncomfortable" and "exposed to the wind" outdoors which differ from feelings of comfort inside. Although more pleasant thermal sensations were noted inside than outside, the opposite trend was observed in the perception of odours. The outdoor air was perceived as "crisp" and "fresh" and the air in the entrance hall was "odourless" and "fresh". Upstairs, an artificial flower fragrance was noted in the corridor which carries into the "fragrant (artificial)" classroom. Conversely, the gymnasium was perceived as "not fresh" and some researchers even noted a "weird smell".

Sensations recorded in the textual fields in School T embodied the environmental features light, air, wind and vegetation included in the rose. For example, air was most often expressed using terms such as "fresh" and "cold" outdoors and "warm" inside. As in School C, sensations related to elements absent from BERT were also noted. These descriptions concerned human activities (such as car noises and conversations) and building systems (such as artificial light and mechanical ventilation). The indication of other parameters in the textual fields of BERT reveals that even if the tool focused on natural forces and processes, other elements noticed in the built environment that contributed to its experience were not excluded.

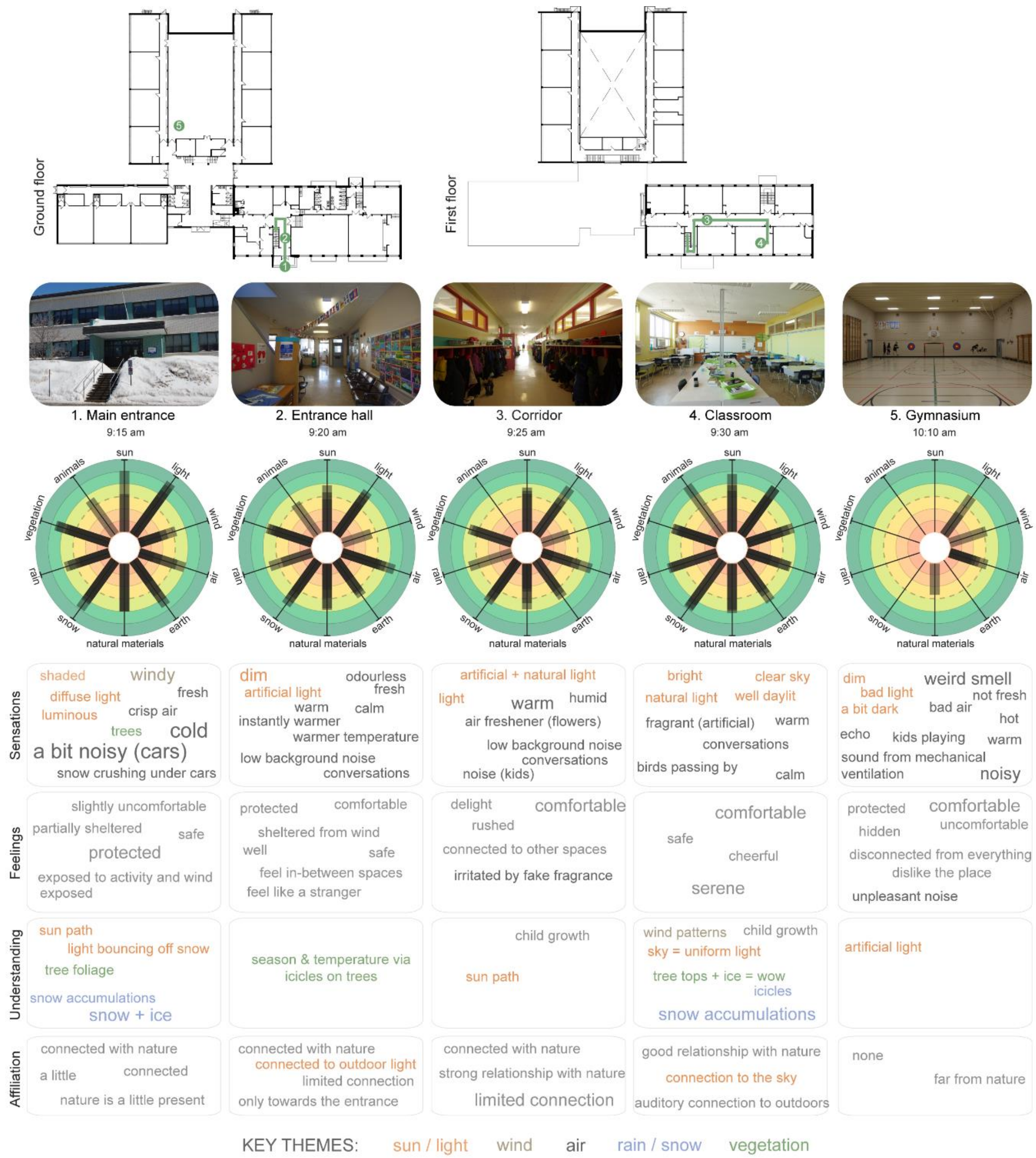

Figure 4.6 BERT summarising perceived experiences during a walk from the main entrance to a classroom and the gymnasium in School T.

4.7 Discussion

This research provided a representation tool that displays and relates biophilic experiences in buildings. The use of BERT in this study successfully documented multisensory experiences (aim 1). In addition to visual experiences, the textual fields documented thermal, olfactory and auditory experiences in indoor, semi-enclosed and outdoor spaces. Moreover, BERT integrated subjective experiences by focusing on people's feelings and environmental features that contributed to an understanding and affiliation with natural forces and processes (aim 2). In both schools, the sensation field tended to provide a more detailed description of environmental features noted on the rose. Words and expressions describing researchers' feelings revealed their degree of comfort and appreciation of the space. Natural forces and processes documented in the understanding field showed how certain spaces (particularly outdoor spaces and rooms with direct views to the outside) enabled an understanding of daily and seasonal patterns. Although researchers noted few terms in the affiliation field, the absence of terms or the selection of negative terms (such as "far from nature") further indicated the spaces where experiences of nature could be enhanced during a renovation project. BERT can be completed in less than five minutes. This rapidity minimises disruptions for schoolchildren and staff while enabling architects to evaluate multiple spaces in a short period of time. Finally, both the rose and textual fields documented the presence and quality of nature experiences during winter (aim 3). The analysis of BERT also tested the hypothesis that School T has more biophilic qualities than School C.

4.7.1 Comparing biophilic experiences in different types of school spaces and buildings

Comparing experiences in School T and School C revealed that the main entrances, classrooms and gymnasiums in both schools offer similar biophilic experiences. Outdoor spaces and classrooms were deemed to have the most *exceptional* environmental features while gymnasiums were noteworthy for the absence of pleasant nature experiences. The main entrance of School T "protected" the researchers, yet sensations in this space illustrate that it was noisier (due to cars) and colder than the main entrance of School C. Also perceived as "very cold" and "cold but enjoyable", School C made researchers aware of birds, water cycles and vegetation. Thus, while both spaces shelter people from above and from one side, environmental features present in the field of view contributed to different experiences in both spaces and suggest that the schoolyard of School C fosters more *exceptional* biophilic experiences than School T.

The biophilic qualities of the School T classroom were expected to be more abundant and pleasant than in the School C classroom, based on their spatial geometry. The classroom in

School T is elongated parallel to the facade and has a higher window glazing to floor area ratio (24.0%) than the classroom in School C (9.6%) which is elongated perpendicularly to the facade (Watchman et al., 2021c). However, the rose and textual fields completed for both schools reveal pleasant experiences of nature in both classrooms. The School T classroom was perceived as “well daylit”, “comfortable” and connected to the sky with elevated ratings of light and snow while experiences in the School C classroom were described as “bright”, “comfortable” and “connected to nature” with elevated ratings of sun, light, snow and vegetation. The presence of abundant vegetation surrounding School C could explain this difference. As previous studies have shown, quality outdoor views, such as those that include vegetation, can positively influence people’s satisfaction and performance in buildings (D. Li & Sullivan, 2016; Matusiak & Klöckner, 2016). In School C, pleasant outdoor views towards abundant trees and snow in the schoolyard could explain why a classroom that was expected to be less biophilic based on its architectural characteristics, could be perceived as having similar biophilic qualities to the classroom in School T which, according to architectural drawings, fosters experiences of nature, but offers occupants a less diverse outdoor view.

BERT confirmed certain biophilic design opportunities while disproving others. As expected, outdoor spaces and classrooms in both schools fostered the most biophilic experiences and both gymnasiums presented no biophilic qualities. However, experiences in the classrooms of both schools were similar although the analysis of their architectural characteristics suggested that the School T classroom should foster more biophilic experiences. Graduate researchers generally described fewer biophilic experiences in circulation spaces in School C than in School T. Although these spaces in both schools create similar experiences in terms of background noise and artificial light, a sense of connection with nature was only experienced in School T. This could be explained by the linearity of the corridor in this portion of School T as well as the presence of transoms and windows at both extremities of the corridor which enable daylight to enter the circulation spaces while offering outdoor views. Meanwhile, interior spaces in School C offer no experience of outdoor features, except when looking outside from the main entrance. Thus, experiences of environmental features could be identified as an issue to improve during a renovation project in the gymnasiums and in the interior circulation spaces. This difference between subjective experiences and expectations based on architectural drawings suggests the usefulness of discussions among BERT users after site visits to complete the diagnosis based on multiple diagnostic methods used. This discussion could also clarify terms and expressions noted to describe people's experiences.

4.7.2 Understanding winter experiences in BERT

Both the rose and the textual fields were analysed to determine if BERT successfully drew attention to and included winter experiences in the assessment of spaces. Examples of descriptions related to winter include mentions of snow, cold outdoor temperatures, cold winds, leafless vegetation or winter clothing. The textual field *understanding natural forces and processes* successfully documented seasonal experiences in regard to the third aim of the pilot study. All the words indicated in this field during the site visits were related to seven elements of nature: water, sun, wind, vegetation, animals, people and seasons (Figure 4.7). Although both schools had contrasting amounts and distributions of nature in the schoolyard, water cycles and snow characteristics influenced the semantic field of the terms included. Understandings of nature were mentioned most often in outdoor spaces. In total, more items were mentioned in the compact School C surrounded by vegetation than in School T on its mineral site. No elements were mentioned in this field for the gymnasium in either schools, further reflecting experiences of a disconnection with nature. Because notations on BERT are intended to change with the seasons, several visits under different weather would more adequately assess the variety of experiences of nature. Nonetheless, each time a BERT is completed, it provides a point-in-time description of experiences that occurred in a space and that can be illustrated by the semantic field.

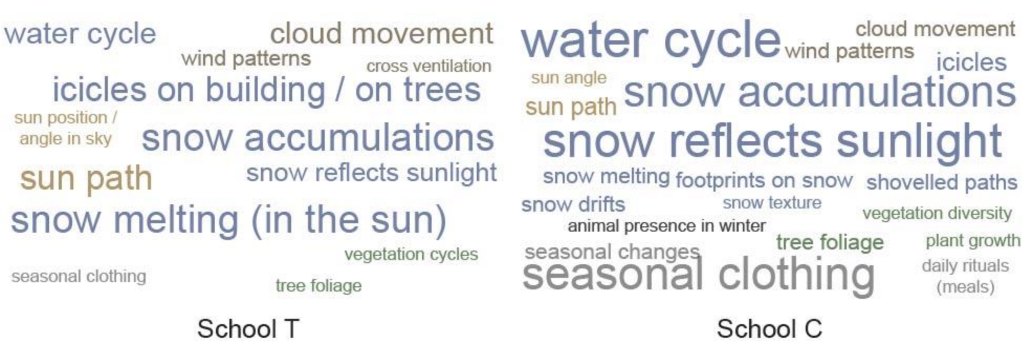

Figure 4.7 Natural forces and processes noted in the understanding *textual field (text size illustrates repetition of the term).*

4.7.3 Educational Potential

A workshop approach suggests that architecture students could benefit from BERT during their studies, considering that limited biophilic design frameworks exist to evaluate nature experiences in buildings (Wijesooriya et al., 2020). During a workshop after the school visits, architecture students were invited to document their desired experiences of nature on the rose. Desired experiences are relevant to design tools because they are more prospective than current experiences and therefore readily connect to the tasks of architects (Demers et al., 2009). Prospective markings made by 33 undergraduate students during the workshop revealed diverse desired experiences. For example, the activity led one student to reflect on her preference for indirect natural light in her office which contrasts with her preference for abundant direct light in her dining room. Another student, who used BERT in his home during the evening, mentioned that BERT made him more aware of non-visual experiences. In the absence of natural light, the environmental features present on the rose prompted him to notice sounds and smells. This has the pedagogical opportunity of making architecture students aware that preferred experiences of nature differ among people, spaces or times of the day. Learning about BERT in architecture schools could help future architects to better describe their experiences in different settings and identify spaces or issues that merit more detailed assessments.

4.7.4 Limits and outlook

BERT organises subjective descriptions of people's experience of environmental features to provide a design understanding of complex situations. The precision and clarity of subjective biophilic experiences depended on each person. Moreover, photographs could only provide additional clarity to experiences with visible manifestations. Future research could explore the use of instrumental survey measurements during building walkthroughs to provide quantitative information that can be matched against subjective experiences. This combination of measurable and perceptual information could refine the representation of biophilic experiences against known indoor environmental quality parameters (such as surface temperatures and illuminance levels) to identify design opportunities that foster nature experiences. BERT documents some qualities of biophilic design that could be quantified and subjective experiences of space. For instance, in terms of auditory stimuli, objective measurements could be compared among spaces and between schools. However, sounds documented in the sensation field in the schoolyard of School C (Figure 4.5) evoke "birds" and the "soft sound" of icicles hanging from trees moving in the wind. These descriptions capture biophilic qualities that decibel levels cannot reveal. Inversely, while biophilic qualities have many benefits for occupants, other spatial and environmental considerations contribute to pleasant and functional spaces. For instance, a soft light entering the periphery of a classroom can be welcoming and enjoyable, yet this might be insufficient light for reading and writing activities. Combining measurements of environmental parameters with perceptual qualities of a space could help designers to assess whether a space fosters experiences of nature while also providing adequate visual, thermal and auditory settings for the intended use of a space. In this sense, documenting multisensory stimuli contributes to a more precise representation of complex situations which can inform design decisions in early stages of renovation projects. Nonetheless, the current form of BERT enables architects to represent nature experiences without expensive or complex equipment.

BERT was developed primarily for the assessment of schools, thus environmental features included in the tool relate to nature experiences that occur throughout the day. The workshop feedback indicated that future research could expand BERT to other occupancy periods, for instance by including environmental features experienced at night, such as the moon.

The intended users of BERT are architects with an understanding of environmental variables. Future research could adapt the tool for other users by modifying certain aspects, such as replacing the textual fields by spaces where children can draw their experience, for example. Offering this graphical flexibility could generate additional sensory representations. Such instinctive, rather than analytical, descriptions of biophilic experiences could enable a concise yet complex synthesis of a space or building. Asking occupants to describe their experiences of nature daily could provide architects with a variety of perceptions to complement their assessment from building walkthroughs. This could also benefit occupants as noting the good things in nature daily can increase people's connection with nature and improve their psychological health (Richardson & Sheffield, 2017). In expanding the tool to other users, additional information, such as demographics and familiarity with the building, could be included to better understand reported experiences.

As this paper focused on the development of a novel representation tool, the one-day school visits served to illustrate the potential of BERT. The perceptual information gathered in two cold climate schools offers an example of biophilic experiences that can be organised and discussed for a diversity of learning spaces during specific occupancy and climatic conditions. BERT does not replace the analysis of architectural drawings, occupant surveys or detailed indoor environmental quality measurements. It provides a novel tool that designers can use during post-occupancy evaluations to focus on subjective biophilic experiences currently overlooked by other tools. Thus, further sample designs and architectural settings would continue to showcase the potential of BERT.

4.8 Conclusion

The value of the proposed diagnostic tool entitled Biophilic Experience Representation Tool (BERT) lies in its ability to enable architects to document and confront subjective experiences of nature in buildings and evaluate multiple spaces in a short period of time while minimising disruptions for schoolchildren and staff. The tool was developed as a result of the discussed pilot study, aiming to assist architects assessing experiences of nature during short site visits in preliminary stages of renovation projects. It considers a selection of environmental features which is based on recurring biophilic design strategies. Adding to sensory notations systems (Demers et al., 2009; R. Lucas & Romice, 2010), BERT evaluates the perception of natural elements in architecture. It also includes textual descriptions of sensations, feelings, understanding and affiliation with nature that the settings engender. Used in two primary schools in Quebec during winter, BERT documented biophilic experiences in various indoor, semi-enclosed and outdoor spaces. The use of BERT explored in this study was centred on primary schools in a cold climate as nature experiences can impact children's and staff's well-being. Using BERT to document subjective experiences in different building programmes and climate contexts could lead to new and overlapping representations of biophilic experiences. In the context of a building renovation, the perceived quality of environmental features helps designers to determine the spaces where people's experience of nature could be enhanced to ultimately foster their well-being.

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Chapter 5 Design vocabulary and schemas for biophilic experiences in cold climate schools

The previous chapters contributed to a better understanding of the architectural and biophilic qualities of three school buildings in the Quebec City area. The analysis tools developed focused primarily on assisting architects during post-occupancy evaluations. They were shown to be useful to analyse architectural drawings, to conduct site visits and to document experiences during building walkthroughs. The extent to which they can inform the design process was discussed less. This last article of the thesis shifts the focus to design-oriented tools while also considering an architectural and experiential understanding of existing spaces.

The research presented in this chapter aims to provide architects with a better understanding of the architectural challenges and opportunities that affect the health and well-being of students by developing a classification of biophilic design strategies. This responds to the need, identified in the Introduction and in Chapter 1 of this thesis, to identify and define biophilic design guidelines that translate readily into architecture. This chapter describes a portion of the work conducted during a research semester at the University of Tennessee, Knoxville. As part of this international collaboration with Professor Mark DeKay, the goals of this particular project were to develop a classification of biophilic design strategies and to refine and analyse several of the design possibilities identified in the classification in regard to cold climate school settings. It also raised questions as to how complementary fields, such as child development and integral design, could inform the research.

While the diagnostic tools and approaches developed in the previous chapters focus either on architectural drawings or *in situ* experiences, both aspects are incorporated in the biophilic design vocabulary and the biophilic design schemas to offer a design approach for children's learning environments that foster experiences of nature. The *biophilic design vocabulary* describes spatial enclosure and adjacencies as well as abiotic and biotic nature in architecture that may engender biophilic experiences. *Biophilic design schemas* are defined 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.

An iterative research and design process was used to identify current gaps in the literature, to develop a biophilic design vocabulary and to generate biophilic design schemas. 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. A broader version of certain matrices and more detailed descriptions of some schemas were omitted from the article presented in this chapter. For example, Appendix G presents an extended adjacency matrix (Figure 5.5) for the biophilic design vocabulary. Appendix H offers a detailed description of the schema SKY AWARE SPACE. Both this extended matrix and detailed schema illustrate how the vocabulary and schemas presented in this chapter represent a starting point and offer the potential for continued research.

The design studio course taught by Mark DeKay during the fall semester of 2019 provided an opportunity to use these design schemas in the work of advanced undergraduate students. Weekly discussions with the fourteen undergraduate students in the studio helped to improve the communication of the design schemas and continuously led to their enhanced clarity and representation. This was also beneficial for the undergraduate students, who were taught about designing for cold climates as well as designing for biophilic experiences. As part of this course, a three-day field trip was organised to visit numerous schools in Columbus, Indiana. Since 1960, schools designed by renowned architects, such as Norman Fletcher, Edward Larrabee Barnes, Richard Meier and Harry Weese, have been built in this city as part of the Architecture Program of the Cummins Foundation. The variety of semi-enclosed spaces visited in these schools was helpful to verify that the matrices developed in the biophilic design vocabulary were sufficient to document each space type and various experiences of nature. These additional precedents further enhanced the descriptions and visual representations used in the biophilic design schemas.

The vocabulary and schemas presented in this chapter have the potential to assist architects throughout different stages of the design process. During post-occupancy evaluations, designers could use the ensemble of matrices, strategies and schemas to understand, describe and qualify the architectural and living elements that generate positive experiences of nature.

This applies to indoor, semi-enclosed and outdoor spaces as both the vocabulary and schemas cover several building scales. Later during the design process, architects could use these schemas to foster nature experiences in renovation interventions while considering their project's distinct variables. The schemas therefore play a creative role by helping architects to recognise relevant characteristics and then to convert them into their target project.

This chapter presents the article "Design vocabulary and schemas for biophilic experiences cold climate in schools" by Mélanie Watchman, Mark DeKay, Claude M. H. Demers and André Potvin. The article was published in the journal *Architectural Science Review* and is available online since May 2021 (https://doi.org/10.1080/00038628.2021.1927666).

5.1 Résumé

Cette recherche explore une approche de conception d'expériences biophiliques appliquée aux environnements d'apprentissage des enfants. Les principales lacunes auxquelles l'article répond sont la confusion entre principes, expériences et caractéristiques architecturales dans la littérature sur le design biophilique ; le manque de terminologie commune pour référer aux patterns spatiaux qui induisent des réponses biophiliques ; et l'accent mis sur la validation empirique et les généralisations théoriques qui laissent les concepteurs à la recherche d'approches génératives. Un *vocabulaire de design biophilique*, comprenant le degré d'intériorité / extériorité et de contiguïté, est développé pour les expériences des forces naturelles et des organismes vivants. Un cadre conceptuel est proposé pour des *schémas de design biophilique* dans les écoles en climat froid. Ce langage graphique commun intègre les expériences de la nature dans les processus de conception, permettant aux chercheurs et aux architectes de décrire des espaces biophiliques avec une logique et des termes partagés.

5.2 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.

5.3 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 et al., 1977; Gstach & 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 et al., 2014; Kellert et al., 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 & 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 & 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 et al., 2021a). 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.

5.4 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, p. 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 & 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 et al., 2014; R. Kaplan et al., 1998; Kellert et al., 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, p. 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 architects and 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 et al., 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 et al. (2014, p. 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 & 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 et al., 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 et al. (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 et al. (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 & Ryan, 2020; Kahn & 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 et al., 2021a), this paper explores design methods and generative approaches to describe and organise forms and spatial configurations that may foster experiences of nature.

5.5 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.

5.5.1 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 & 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 & 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, p. 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, p. 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, p. 303). Thus, it offers a framework that could facilitate the collaboration among different researchers.

5.5.2 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 et al., 1977; DeKay & Brager, Forthcoming; DeKay & Brown, 2014; R. Kaplan et al., 1998; Mazria, 1979; Thiis-Evensen, 1989), 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, p. 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." 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.

5.5.3 Application in a design studio course

The architectural studio offers an ideal opportunity to investigate and test 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. School settings 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 (Chawla, 2015; Kahn & Kellert, 2002). 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 combined principles of sustainable design during an entire semester. Students were introduced to biophilic design by reading *14 Patterns of Biophilic Design* (Browning et al., 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 and two specialised spaces (music, art, library or cafeteria) based on the school's needs. Figure 5.1 illustrates the alignment of the development of the biophilic design schemas and the activities in the design studio. 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.

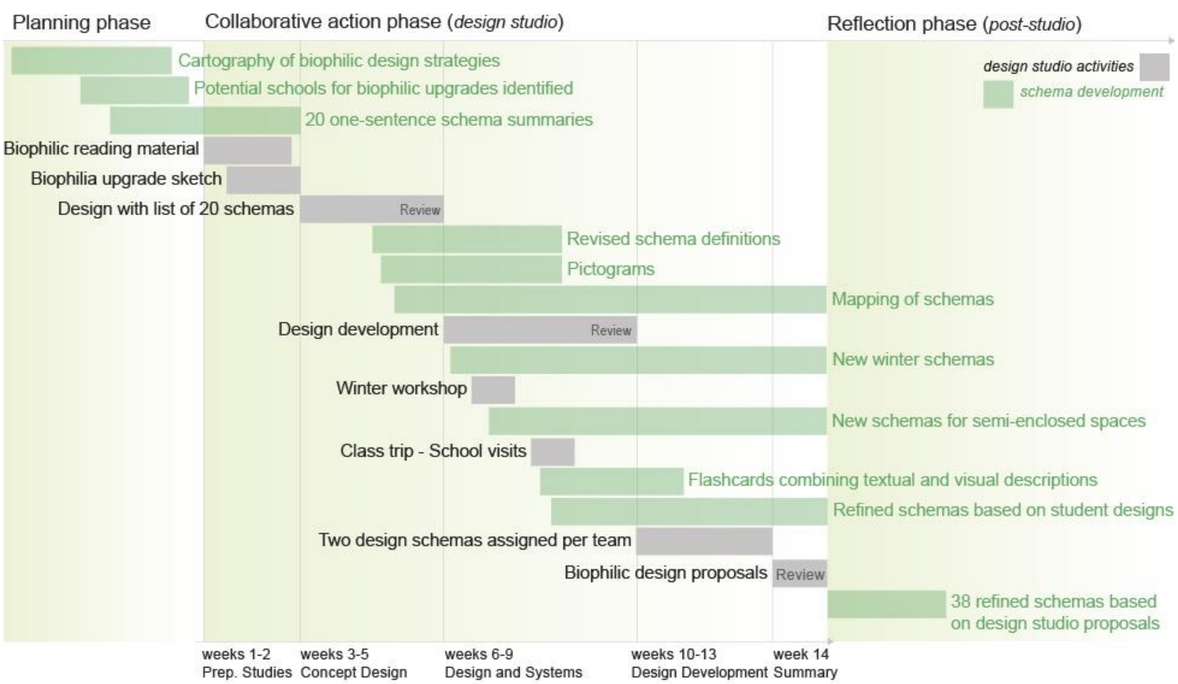

Figure 5.1 Design studio course activities in relation to the development of the biophilic design schemas.

5.6 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.

5.6.1 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 5.2). 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.

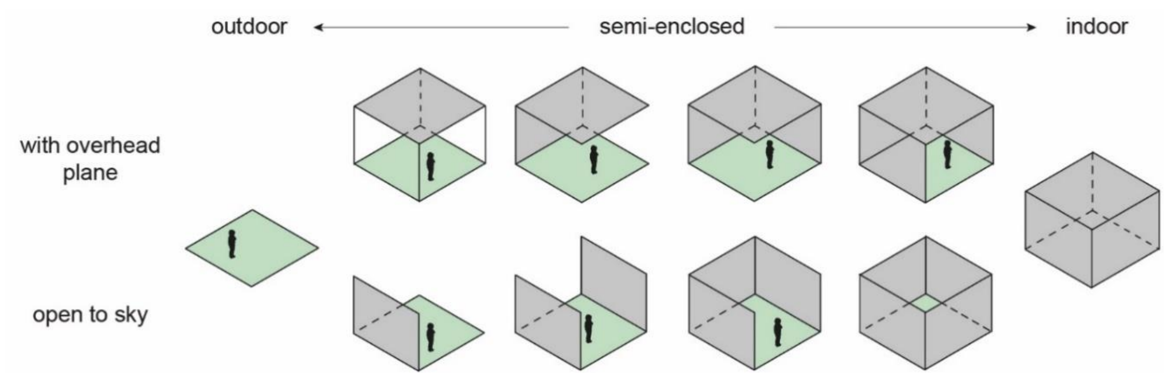

Figure 5.2 Degrees of spatial enclosure: vertical and horizontal interfaces.

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 5.3). 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.

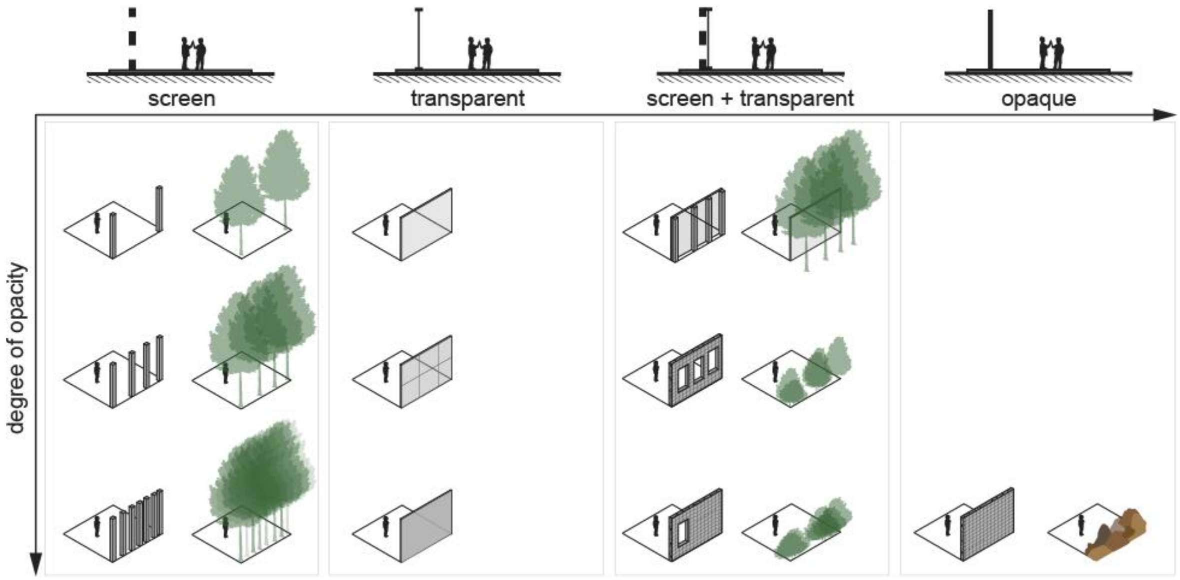

Figure 5.3 Representation of vertical built or natural components organised by degree of opacity.

5.6.2 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 5.4 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 5.5). Thus, the adjacency of a space to the ground can generate different experiences of the sky, horizon and earth.

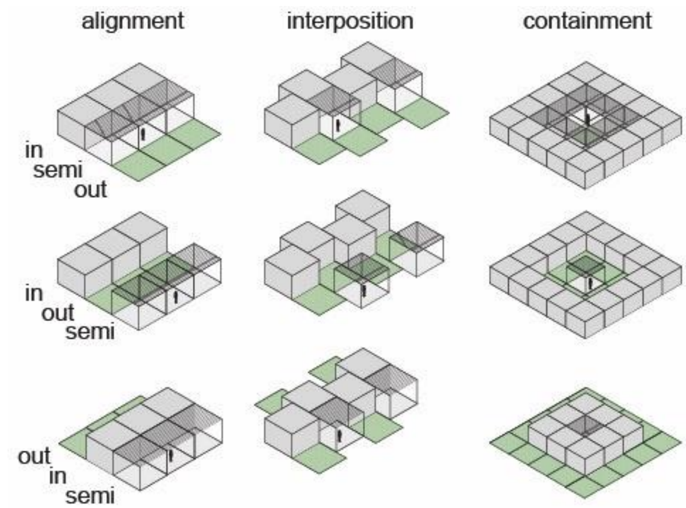

Figure 5.4 Possible spatial adjacencies including indoor, semi-enclosed and outdoor spaces.

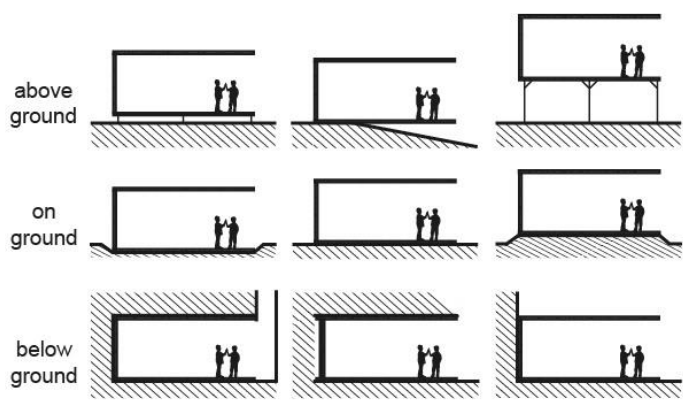

Figure 5.5 Possible adjacencies to the ground for rooms with the same spatial enclosure.

5.6.3 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 & 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 5.6). 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.

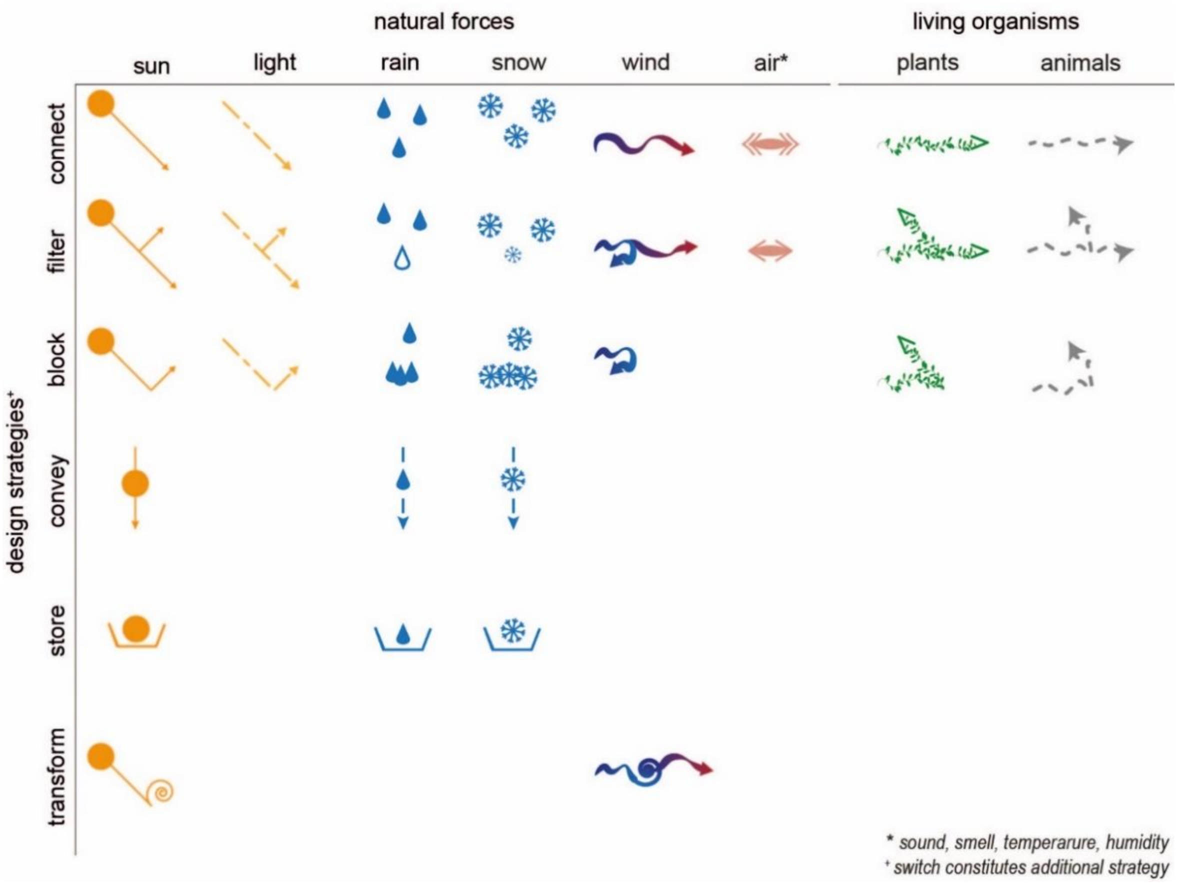

Figure 5.6 Design strategies for regulating natural forces and living organisms.

The concept of *switch* offers a unique opportunity to modulate different design strategies in time (Figure 5.7). 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.

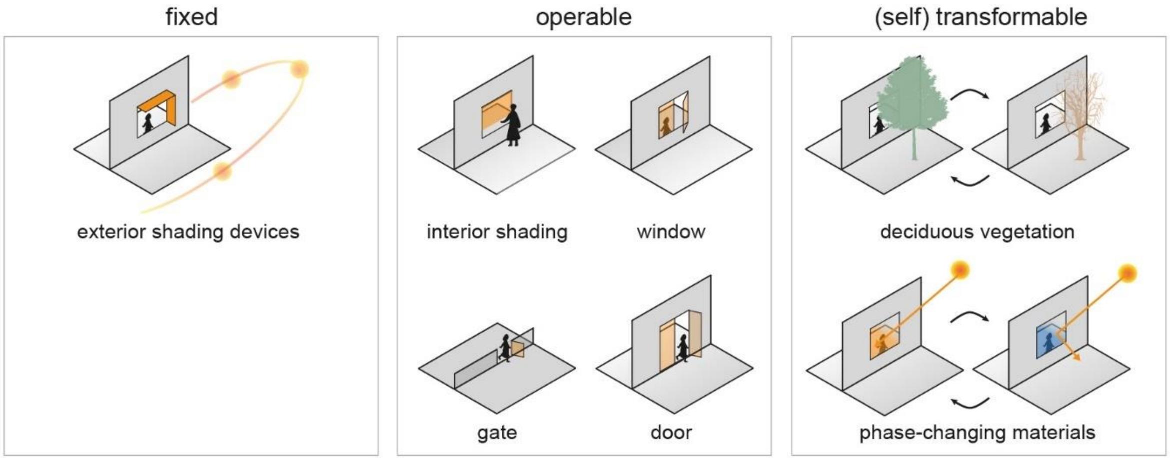

Figure 5.7 Types of built and biotic switches.

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 5.6) and different types of horizontal and vertical components (Figure 5.3) shows how each component renders manifest the design strategies. Figure 5.8 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.

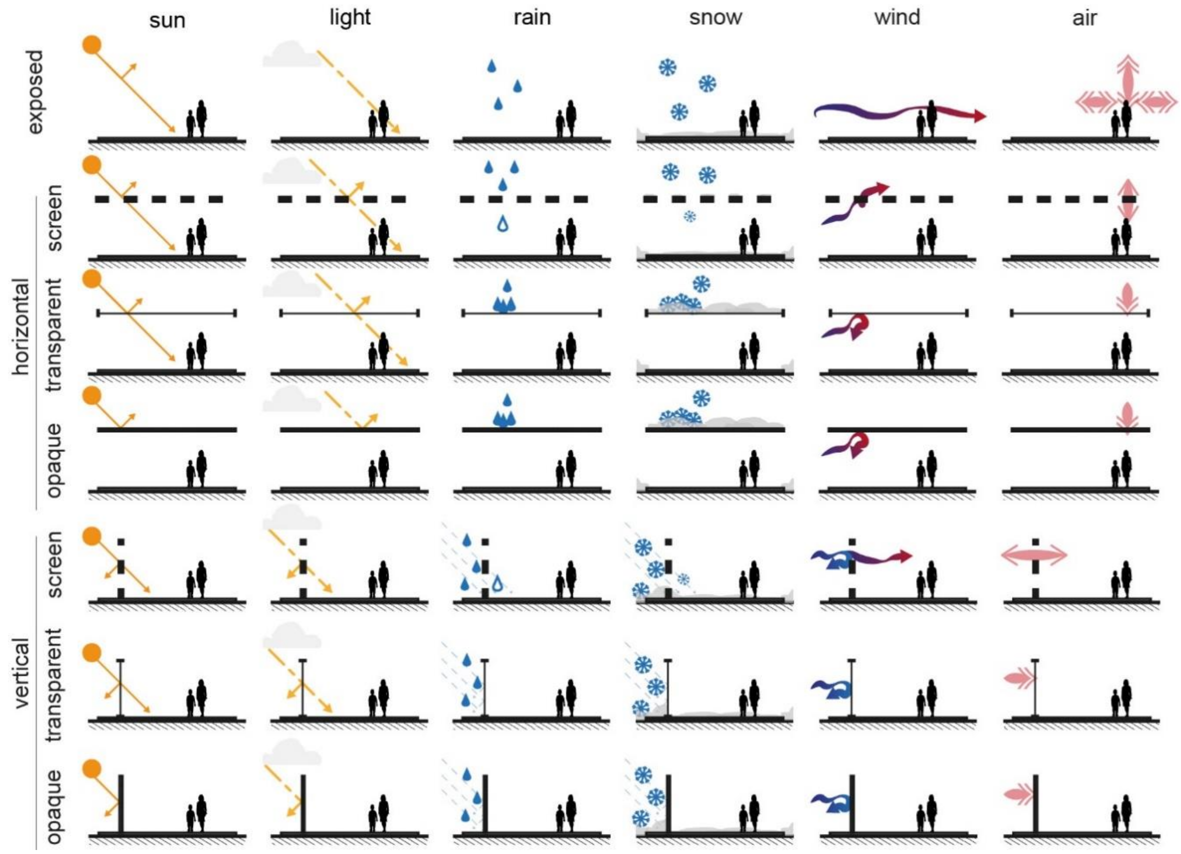

Figure 5.8 Modulation of natural forces by horizontal or vertical component, the catalytic conditions for experience.

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 5.9). 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.

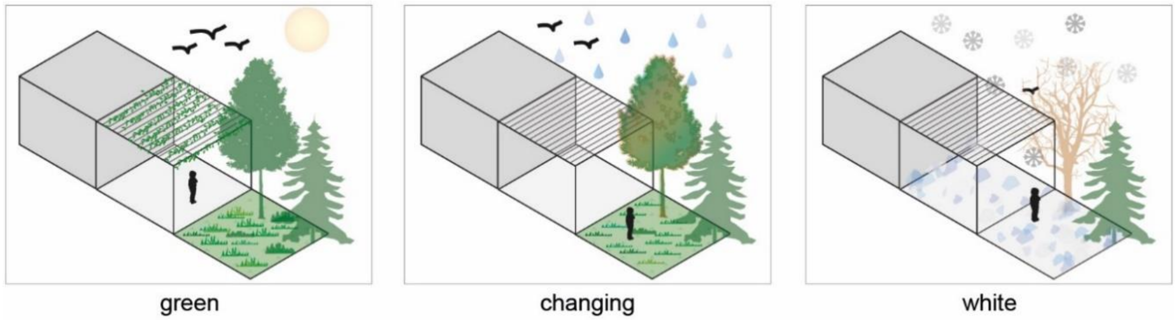

Figure 5.9 Experiential possibilities of seasonally changing biotic and abiotic nature.

5.6.4 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 5.10 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 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.

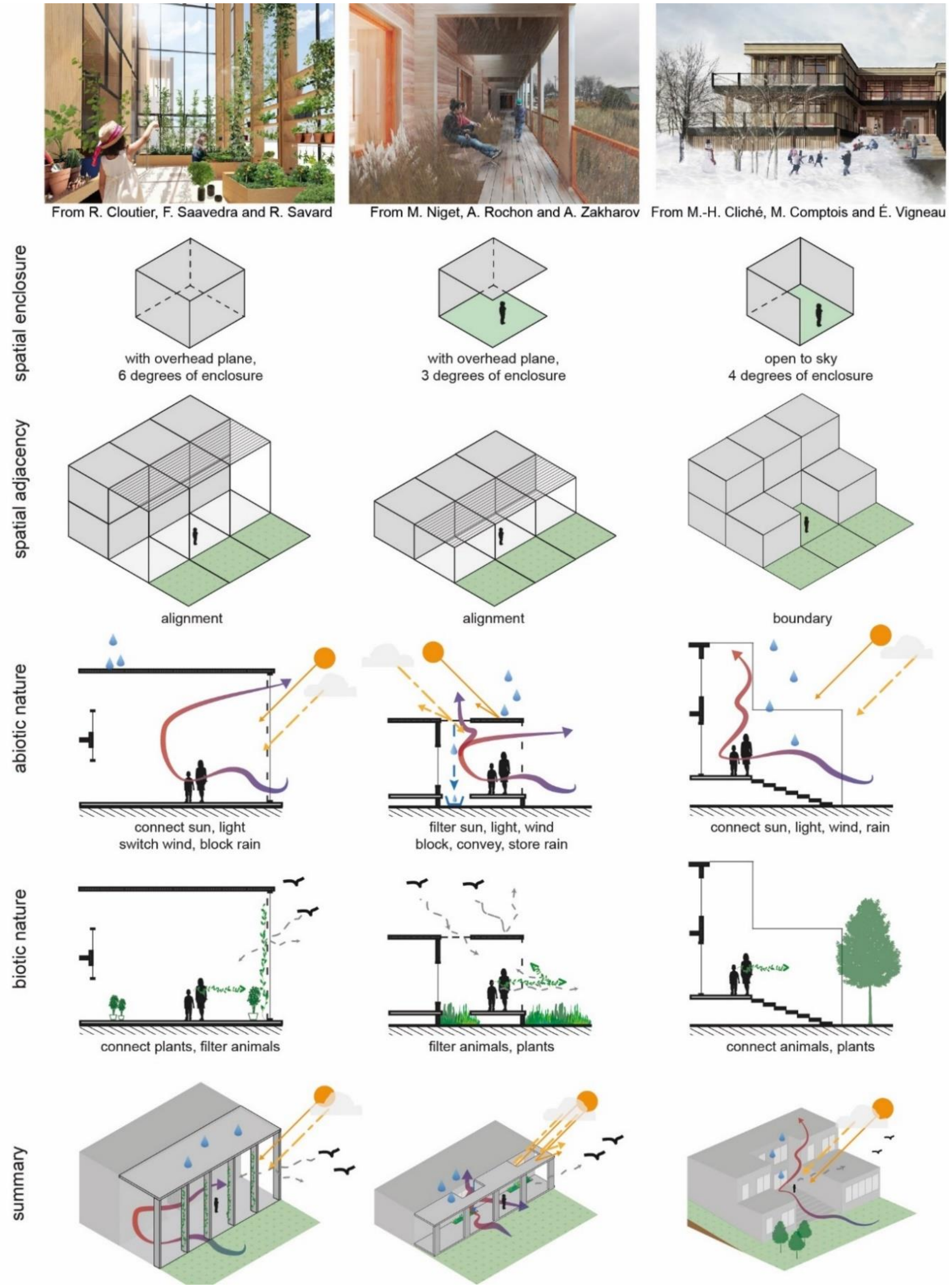

Figure 5.10 Biophilic design vocabulary employed for project analysis.

5.7 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 flash card and an extended two-page format.

5.7.1 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 5.11, rows) and on a spectrum of insideness and outsideness (Figure 5.11, 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 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 5.11.

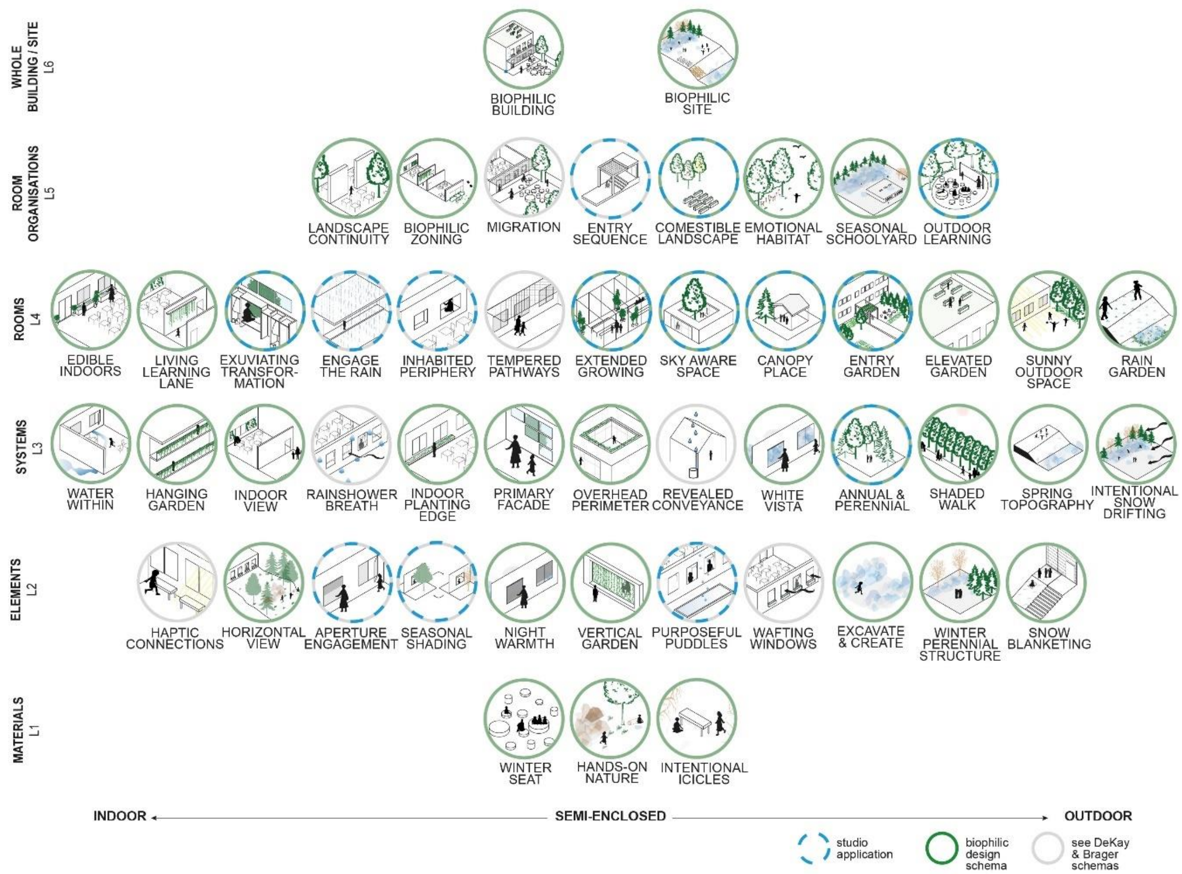

Figure 5.11 Biophilic schema map for cold climate schools.

Each image in the schema map represents a different design schema architects can employ. In principle, at least two lower-level schemas help to 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 5.12 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 and themes. Hence, extended research to map and connect all the biophilic design schemas presented in Figure 5.11 could generate additional schemas while further communicating their interrelationships.

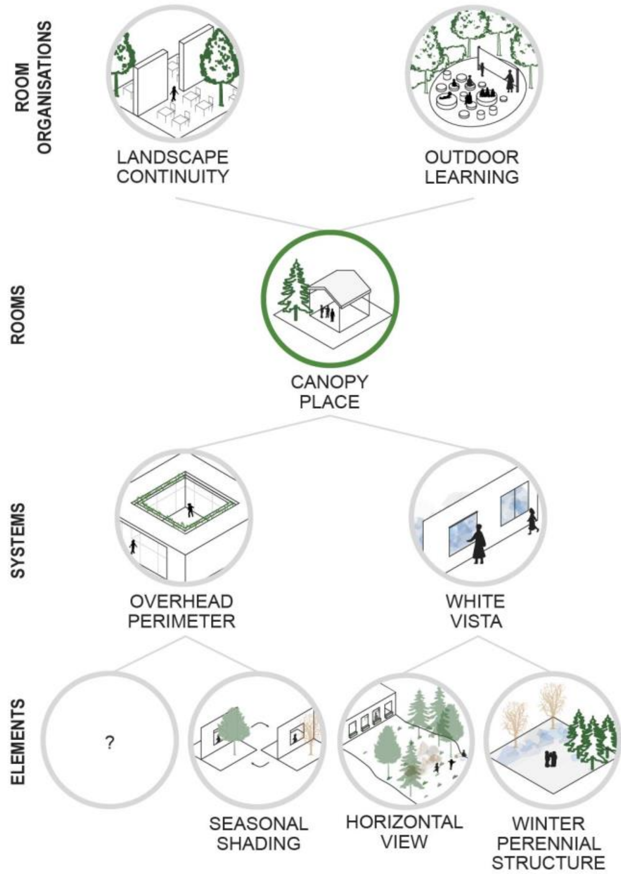

Figure 5.12 CANOPY PLACE *and related schemas of higher and lower complexity.*

5.7.2 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 5.1 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 5.13 which combine the pictogram used in the biophilic schema map (Figure 5.11) and the one-sentence summary (Table 5.1). This enables the schemas to become tangible, shared resources during the design process.

Table 5.1 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 life cycles 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.

(continued)

Table 5.1 Continued.

Level of Complexity	Biophilic schema	Experiential summary
L3 Systems (*continued*)	PRIMARY FACADE	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.

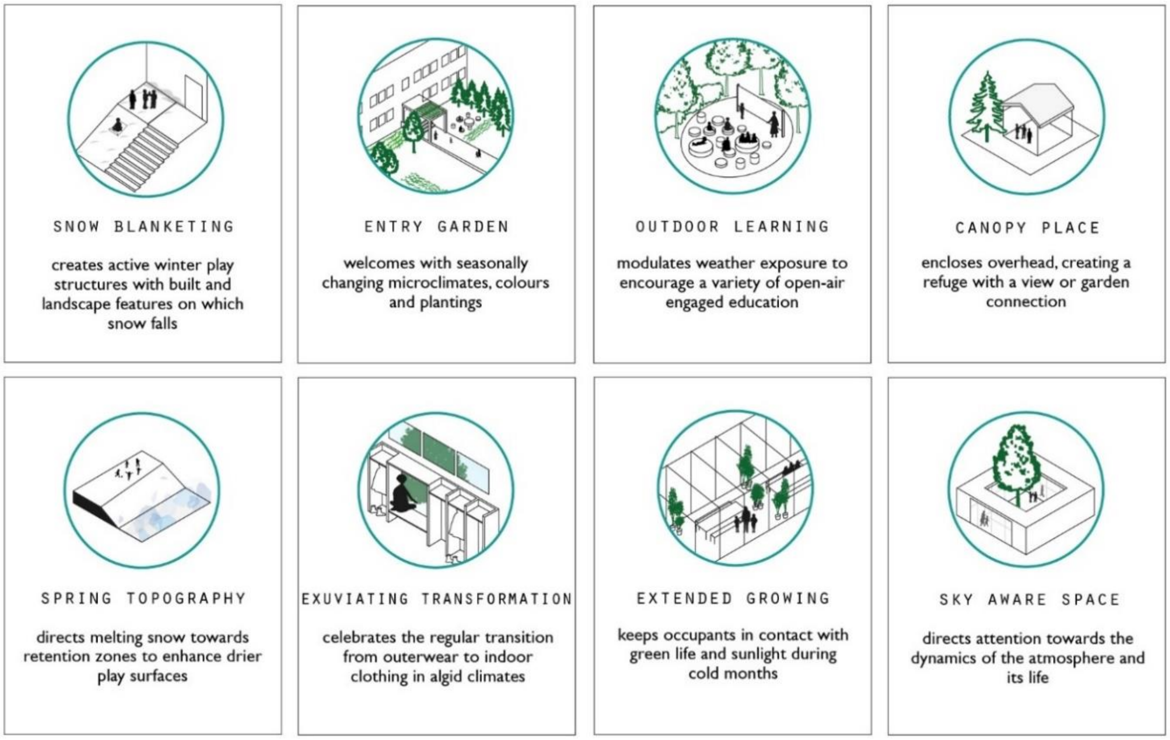

Figure 5.13 Pictogram and one-sentence summary for selected biophilic design schemas.

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 5.14 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.

5.7.3 Extended two-page schema

The development of a 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 5.15 illustrates the anatomy of a biophilic design schema, which is composed of the biophilic design vocabulary and previously described figures.

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 5.14 Examples of schema descriptions summarising the intended experiences of nature.

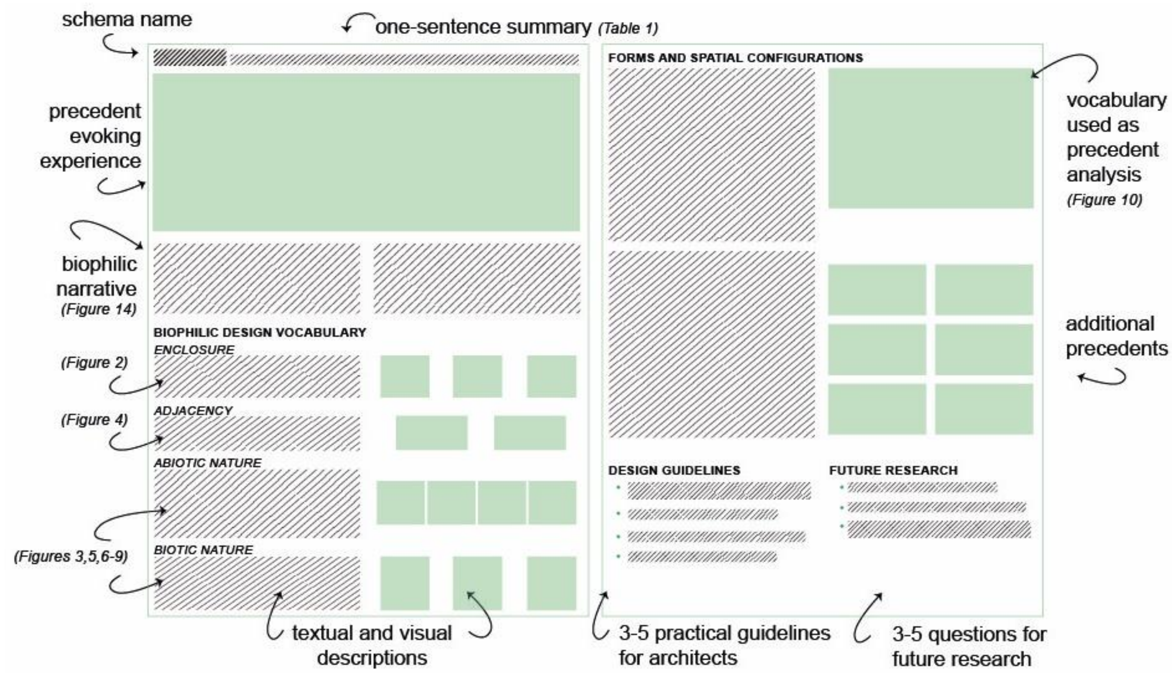

Figure 5.15 Anatomy of a biophilic design schema.

The first portion of the schema is descriptive to help architects understand the biophilic design intention. It includes three 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 5.1 and Figure 5.13). The narrative explanation and architectural precedent provide a longer description of the experience of nature involved (Figure 5.14).

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 Figure 5.16 and Figure 5.17.

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.

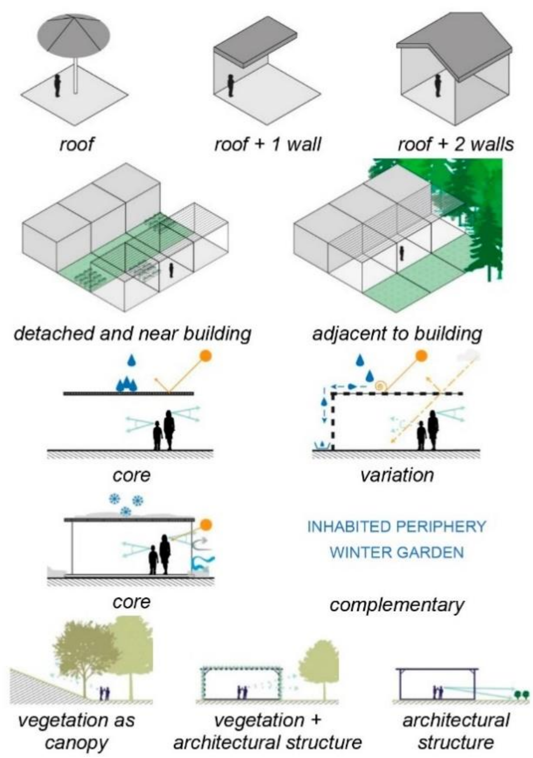

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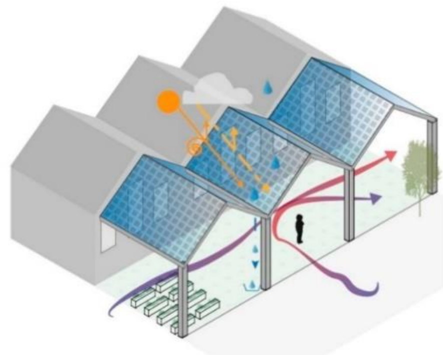
Figure 5.16 CANOPY PLACE schema, page 1.

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.

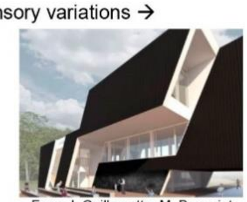
The precedents are organised top-to-bottom based on their suggested sense of refuge, of protection from the sun and the rain. The adjacency of a CANOPY PLACE to a building edge and the size of the space created by the canopy can influence the sense of refuge. The opacity of the canopy further affects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

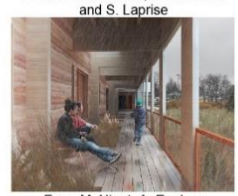
← Sense of shelter, refuge

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



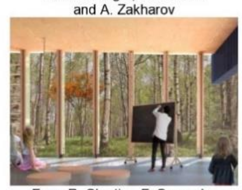
From J. Guillemette, M. Bazeniet and S. Laprise

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



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

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 5.17 CANOPY PLACE schema, page 2.

5.7.4 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 5.1). 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 et al., 2014), however discussions about this material did 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 the 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 5.18). 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 school 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.

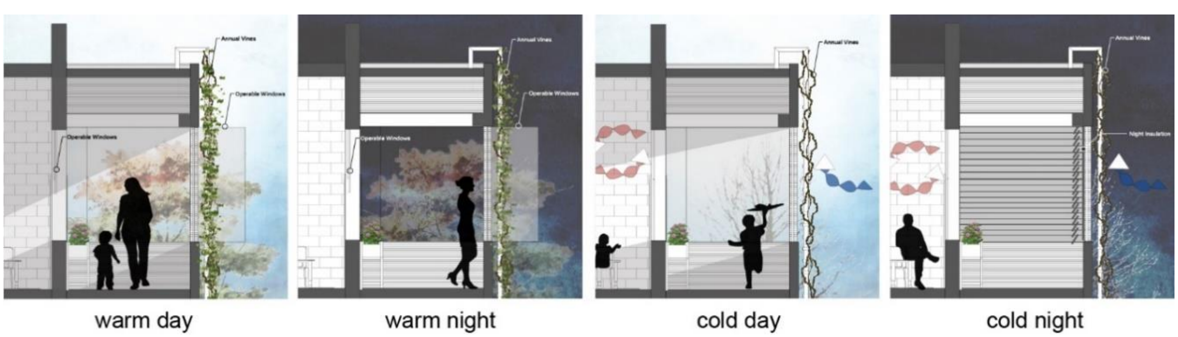


Figure 5.18 Studio exploration of an INHABITED PERIPHERY*. From A. Brotzman and M. Hooper.*

Perhaps because their previous studios were oriented towards formal compositions and other issues, students initially expressed some difficulty in thinking about biophilic experiences. To them, it was unfamiliar territory. Thus, as the school addition 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 multisensory 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 5.19). 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.

Figure 5.19 Studio exploration of EXTENDED GROWING. *From H. Dennis and I. West.*

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 5.20). 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.

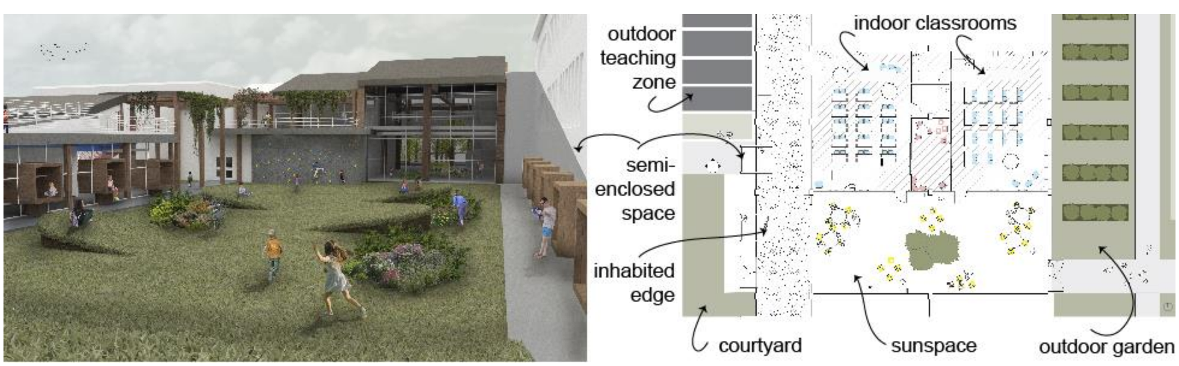


Figure 5.20 Detailed indoor, semi-enclosed and outdoor learning spaces. From H. Dennis and I. West.

5.8 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 et al. (2008), Kellert and Calabrese (2015) and Browning et al. (2014), the absence of a map or a description of how the strategies within a category 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 et al., 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 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 the 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 at the end. Being able to name and describe the indoor, semi-enclosed and 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.

5.9 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.

Conclusion

This thesis developed an ensemble of architectural tools to support the realisation of diagnoses and to identify solutions at several building scales in the context of renovating primary schools in Quebec to improve the well-being and academic success of students. By a multi-method approach in a post-occupancy evaluation and evidence-based design framework, it has identified, examined and communicated biophilic design opportunities that foster people's experiences of nature and, ultimately, their well-being. In doing so, it has been shown that biophilic design provides an insightful framework to enhance well-being and academic achievement in learning environments, even in a cold climate. The diagnostic methods developed in this thesis help architects to identify current challenges and opportunities for biophilic experiences in schools. They also enable a rapid comparison of design alternatives during the design process. The evaluation criteria used in the assessment method based on spatial geometry (Chapter 2) and in the Biophilic Experience Representation Tool (Chapter 4) facilitate a real-time integration of biophilic issues and opportunities for architects intervening in renovation projects (Chapter 5). From the early assessment of a building, these tools could be used during site visits, in the design development process and ultimately, in the post-occupancy evaluation of the renovated schools. This conclusion presents (1) the findings and contributions of the diagnostic and design tools developed in the thesis, (2) the key challenges and opportunities identified for the current renovation of primary schools in Quebec and (3) the limits of the thesis and an outlook on future research.

Findings and contributions of each diagnostic and design approach

Chapter 1 provided important insights into the gaps in current knowledge of biophilia in cold climates. The narrative review aimed to analyse the relationship between principles of biophilic design and well-being and to examine the importance of considering the particularities of learning environments in cold climates. The reported associations between biophilic design principles and the health, achievement and well-being of children indicated that architects should not only avoid creating undesirable settings, but also aim to achieve an enhanced connection with nature. Special consideration should be given to school site selection, schoolyard design and building design to maximise the biophilic potential of indoor spaces. Additionally, daylight, natural ventilation, pleasant temperatures and enjoyable sounds should play an important role in the design and renovation of learning environments. In cold climates, the perception of these biophilic design principles is diverse due to seasonal variability. The climatic context of learning environments therefore represents an unavoidable consideration that may alter the expression of nature in the built environment. However, it was shown that limited research has considered the issues people face in cold climates. More research is therefore needed to further examine seasonal diversity and extreme climate conditions and its effects on biophilic experiences. Moreover, the review indicated that some qualities of biophilic design can be quantified and measured in the built environment, such as light quantities and sound levels. However, several principles allude to the subjective experience of space. This distinction between measurable and perceivable biophilic design principles could in part explain their unequal documentation in terms of health and well-being benefits. These reflections on biophilic experiences in cold climates provided a powerful and clear foundation for subsequent steps of this research. By incorporating subjective experiences into the understanding and application of biophilic architecture, it becomes possible to complement the current dominant focus of measuring the quantifiable impacts with engendering and assessing *philia* in biophilic buildings.

Chapter 2 aimed to diagnose the biophilic qualities of current primary schools in Quebec. Building on the extensive scientific interest in evaluating the biophilic qualities of buildings (McGee & Marshall-Baker, 2015; Roös et al., 2016; Terrapin Bright Green, 2019), the work described in this chapter is among the few studies that explicitly considered the measurable elements contained in architectural drawings to assess biophilic architecture. This approach allows architects, before site visits, to identify which indoor environmental parameters may fall below the recommended thresholds and the areas of the school in which they may occur. The combination of biophilic design guidelines, building certification criteria and bioclimatic design principles created an assessment tool that critically analyses architectural plans, sections and elevations. Used on three primary schools in Quebec, the diagnosis revealed that although the schools differ from biophilic precedents of new schools built throughout the world, they do offer opportunities for experiences of nature. The narrow floor plans, adequate glazing areas in classrooms and regularly occupied spaces with windows in Schools L and T facilitate visual, thermal, olfactory and auditory exchanges between indoor and outdoor spaces. However, School C, with its more compact floor plans, has more challenges for experiences of nature as regularly occupied spaces without windows and a higher reliance on mechanical systems were observed. The analysis of architectural drawings highlighted the importance of the building envelope. Considering the size and placement of windows served as an indicator of the magnitude of potential nature experiences. Window orientation and shading devices further informed the biophilic qualities of space. The assessment method illustrated the potential of architectural drawings to identify aspects of biophilic design, even though the objective and quantitative metrics used could not assess the experiential aspects of biophilia. Nonetheless, if the goal is to foster well-being in the built environment, then a simple means of assessing architectural qualities that considers the climatic context can be highly beneficial in the early diagnostic and design stages.

Chapter 3 acknowledged the importance of site visits for an effective diagnosis of existing opportunities for experiences of nature. Analysing sensory experiences during site visits enables architects to confirm or disprove the design opportunities identified using architectural drawings. It further allows weather and daily occupancy considerations to emerge and provides a more accurate representation of the existing opportunities and challenges for the well-being of occupants. Assessing positive experiences of nature based solely on objective measurements of the environmental conditions during site visits in School L, School T and School C proved difficult as positive experiences of nature not only concern the amount of nature available in a space. The way students and school staff interact and adapt the built environment also shows how opportunities for experiences of nature are seized and how challenges are overcome. This illustrates the strength of a multimethod approach to investigate the diversity of potential biophilic experiences in school settings. Whether using information from architectural drawings, occupant surveys, instrumental measurements or photographic surveys, each methodological tool reveals and simultaneously conceals information about biophilic experiences that a different method does not.

Chapter 4 aimed to facilitate the assessment of biophilic experiences during building walkthroughs in the preliminary design stages of renovation projects. This further aimed to complement the simplified assessment method based on spatial geometry, developed in Chapter 2, which could not evaluate experiential aspects of biophilia. It also complemented the observations and measurements presented in Chapter 3, which described school spaces in different seasons and began to characterise sensory experiences as the fundamental level of biophilic experiences. The value of using the Biophilic Experience Representation Tool (BERT) lies in its ability to enable architects to document and confront subjective experiences of nature in buildings and evaluate multiple spaces in a short period of time while minimising disruptions for schoolchildren and staff. BERT considers a selection of environmental features which is based on recurring biophilic design strategies (Browning et al., 2014; Kellert, 2018; Kellert et al., 2008; Kellert & Calabrese, 2015). Adapting sensory notation systems such as those developed by Demers et al. (2009) and Lucas and Romice (2010) to biophilic experiences, BERT evaluates the perception of sun, light, wind, air, earth, natural materials, snow, rain, vegetation and animals. It uses the model of biophilic experiences proposed in Appendix E to include textual descriptions of the sensations, feelings, understanding and affiliation with nature that the settings engender. During the two school visits performed during winter, BERT illustrated its capability to assess natural elements in indoor, semi-enclosed and outdoor spaces. In the context of a renovation, such an assessment indicates spaces where the intensity of natural elements could be enhanced to foster multisensory experiences of nature.

Finally, Chapter 5 aimed to examine the forms and spatial configurations that engender biophilic experiences. While the diagnostic tools and approaches developed in Chapter 2 and Chapter 4 focus either on architectural drawings or *in situ* experiences, both aspects are incorporated in the biophilic design vocabulary and the biophilic design schemas to offer a design approach for children's learning environments that foster experiences of nature. By their seasonal, multi-scalar and multisensory considerations, the vocabulary and schemas for biophilic experiences in children's learning environments can inform the renovation of primary schools in Quebec. The vocabulary of biophilic design offers a common way of describing architectural elements and spaces. It focuses on four themes: spatial enclosure, spatial adjacency, abiotic nature and biotic nature. This vocabulary aims to clarify and facilitate the communication of design intentions during the design process and to better compare future experimental studies. The aim was not to develop all the spatial configurations that may foster experiences of nature, but rather to provide an ensemble of matrices, strategies and schemas that architects can use to generate nature experiences while considering their project's variables. While the notion of *design schemas* is borrowed from the 40 schemas being developed by DeKay and Brager (Forthcoming), the 38 biophilic design schemas presented in this thesis are a novel contribution that focuses on the particularity of nature experiences in cold climate schools. Unlike the disconnected biophilic design strategies or principles often present in the literature (Browning et al., 2014; Kellert et al., 2008; Kellert & Calabrese, 2015), the organisation of biophilic design schemas proposed in this thesis provides a structure and an understanding of the interrelatedness of the information. Similar to but more structured than the linkages in *A Pattern Language* (Alexander et al., 1977), this organisation communicates that integrating biophilic design schemas in a design project cannot focus on a single element or space. Overall, the design tools developed in this thesis guide future interdisciplinary work regarding design decisions that foster experiences of nature in buildings.

The diagnostic and design tools developed in this thesis address quantitative and qualitative dimensions of biophilic design. They characterise nature, people's experiences, the architectural context in which they occur or a combination of these issues. Each approach contributes to a better understanding of biophilic design. By combining the findings obtained with each tool, it becomes possible to generate a more exhaustive representation of the biophilic qualities in an existing space. Figure 20 illustrates the anatomy of such a biophilic design assessment. The first portion of the figure identifies the space investigated by a few keywords and a general photograph. It includes the assessment based on spatial geometry (described in Chapter 2) to locate the space within the building and recognise key opportunities and challenges for nature experiences based on architectural characteristics (such as doors to the outside, glazing or the daylighting zone). The second portion of the figure serves to summarise the environmental information measured during a site visit (as presented in Chapter 3). Following a brief description of the weather and occupancy conditions of the visit, photographs illustrate the distribution of light, thermal gradients, materials and auditory events. The third portion of the figure frames subjective experiences documented using BERT (developed in Chapter 4). The rose and four textual fields completed during a site visit are included. The fourth portion of the figure uses the four themes of the biophilic design vocabulary to analyse the space (as shown in Chapter 5). A detailed example for the sheltered main entrance, or CANOPY PLACE, of School T visited during winter is presented in Figure 21. Combining measurable and perceptual dimensions of biophilic design in a single document facilitates its interpretation. Subjective experiences, such as the appreciation of a luminous space, can be related to quantitative data, such as the amount and distribution of light, in this location at a specific time. Regrouping this information in a single page further facilitates comparisons of the space at different times of the day or year as well as comparisons with other spaces. Visiting this space at a different season provides an additional understanding on the impact of the built environment and natural patterns on biophilic experiences. This template can also serve to compare two spaces with similar spatial configurations. For example, comparing the photographs and experiences in this CANOPY PLACE with CANOPY PLACES identified in other buildings would help to refine this biophilic design schema in terms of objective and subjective descriptions. Completing this assessment before and after a building renovation could also enrich post-occupancy evaluations by including multisensory experiences of nature.

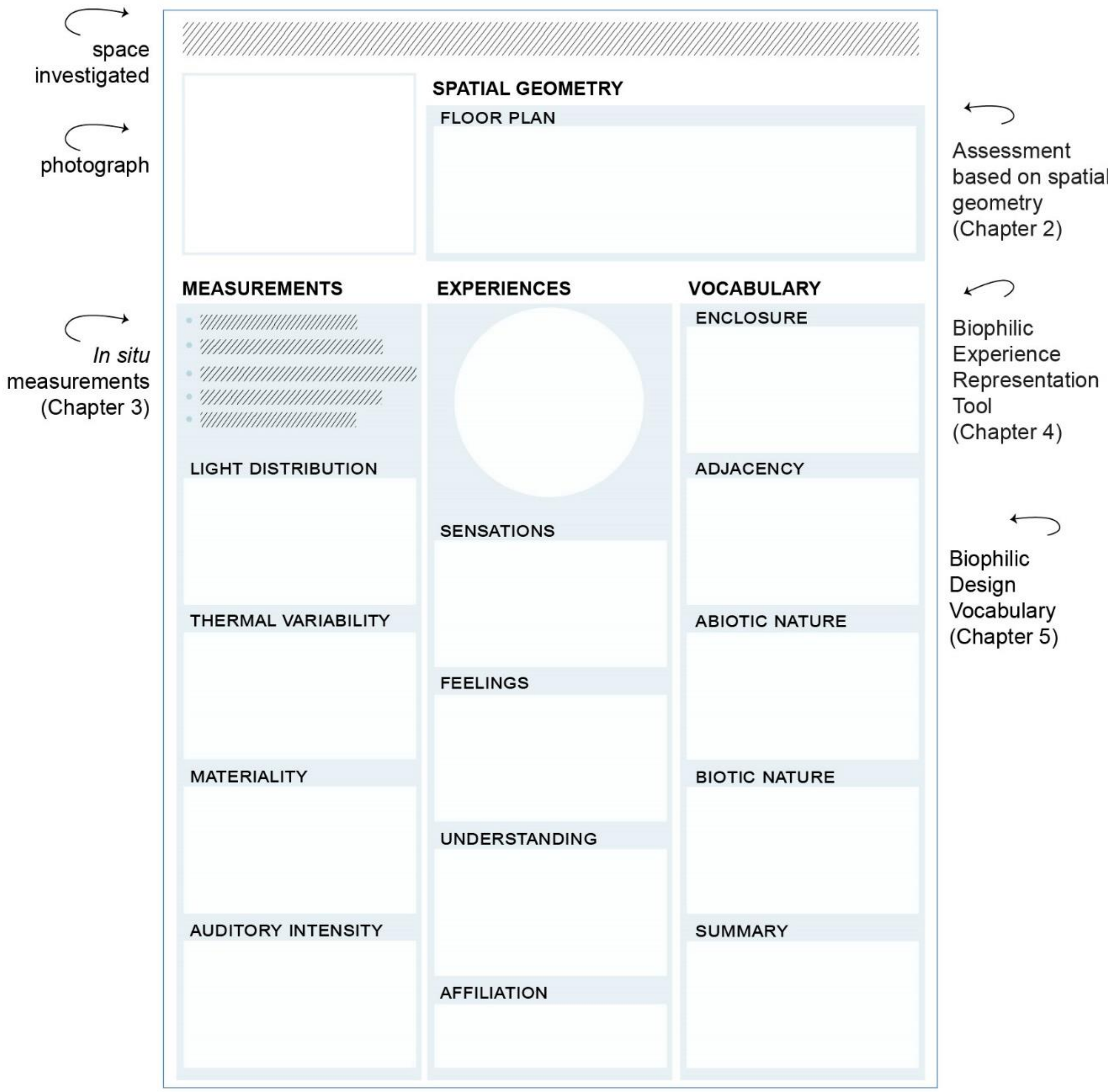


Figure 20. Anatomy of the biophilic design assessment combining architectural drawings, in situ measurements, experiential descriptions and vocabulary themes.

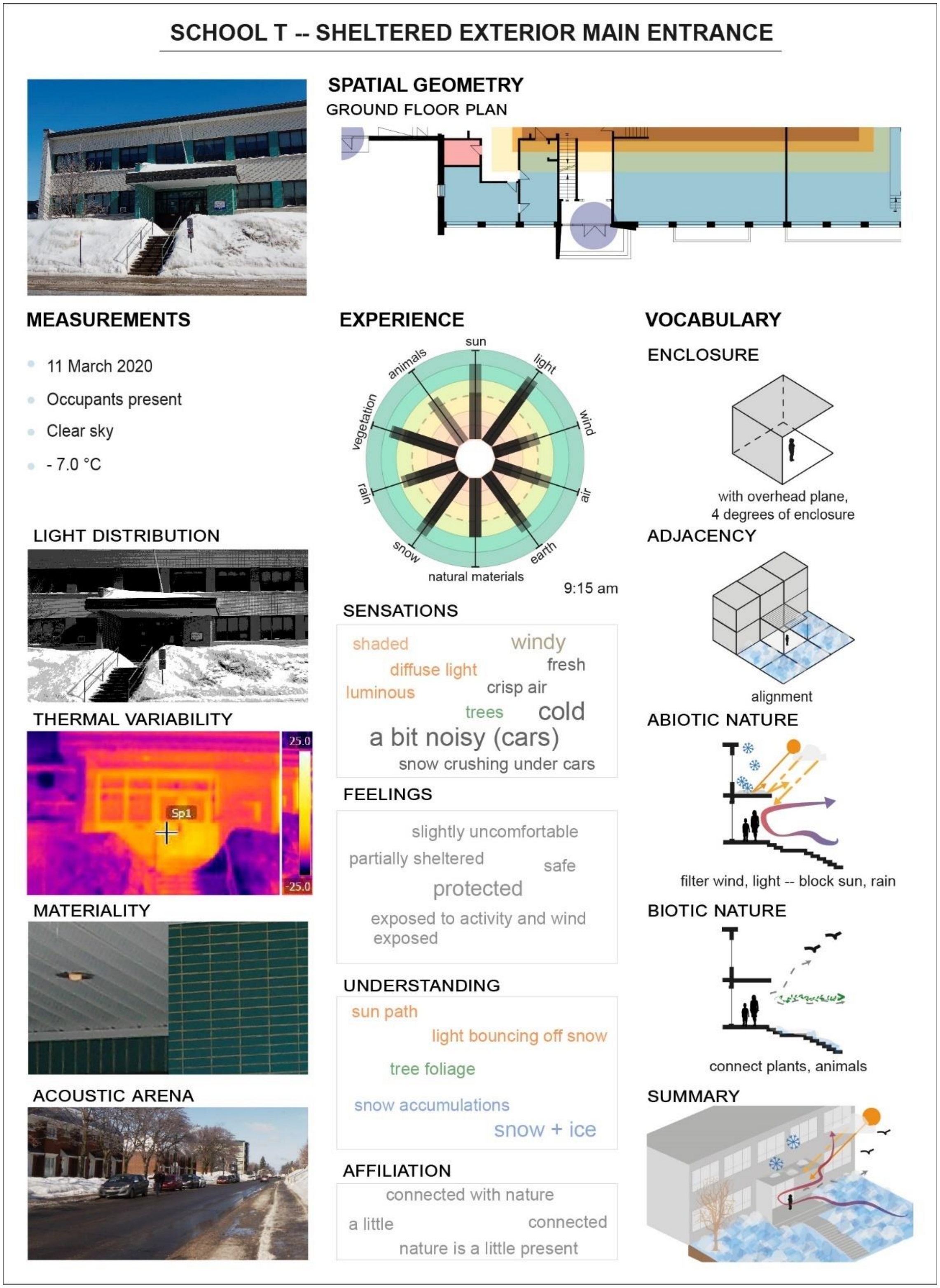


Figure 21. Example of a biophilic design assessment for the sheltered main entrance of School T during winter.

Key opportunities for the renovation of primary schools in Quebec

The findings described in this thesis provide several reflections for architects renovating primary schools in Quebec to identify the challenges and opportunities for multisensory experiences of nature. They also address the overarching objective of informing how to design schools that foster the well-being and academic success of children. The key design considerations identified in this thesis for the renovation of schools in Quebec are summarised in Table 2.

Table 2. Design challenges and opportunities for positive, yearly and multisensory experiences of nature fostering occupant well-being in Quebec schools (relevant thesis chapters in parentheses).

	Challenges	Opportunities
Climate	Increased cloud coverage, cold outdoor temperatures, reduced sunlight availability and less variety in colour, sound and smell in nature during winter (1, 3)	Snow brightens settings by reflecting light, absorbs sound based on its surface texture and blocks harsh winds when accumulated (1, 3, 5)
Neighbourhood	Undesirable noises and smells (airports, busy roads, factories) (1)	Vast natural spaces (parks, bodies of water) within walking distance (C)
Site	Solar orientation of the existing school building (4, C)	Nature surfaces and mature vegetation in the schoolyard (3, 4, 5, C)
Building	Abundant floor area more than six metres from the facade (2) Complex interior circulation with limited physical access to outdoor spaces (C)	Abundant floor area less than six metres from the facade (2) Presence of transitional spaces (1, 3, 5)
Room organisation	Regularly occupied spaces without windows (2, 3, 4)	Windows in regularly occupied spaces (2) Shared spaces facilitating occupant migration (1, 5, D)
Rooms	Classrooms deeper than wide along the facade (2, 3, 4) Low ceiling height in classrooms (2)	Classrooms wider than deep with windows along the facade (2, 3, 4)
Systems	Disruptive mechanical systems in gymnasiums and teaching spaces (3, 4)	Responsive passive design strategies enhancing occupant well-being (1, 3)
Elements	Abundant west-facing windows without functional shading devices (1, 2) Windowsill height above eye height of seated children (2, 3)	Appropriate size, placement and shading of windows (2, 3, 5) Windowsill heights offer views outside for seated children (1, 2, 3, 5)
Materiality	Overstimulation due to the diversity of colours and textures in a space (4, D)	Hands-on experiences of nature during winter via indoor plants and natural materials (1, 2, 3, 5)
People	Passive occupants incapable or unwilling to play an active role in the performance and maintenance of their school (1, 2)	Participatory students and school staff playing an active role in their quest for well-being and nature experiences (1, 3, 5)

The design challenges and opportunities discussed in the thesis reflect the availability and intensity of nature throughout the year. Many of the challenges and opportunities unique to cold climates relate to winter, a season that has been overlooked in biophilic design. As shown in Chapter 1, challenges include early sunsets reducing sunlight exposure, cloudy skies limiting direct sunlight, cold outdoor temperatures affecting natural ventilation and reduced variety in colour, sound and smell in nature during winter creating a colour monotony. However, the presence of snow offers specific opportunities to foster people's experience of nature and to connect buildings and natural systems. This was illustrated in the building walkthroughs during winter (Chapter 4). In School C, the pleasant outdoor view towards abundant trees and snow in the schoolyard could explain why a classroom that was expected to be less biophilic based on its architectural characteristics was perceived as having similar biophilic qualities to the classroom in School T which, according to the architectural drawings, should have offered more multisensory experiences of nature. Moreover, light reflections on snow can brighten outdoor and indoor settings, snow surfaces absorb sound and snow accumulations can block harsh winds. Some of the biophilic design schemas in Chapter 5 that express this idea are SEASONAL SCHOOLYARD, INTENTIONAL SNOW DRIFTING and SNOW BLANKETING. Thus, rather than an obstacle to overcome, seasonal diversity in Quebec represents an opportunity to seize to foster a variety of multisensory experiences throughout the year based on the availability, intensity and qualities of nature.

People's capability and inclination to interact and adapt their settings or activities can further transform a design challenge into a design opportunity. As discussed during the assessment of school buildings based on spatial geometry (Chapter 2) and physical traces of people's adaptive behaviour (Chapter 3), the amount of time people spend in certain spaces (such as those without windows), their activities, their capability and willingness to adjust window openings and shading devices or migrate elsewhere exemplify some of the parameters that affect their experiences of the built environment. The manner in which students and school staff shape their experience of nature is further exemplified by the biophilic design schemas OUTDOOR LEARNING, EXUVIATING TRANSFORMATION, PRIMARY FACADE, INTENTIONAL SNOW DRIFTING, HORIZONTAL VIEW, APERTURE ENGAGEMENT and HANDS-ON NATURE (Chapter 5). The presence of shared spaces, such as libraries and multipurpose rooms, can facilitate occupant migration within the building if classrooms offer a limited access to sunlight, for example. The possibility to seize this architectural opportunity is intertwined with the opportunity for students and school staff to migrate in and around the school based on their needs and desires. As suggested in Chapter 1, when students and staff can easily interact with the building based on the availability of nature, many opportunities for biophilic experiences emerge. In this sense, people's engagement towards their settings impacts the possibility of restoring or implementing bioclimatic and biophilic design strategies to create stimulating learning environments. It is therefore important for designers to recognise the important role people play in the creation of pleasant, healthy and delightful architectural settings.

The characteristics present at one building scale can exacerbate or minimise challenges and opportunities identified at other scales. While Table 2 presented per building scale the challenges and opportunities fostering well-being in Quebec schools, multiple synergies and conflicts exist among them. Renovation decisions that may at first appear to concern only a room or an element may in fact have repercussions at higher or lower scales. As illustrated in the organisation of the biophilic design schemas (Chapter 5), to make a place more coherent, designers are challenged to consider at each scale the larger context of a schema and concomitantly its constituent elements. This reflection can also be applied to the identification of challenges and opportunities in an existing school. For example, a school with large windows enabling natural ventilation (opportunity) may be negatively affected by undesirable outdoor noises and smells that can enter the indoor environment (challenge). Conversely, small schoolyards or those lacking vegetation (challenge) can benefit from city parks within walking distance (opportunity) (further discussed in Appendix C). This illustrates the importance of a holistic approach to diagnose and design school renovations.

Seizing the opportunities present in an existing school may require different levels of effort. For example, gymnasiums along exterior walls without windows, such as in School T and School C (Chapter 2, Chapter 4), could require perforating the facade to connect this space visually and physically with the schoolyard. Other challenges present in existing buildings, such as overheating in a west-facing classroom, may require more limited financial efforts and time (for example, adding or replacing shading devices that can be easily controlled by students and staff). Although less discussed in this thesis, other opportunities, such as those involving changes to interior finishes, furniture or occupant behaviours, can also positively contribute to multisensory experiences of nature during a renovation project.[14] Particularly

[14] Some of these issues were addressed by master students in interior design as part of the research project Schola.ca.

in cold climates, the incorporation of natural materials and indoor vegetation can foster experiences of nature when natural light, airflow and outdoor greenery are limited (see discussion in Chapter 1). In this sense, the biophilic design schema HANDS-ON NATURE (Chapter 5) was proposed to encourage child development and learning by touching and manipulating vegetation. In transitional spaces, such as entrance halls and corridors, incorporating plants may encourage children to learn about gardening and botany, even during winter. As shown in Chapter 3, the presence of plants in indoor spaces can serve as an indicator of abundant natural light when observed during site visits. The use of natural materials for indoor surfaces and furniture represents another interior design element that fosters experiences of nature and that can be incorporated over time in a school. Therefore, a combination of spatial, temporal, and financial considerations impacts the challenges tackled and opportunities seized during a school renovation.

Renovating primary schools to foster multisensory experiences and occupant well-being represents a collective process that involves a diversity of stakeholders. This thesis has shown that children and adults view nature differently (Chapter 1, Chapter 5, Appendix E). This is attributable to their physiological characteristics (e.g., eye height when standing or sitting) and developmental stages (e.g., understanding of complex forces and processes). Thus, the affordances school spaces offer students and school staff can lead to different experienced challenges and opportunities. Moreover, school staff using the building at different times for different activities may perceive additional challenges and opportunities that can inform renovation decisions. Some spaces used early in the day might not present any challenges; yet they can represent an obstacle to student activities later in the day (e.g., west-facing classrooms in summer) or in a different season (e.g., snow-covered basement windows). While sharing spaces effectively uses spatial resources, it may also generate challenges (as shown in the research project Schola, 2020). For instance, classrooms in which students also eat warm lunches can have lingering smells and increased temperatures when classes resume in the afternoon if inadequate natural ventilation takes places. Considering multisensory experiences in schools from the perspective of children of different ages, school staff with various responsibilities and building managers with diverse expertise offers architects renovating these schools the potential to identify new challenges, while also discovering new opportunities to foster quality learning environments.

Limits of the thesis and avenues for future research

The diagnostic and design tools developed in this thesis contain certain shortcomings, however they also offer promising pedagogical opportunities and avenues for future research. A limitation of the research method is undoubtedly the small sample size of the schools analysed. While representative of common spatial typologies in the province, all the analyses of the architectural drawings (Chapter 2) and site visits (Chapters 3) focused on a limited number of schoolyards, building configurations, classroom windows and apertures, etc. By focusing on the production of an innovative methodological framework, we favoured an approach that obtains detailed and nuanced information on most of the physical ambiances, at the detriment of a greater quantity of information which would have enabled us to assert our results more confidently and to establish a detailed portrayal of primary schools in Quebec. However, in the near future, we could use the larger sample of schools in the Schola project and take advantage of the proposed methodological framework and related tools (notably the Biophilic Experience Representation Tool detailed in Chapter 4 and the biophilic design vocabulary presented in Chapter 5) to expand this simplified assessment method based on spatial geometry to a wider audience of school buildings. Such work has begun as the diagnostic criteria presented in Chapter 2 contributed to the development of an ensemble of diagnostic tools in the research project Schola (specifically in the document "Fascicule B").

The master and doctoral architecture students who participated in the development and testing activities were all members of the *Groupe de recherche en ambiances physiques* and were therefore familiar with the concepts of biophilic architecture and physical ambiances in the built and urban environment. In the future, the use of BERT by students or professionals less familiar with these concepts would further show the effectiveness of the tool to document and bring awareness to biophilic experiences. A diagnostic activity adapted for architectural students began in the fall of 2020 as part of an undergraduate course with students who are beginning to deepen their understanding of visual, thermal, olfactory and auditory experiences. Such activities aim to continue to use the representation tool and to observe potential issues and divergent descriptions of biophilic experiences with people less familiar with the themes of BERT.

At the time of this study, a broader range of biophilic design schemas and themes for the biophilic design vocabulary (Chapter 5) was hypothesised but not explored due to time constraints. Further documentation of the experiences proposed in the description of the vocabulary and the schemas could also be undertaken. Currently, the Biophilic Experience Representation Tool (BERT) provides a simple method to begin the assessment of such experiences. Visits of spaces that include a greater diversity of biophilic design qualities than some of the spaces in Quebec schools could help refine BERT, further test the application of the vocabulary and contribute to the ensemble of biophilic design schemas.

The biophilic school renovation projects that were developed in an architectural design studio course at the University of Tennessee Knoxville confirmed the interest for designers to be able to name biophilic intentions, to have a simplified visual representation and to connect strategies throughout building scales in the preliminary design stages (Chapter 5). The schemas helped fourteen fourth year architecture students to generate school additions beyond formal, functional, technical and aesthetic considerations to embrace potential biophilic experiences for the occupants. As the applicability of the schemas was only tested in academic settings, the next step could be to determine the value and ease of use of the proposed tools for practitioners.

The pedagogical opportunities of the diagnostic and design tools developed in this thesis appear important. The simplified assessment method based on architectural drawings (Chapter 2) provides architecture students with an understanding of the key design parameters that shape the quality of the visual, thermal, olfactory and auditory environment. It combines in a single assessment various bioclimatic and biophilic design guidelines as well as building certification criteria to create a rapid comparison of design alternatives during the design process. Meanwhile, the Biophilic Experience Representation Tool (Chapter 4) helps designers to identify and describe their subjective and multisensory experiences relating to environmental features. This has the pedagogical opportunity of making architectural students aware that exceptional experiences of nature may not be required at all times in every space. The biophilic design vocabulary and schemas (Chapter 5) provide an organisational structure in teaching activities for architecture students, because the important aspects of biophilic design are identified, organised and connected. As shown during their use in the architectural design studio, the tangible concepts presented in a concise visual and textual flash card help students to understand, name and incorporate spatial ideas that can foster experiences of nature. The vocabulary and schemas could also assist professionals communicate biophilic design concepts to clients and stakeholders. Although it was not examined in this thesis, their use in a real school renovation or construction could foster the development of the knowledge and skills of the design team and school board project managers. As an ensemble, the biophilic design tools show how to create learning environments that foster delightful multisensory experiences of nature that contribute to the well-being of students and staff. In doing so, they increase environmental awareness and understanding of the natural forces and processes and the importance of people's interaction with the building to maximise experiences of nature.

The renovation of primary schools in Quebec was the focus in this thesis, yet many of the key research questions concerning biophilic design apply to other programmes. Broadly, the ensemble of diagnostic and design tools was developed with the goal of enhancing the well-being of building occupants and fostering experiences of nature in every season without compromising the sustainability goals of the building. For the Quebec school context specifically, the development and application of these tools have been successful in recognising the biophilic opportunities that exist in buildings designed with passive strategies in mind and the challenges that often appear with subsequent renovations and additions or with more recent constructions designed with a higher reliance on mechanical systems. The architectural tools developed and tested in this thesis offer a framework for further interdisciplinary research. Future work is vital to build a strong science-based foundation to continue to guide the effective selection and implementation of biophilic design principles in cold climate schools. Acknowledging and celebrating seasonal diversity in architecture as a rich opportunity for multisensory experiences of nature that positively impact children and adults represents a promising avenue to continue exploring.

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Appendix A Examination of physical ambiances and cold climates in building certification standards

This appendix focuses on building certification systems that positively influence the health and well-being of occupants. It analyses the criteria relating to physical ambiances and identifies opportunities and gaps for their application in cold climates. It further discusses the applicability of these criteria to new or renovated school buildings in Quebec.

Many building certifications can be obtained in Quebec, but the aims of these certifications differ greatly. In response to the ecological emergency to build more respectfully of the environment, many tools have emerged to accelerate the transformation of practices. Criteria relating to the quality of the indoor environment appear in most building certification standards, yet the importance of well-being criteria in these certifications differs greatly. For this reason, the certification systems selected for further analysis are the *Living Building Challenge* (LBC) and the *WELL Building Standard*[15]. LBC aims to improve the human component in building assessment systems by promoting a holistic approach. Recently, WELL proposed a rating system entirely focused on the well-being of occupants in buildings. The analysis of these systems presented here focuses on criteria relating to the visual, thermal, olfactory and auditory environment and their impacts on well-being in a cold climate.

Visual well-being

"Every regularly occupied space must have operable windows that provide access to fresh air and daylight." This Living Building Challenge criterion for the *civilised environment* imperative offers the advantage of simplicity, both for the design team and for the building occupants. However, the details to implement this design strategy are not specified in the documentation available online. The WELL Building Standard presents a more precise and detailed description of the quantity and quality of natural light to be incorporated into buildings. Figure A.1 illustrates the possible application of some of these criteria in a school environment.

The elements that contribute to visual well-being in a biophilic approach depend on the climatic context. In a northern climate, the availability, intensity and colour of sunlight as well as the strong presence of cloud cover influence the design strategies employed. Some strategies in particular call for temporal considerations. They require reaching precise amounts of light during the occupation of the building. For example, light contributing to the circadian rhythm should be present at least four hours a day, every day. Another WELL criterion aims to ensure a healthy exposure to the sun by specifying a minimum illuminance for 50% of the yearly occupancy hours. Depending on the climatic context of the project, these elements may be complex to provide. For this reason, criteria for the indoor environment that depend on the outdoor conditions, like the daylight factor, may be more

[15] Carried out in the fall of 2017, the analysis concerns the Living Building Challenge 3.1 and version Q1 2018 of the WELL Building Standard.

appropriate in extreme climates. In this sense, the minimum quantity and minimum exposure time would be adaptable to the particularities of a cold climate.

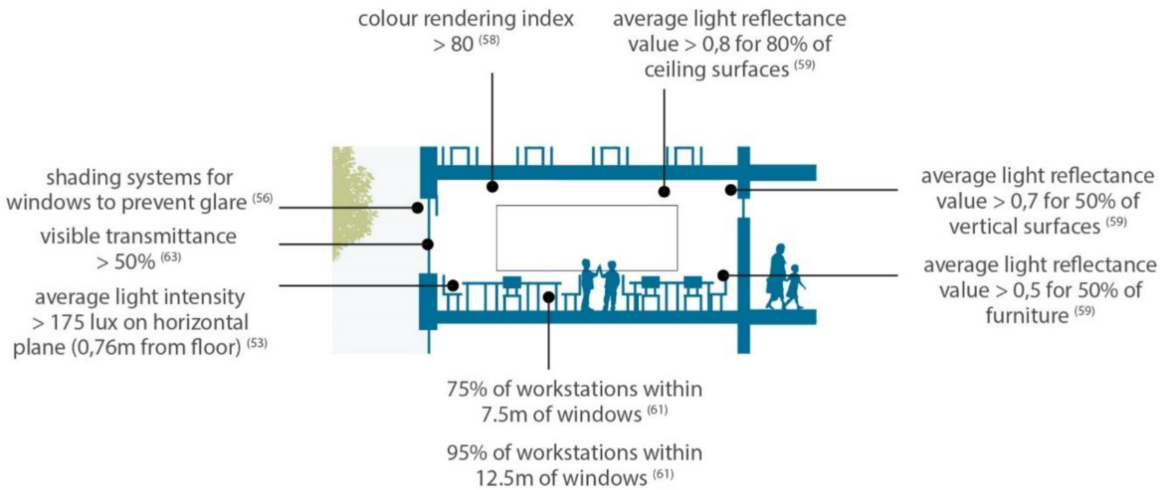


Figure A.1 Possible application of visual well-being criteria in a classroom.

Thermal well-being

Thermal well-being is briefly addressed in the two evaluation systems. While the Living Building Challenge does not seem to offer specific parameters for thermal well-being, it is expected that occupants can access a window to benefit from fresh air and light (*civilised environment* imperative). It is therefore possible to believe that occupants are encouraged to interact with windows to modulate the interior temperature, if necessary.

WELL has a limited amount of thermal performance criteria to be achieved: thermal comfort, individual thermal control and radiant thermal comfort. These criteria refer mainly to technical standards of comfort, rather than well-being, and seem to take little account of the climatic context of the architectural project. However, “climate is a basic element of the natural environment, and as such, one of the parameters of all architectural and urban design” (Culjat, 1975, p. 1). Referring to the “operable windows” criterion in the section “Air” helps to contextualise the WELL thermal recommendations.

WELL states that the presence of operable windows is encouraged if the local climatic and environmental parameters indicate very good quality of the outside air. This suggests climatic considerations, but remains imprecise due to the international approach used. WELL adds that outdoor air measurements taken by a data collection station can be used to operate windows with technological devices (smartphone, computer or indicator light on windows). Although these technological systems constitute a means of empowering occupants, they represent an additional cost for the management and maintenance of the building, while other strategies, such as education, provide occupants with knowledge that is transferable to other buildings.

According to WELL, occupants should be discouraged from opening windows if the outside temperature deviates by plus or minus 8°C from the set temperature inside. In a cold climate like Quebec, the outside temperature often differs from the desired inside temperature.

According to CIBSE (2015), the comfort temperature in winter for learning spaces is between 19 and 21°C. Considering the recommendations of CIBSE and WELL (interior temperature - 8°C), occupants should not open windows if the temperature is below 11°C. However, the outside temperature during winter in cold climates rarely exceeds the freezing point, which means that occupants should be discouraged from opening windows during this season. The applicability in a cold climate of this thermal criterion to encourage or deter occupants from opening windows should be questioned. Opening windows generates variations in the thermal environment which can be beneficial for well-being. For example, Mower (1976) indicates that pleasurable thermal sensations are best perceived when the initial body state is hot or cold, and not neutral. More recently, Arens et al. (2006) indicate that the temporary cooling of part of the body when it is hot (or temporary overheating when it is cold), is perceived as very comfortable, even without influencing the temperature of the whole body.

The thermal well-being criteria proposed by WELL and LBC could be improved for cold climates to consider the beneficial effects of thermal variations and air renewal when windows are open for a short period of time, even if the outside temperature is very cold. For example, in school environments, opening windows during recess causes thermal and olfactory variations that could be beneficial for learning when students return to their class.

Olfactory well-being

Excessively strong or distinct odours can disturb the physical and psychological comfort of occupants. WELL therefore aims to limit the transmission of intense odours within the building. In the “comfort” category, the only criterion for odour aims to prevent air from “smelly” areas of the building, such as cafeterias or toilets, from migrating into workspaces. In the “air” category, other criteria based on ASHRAE standards aim to ensure air quality by reducing odour contaminants.

To promote good air quality, the Living Building Challenge requires projects to create a *Healthy Interior Environment Plan*. This includes compliance with ASHRAE 62 as well as satisfactory results from an air quality test before and nine months after occupancy of the building. The “universal access to nature and place” imperative within the *Equity* petal states that projects must not reduce the fresh air for the building occupants or for neighbouring projects. In this sense, projects must protect adjacent properties from any harmful emissions that could compromise their ability to provide natural ventilation.

Pleasant odours are absent from both rating systems. WELL and LBC mainly present strategies to reduce unpleasant and harmful odours. WELL even states that the olfactory comfort criterion supports building policies that discourage strong odours from chemicals and fragrances, with the aim of keeping indoor environments odour-free. However, the olfactory system processes odours directly in the brain, which can trigger memories (Browning et al., 2014). Studies suggest that natural scents can positively influence the immune system and the healing process (Li et al. 2012; Kim et al. 2007). It would therefore be possible to think that pleasant smells coming from outside when the windows are open contribute to a positive experience in the building by connecting the inside and the outside.

Odours in the indoor environment also arise from occupancy. In a school context, odour issues are reported in classrooms after lunch, when hot meals are eaten. Opening windows is a simple way of removing these food smells and bringing fresh air into the room. In a cold climate, the length of time windows are open varies with the season. During winter, outdoor temperatures can greatly reduce air renewal using only open windows. It is therefore a question of balancing olfactory and thermal well-being issues.

Auditory well-being

WELL presents six criteria to promote the acoustic comfort of occupants. These mainly aim to avoid occupant distraction by reducing sound transmission. However, research suggests that exposure to natural sounds, compared to urban or office noise, accelerates physiological and psychological restoration up to 37% after exposure to psychological stress (Alvarsson et al. 2010). Natural sounds can also reduce cognitive fatigue and help motivation (Jahncke et al. 2011). No mention of pleasant sounds, such as sounds that create connections with nature, is addressed by WELL.

Exposure to loud or repetitive noise, especially in urban areas, can be a source of stress and a risk factor for health according to WELL. The “exterior noise intrusion” criterion defines a sound limit from outside to avoid occupant distraction. The “internally generated noise” criterion raises awareness of noise from electronic, mechanical, heating, ventilation and air conditioning (HVAC) systems and other noise-producing devices in buildings. The “sound masking” feature reduces acoustic disturbances in a quiet environment. However, in a school setting, a background noise is undesirable since it can interfere with teaching.

Since the auditory elements presented by LBC and WELL mainly refer to the reduction of noise pollution, biophilic auditory well-being is overlooked, especially in relation to the climatic context. However, cold climates, due to their significant seasonal variations, are conducive to sound variations. Indeed, the activities that take place outside vary from season to season. The sounds that emerge can be related to human activities (children’s voices), machines (lawn mowers, snowblowers), animal activities (birdsong) and even weather phenomena (sounds of falling rain). These non-visual elements contribute to the experience of a space by establishing a connection with the outside environment.

Summary

The Living Building Challenge and WELL Building Standard contribute to creating buildings that positively influence the health and well-being of occupants. Many of the proposed elements align with the principles of biophilic design, in particular the criteria of visual well-being that promote natural light. However, there is room for improvement, particularly for biophilic design in cold climates. The thermal criteria are modelled on standards relating to building systems and offer little opportunity for daily and seasonal variations. The olfactory criteria aim to reduce nuisances and contaminants and therefore exclude the notion of pleasant odours. The sound criteria seek to avoid the propagation of noise and thereby prevent the propagation of pleasant sounds. On the other hand, WELL encourages the presence of technological systems to control solar blinds, electric lighting, open windows, etc. These technological devices can contribute to efficient building management. Yet they can also disconnect occupants from their buildings and the natural environment by removing their means of action to create comfortable environments that contribute to their well-being.

In terms of climate, these two certification systems seem to favour an international rather than local, approach. This omits the challenges and constraints of extreme climates, especially cold climates. Several avenues exist to adapt the well-being criteria to colder climates.

- The visual criteria could be evaluated according to the sun conditions of the climatic regions. The amount of natural light and the length of exposure could depend on indoor to outdoor ratios. Like the daylight factor, visual acuity for learning, melanopic light intensity, window size, and light exposure, for example, could be assessed using local climate information.
- The thermal criteria could be improved to consider the beneficial effects of thermal variations, as advocated in the biophilic design literature. The outside temperature levels above which opening windows is undesirable should also be revised, provided that the duration of opening is considered.
- The olfactory criteria could be expanded to include the notion of pleasant smells from the outdoor environment. In addition to cooling, natural ventilation provides occupants with information on outdoor conditions and activities.
- Sound criteria, like olfactory criteria, could also consider the benefits of pleasant stimuli. Sounds participate in the non-visual connection with the natural environment and can thus generate positive effects on human well-being. While it remains important to limit noise pollution to avoid distraction for students, the criteria could be broadened to provide a greater tolerance of pleasant sounds.

Appendix B Staff perceptions of school settings in Quebec

Understanding how school staff perceive the quality of the indoor environment provides architects with a better understanding of the opportunities to seize and challenges to overcome in cold climate schools in order to enhance occupants' experiences of nature. This Appendix discusses adaptive actions and occupants' satisfaction with lighting, temperature, air quality and noise in primary schools in Quebec.

As part of the research project Schola.ca, an online survey gathered concrete and practical knowledge and perceptions from a diversity of staff members. Variations of the survey were created for nine different staff profiles: teacher, speciality teacher (e.g., arts, music), physical education teacher, provider of complementary student services (e.g., psychologist, speech therapist), in-school childcare supervisor, in-school childcare educator, school principal, administrative staff, janitor. Throughout the survey, a combination of single choice, multiple choice, semantic differential, and open-ended questions were used. The survey was approved by *Université Laval*'s Ethics Board. Invitation emails were sent in June 2018 to all the staff members in a random sample of 308 schools to voluntarily participate in the survey. The survey took place at the end of the school year in order to ask participants about their various experiences throughout the school year, including changes made to their regular workspace.

Overall, 1036 staff members from 195 schools participated. Teachers represent the staff profile with the most participants, followed by complementary student service staff, such as speech therapists and psychologists. As the survey generally required two hours to complete, the participation rate decreased and only 638 completed the survey. Nonetheless, the strength of the survey results lies in the ability to confront survey data with architectural drawings and associate participants' answers with specific rooms in the school buildings. Moreover, the survey considers a variety of staff profiles and use of the building during the day and in different seasons offering insight into annual visual, thermal, olfactory and auditory experiences. The following figures present some of the survey results for questions included in the portion of the survey titled "Daylight and comfort". A more detailed analysis of the survey is available in the *Fascicule A: Apprendre* (Schola, 2020).

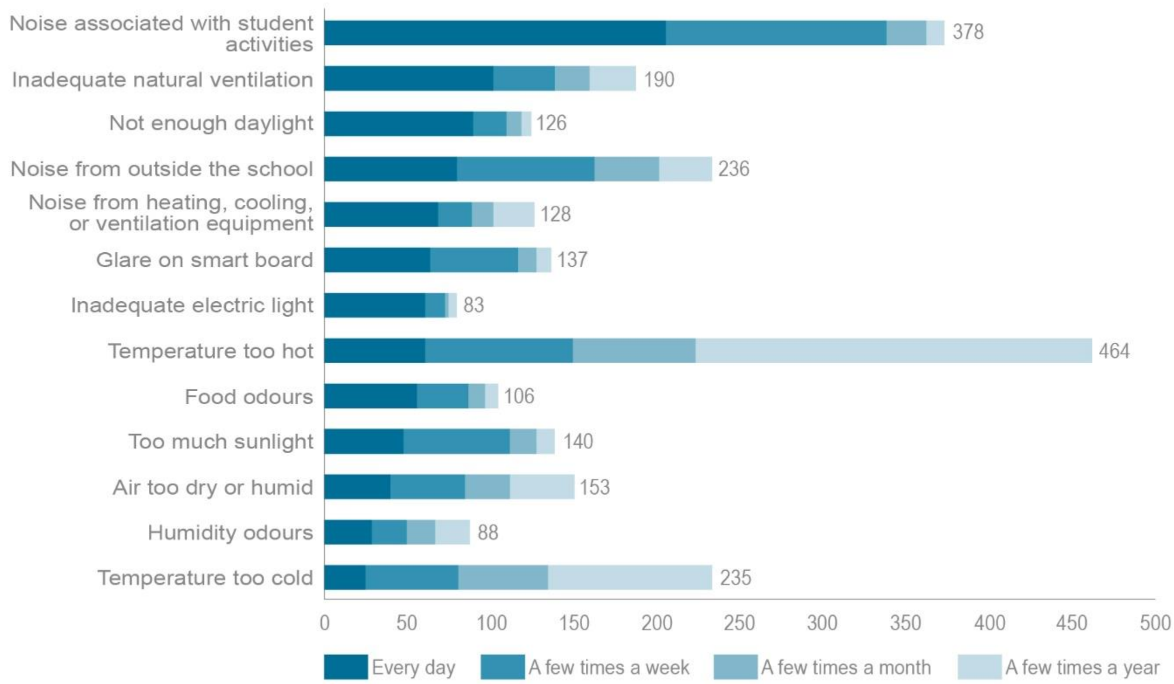


Figure B.1 Sources of discomfort encountered by school staff during the last school year (n=647). Data source: Survey Renseignez-nous!, Schola (2018).

	1	**2**	**3**
Teachers	Temperature too hot	Noise - Student activities	Noise – From outside
Speciality Teachers	Temperature too hot	Noise - Student activities	Noise – From outside
Physical Education Teachers	Noise - Student activities	Temperature too hot	Noise – From equipment
Complementary Student Services	Temperature too hot	Noise - Student activities	**Temperature** too cold
In school Childcare Providers	Temperature too hot	Noise - Student activities	Air too dry or too humid
In school Childcare Supervisor	Noise - Student activities	Temperature too hot	**Temperature** too cold
Principals	Temperature too hot	Noise - Student activities	**Temperature** too cold
Administrative Staff	Temperature too hot	Noise - Student activities	**Temperature** too cold

Figure B.2 Three main sources of discomfort for each survey profile. Data source: Survey Renseignez-nous!, Schola (2018).

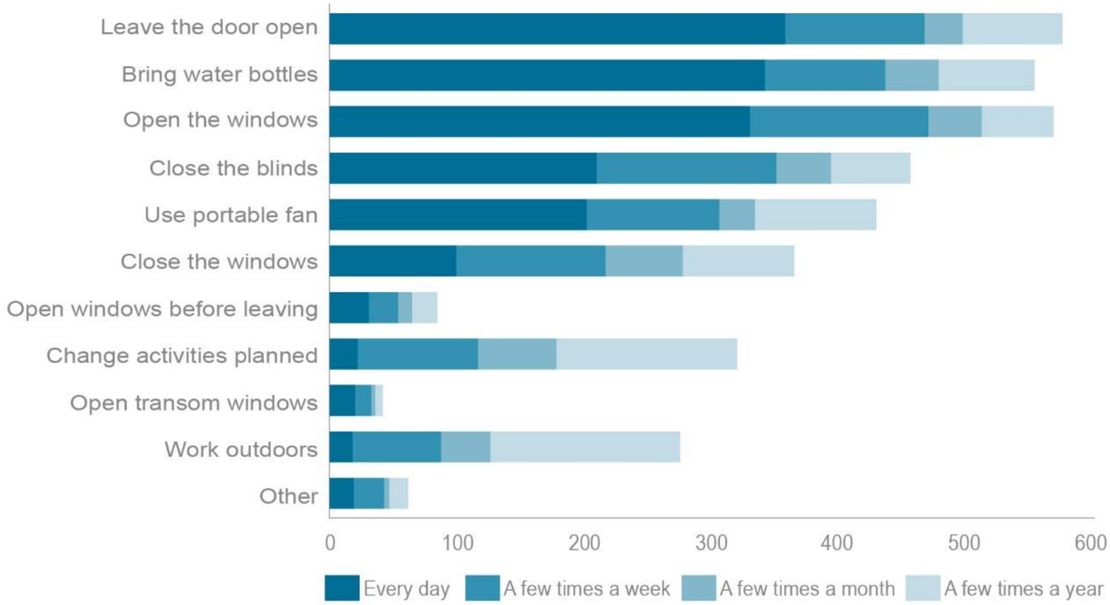


Figure B.3 Type and frequency of adaptive actions taken by school staff on hot school days. Data source: Survey Renseignez-nous!, Schola (2018).

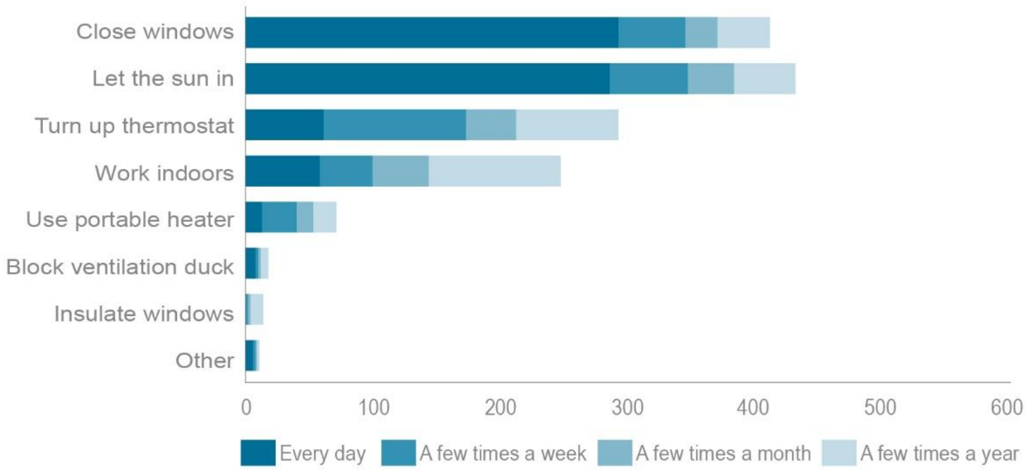


Figure B.4 Type and frequency of adaptive actions taken by school staff on cold school days. Data source: Survey Renseignez-nous!, Schola (2018).

How often do you adjust the shading devices (blinds, curtains, etc.) in your main workspace?

32.4 %	Several times a day
19.9 %	Several times a week
10.2 %	Several times a month
10.9 %	Several times a year
26.6 %	Not applicable

n=256

Figure B.5 Frequency school staff adjust shading devices. Data source: Survey Renseignez-nous!, Schola (2018).

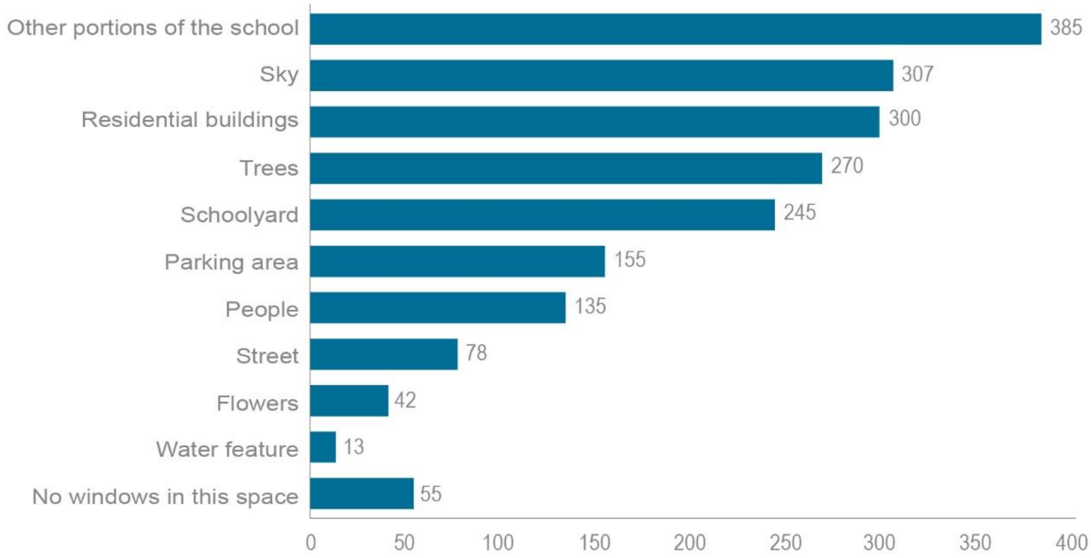


Figure B.6 Views to the outside from the main workspace of school staff. Data source: Survey Renseignez-nous!, Schola (2018).

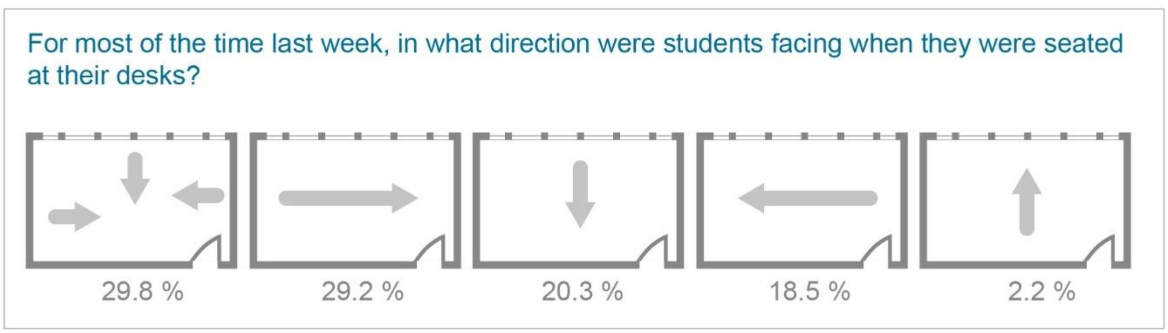


Figure B.7 Orientation of seated students in the main workspace of school staff. Data source: Survey Renseignez-nous!, Schola (2018).

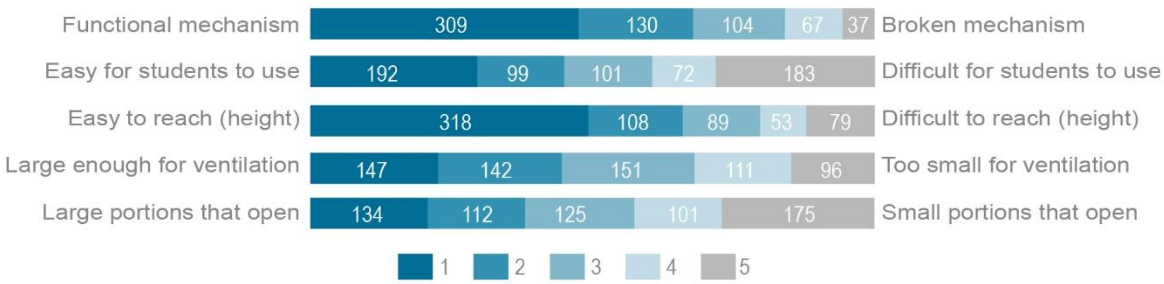


Figure B.8 Characterisation of windows in the main workspace of the school staff. Data source: Survey Renseignez-nous!, Schola (2018).

How would you characterise the transoms (window onto the corridor) in your main workspace?

71.0 %	There are none
7.5 %	There are some and they open
19.5 %	There are some, but they do not open (condemned)
0.8 %	There are some, but they do not open (broken or stuck)
1.2 %	Other

n=241

Figure B.9 Characterisation of transoms in the main workspace of the school staff. Data source: Survey Renseignez-nous!, Schola (2018).

Appendix C Additional criteria for a diagnosis using spatial geometry

The diagnosis criteria proposed in Chapter 2 to evaluate the connection with nature in schools emerged from the combination of biophilic design guidelines and building certification criteria that foster indoor-outdoor connections (Figure C.1). The geometry and envelope categories were chosen for the analysis because sufficient information is available in the architectural drawings. This appendix presents additional architectural evaluation criteria that could be used in future work for the three remaining categories: site, circulation and materiality (Table C.1).

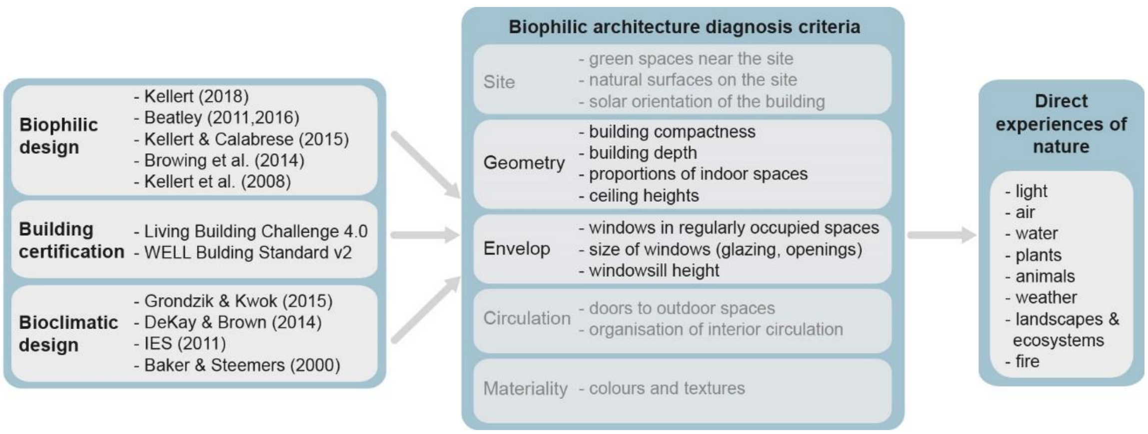


Figure C.1 Literature and research lens informing biophilic architecture diagnosis criteria.

Table C.1 Proposed diagnosis criteria and corresponding type of nature and contact.

Diagnosis criteria	Nature						Contact			
	Sun	Air	Water	Earth	Plants	Animals	See	Touch	Smell	Hear
Site										
Green spaces near the school					•		•			
Natural surfaces on the site	•	•	•	•	•	•	•	•	•	
Solar orientation of the building	•	•					•	•		
Circulation										
Doors to outdoor spaces	•	•	•				•	•	•	•
Organisation of interior circulation	•	•					•	•		
Materiality										
Colours and textures	•	•		•			•	•	•	•

Site: nature near the school

The biophilic architecture diagnosis at the scale of the site focuses on three criteria: green spaces near the school, distribution of natural and artificial surfaces in the schoolyard, and the solar orientation of the school building. Broad and complex definitions of green spaces exist (Taylor & Hochuli, 2017); in this paper, a green space constitutes a form of publicly accessible open space that is partly or completely covered with grass, trees, shrubs, or other vegetation. The presence of green spaces near the schools can describe the biophilic potential of the school neighbourhood. It represents a measurable urban feature that illustrates biophilic design ideas such as the connection with natural systems (Browning et al., 2014), landscape ecology (Kellert et al., 2008) or expanding the view of urban nature (Beatley, 2016). Research also suggests that proximity to green spaces, particularly parks, can increase physical activity (James et al., 2015).

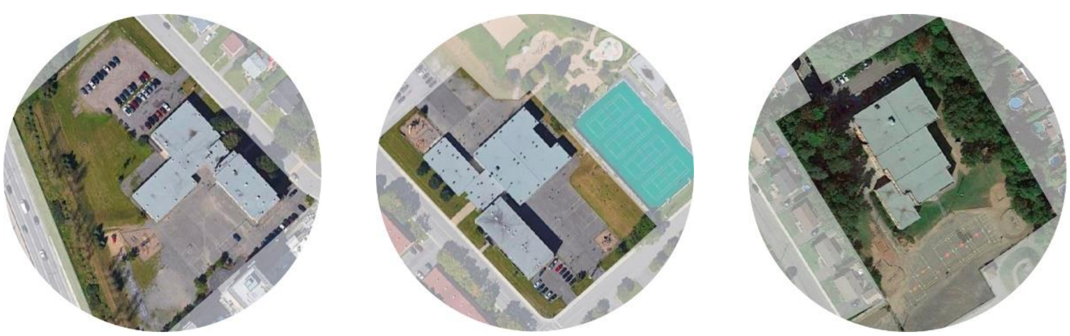
The analysis of satellite images indicates that students in Schools L, T and C can access green spaces within a walking distance of 150 metres (Figure C.2). The green space near School C is mostly covered by trees, contrary to the parks near Schools L and T with mostly mowed lawns. School T has the largest and closest green space. The three schools studied exceed the criteria of the WELL Building Standard that recommends at least one green space of more than 5000 m^2 within 300 m walking distance from the project. This quantitative analysis cannot reveal if students and school staff seize the opportunity of a nearby green space, nor can it reveal the frequency and length of time spent in nature. However, the proximity to green areas could be significant if students frequent them often to compensate for a lack of nature close to the building, such as in School T.

	School L	School T	School C

GREEN SPACES

	School L	School T	School C
Size	9600 m^2	15 600 m^2	5200 m^2
Distance	50 m	0 m	150 m
Vegetation	Grass	Grass	Trees

SITE SURFACES



	School L	School T	School C
Building	11.7%	20.8 %	13.4 %
Asphalt	47.2 %	43.1 %	27.9 %
Grass	41.1 %	36.1 %	58.7 %

Figure C.2 Green spaces near the schools and distribution of surface materials within the school sites.

The distribution of natural and artificial surfaces and the presence of trees on the site of the schools could also indicate children's daily exposure to nature. Trees in the schoolyard have been shown to increase physical activity levels during recess and increase social interactions (Arbogast et al., 2009; Coe et al., 2014; Niklasson & Sandberg, 2010). Moreover, a continual contact with trees can foster connectedness to nature, a meaningful sense of oneness with the natural world (Chawla, 2015; Kellert, 2005). In the three schools studied, between 36.1 and 58.7% of the schoolyard is covered by grass, while the proportion of asphalt varies from 27.9 to 47.2% (Figure C.2). According to the WELL Building Standard, at least 25% of the outdoor area should offer landscaped grounds, rooftop gardens or other natural elements. Schoolyards L, T and C exceed this recommendation. School C has the largest difference between grass and asphalt surfaces suggesting that this school offers children a higher level of connection with nature than the other two schools, in terms of surface materials. Schools L and T nonetheless have the potential to create more biophilic schoolyards. Nearly half of the school site is covered in asphalt whether for staff parking spaces or playground surfaces. In both cases, the schoolyard presents opportunities to increase the amount and diversity of outdoor vegetation while decreasing impervious ground surfaces. Adding schoolyard artwork to the paving could also contribute to the biophilic narrative.

The solar orientation of school buildings informs the opportunities and challenges for visual, thermal, olfactory and auditory comfort in the schoolyard. People generally underuse outdoor spaces exposed to the wind and in the shade for most of the winter, while these characteristics tend to be sought after in summer (Mazria, 1979). Providing microclimate alternatives and a range of environmental conditions provides people with adaptive opportunities. Considering the solar orientation of the site implantation of School L and School T suggests different outdoor conditions within the schoolyard (Figure C.2). In School L, the layout of the building generates a shaded zone in front of the school (north-side) while the children playing in the schoolyard oriented towards the south are fully exposed to the sun, which is more desirable in winter than summer. School T generates the opposite scenario with the building creating shaded areas in a portion of the schoolyard.

The orientation of school buildings also determines the possibilities for daylight, views and natural ventilation in indoor learning spaces. Buildings elongated in the east-west axis expose more surface area to the north and south for controlled daylighting and solar radiation (Mazria, 1979). The layout of Schools L and T are more in-line with this passive design strategy than School C. The orientation of the original constructions of School L and School T enables indoor spaces to face north-east and south-west. Classroom windows open either onto the street or the schoolyard. In both of these schools, the building additions create classrooms with a perpendicular orientation to the original buildings. The later classroom models face south-east and north-west. The compact volume of School C creates classrooms that face all four orientations which can increase the diversity of environmental features in indoor spaces. Given the constructive difficulty of modifying the existing orientation of the building, the three schools may face challenges to control daylighting and solar gain depending on the area of window glazing.

Circulations: indoor movement and physical access to the schoolyard

Interior circulation can ensure that people moving within the building have views to natural features, such as the sky, snow, or outdoor vegetation, that will promote positive experiences. As Heerwagen and Gregory suggest, “biophilic design should also take into consideration the motion of people" (2008). Interior circulation within buildings generates different formal patterns that can facilitate or complicate occupant's sense of orientation and their movements within the school and towards the schoolyard. School L, organised in an L-shaped pattern, places windows at each extremity providing natural light to a portion of the corridor as well as views outside. In School T, the space at the junction of the corridors offers doors to three different portions of the schoolyard and provides sightlines to four circulation corridors as well as a vertical connection to the second floor. Also in School T, the corridor around the gymnasium creates a U pattern, but the opaque emergency exit doors at either end prohibit any visual connection with the schoolyard. The more complex circulation in School C creates several corridors without access to natural light or views to the outside. As a result, this school has more biophilic design challenges than Schools L and T in terms of interior circulation.

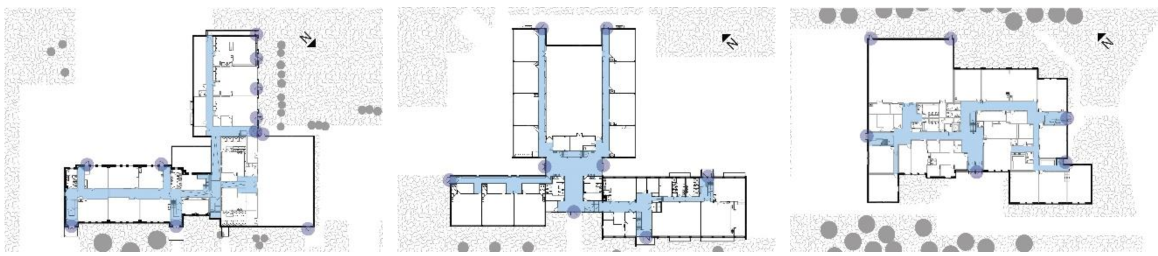


Figure C.3 Physical connection between indoor and outdoor spaces and circulation axes in School L (left), School T (middle), and School C (right).

Physical access between indoor classrooms and outdoor learning areas facilitate frequent interactions with nature, for instance by making it easy for teachers and students to play, do fieldwork and take inside activities outside (Nair, 2014). The biophilic assessment method proposes that the number of doors to the schoolyard provides a rough guide of the opportunity for physical access between indoor and outdoor spaces by students and staff. Considering the ground floor level, School L has the most doors that open onto the schoolyard (11), followed by School T with eight doors and School C with six doors (Figure C.3). School L is also the only school that provides some classrooms with direct access to the schoolyard. Both Schools L and C have two doors connecting the gymnasium to the schoolyard, creating the possibility for outdoor physical activity classes.

Materiality: colours and textures

Materials offer the potential to connect people with the earth, foster a sense of geology and emphasise the spirit of place. Growing scientific literature reports that natural materials can benefit human health and well-being (Browning et al., 2014). Similarly, coloured environments significantly affect students' learning activities and their well-being (Barrett et al., 2015; Jalil et al., 2012). Although satellite images provide some data regarding the colours and textures of outdoors surfaces (as shown in Figure C.2), the main disadvantage of analysing only architectural drawings lies in their limited ability to evaluate the colours and textures of materials of the facades and the indoor spaces. The information that accompanies architectural drawings nonetheless provides some information as to the interior finishes. Figure C.4 indicates that the classrooms in the addition of School L were built with vinyl tile floors, painted concrete block walls and acoustic tiles on the ceiling. Meanwhile, the classrooms in the original construction of School T have linoleum floors, terrazzo baseboards, plaster walls and suspended acoustic tiles. This information can provide a preliminary indication of the appearance of interior spaces. It also highlights the need for complementary methods such as site visits and post-occupancy evaluations to assess this biophilic architecture feature.

School L

ANNEXE — TABLEAU DES FINIS INTERIEURES

No.	Noms des locaux	Plancher: Ciment poli	Plancher: T. vinyle-amiante	Plancher: Tuile ceram.	Plinthe: Blocs B. vernis.	Plinthe: Beton en retrait	Plinthe: Beton poli	Plinthe: T. vinyle amiant.	Plinthe: Tuile ceram.	Dados: Bois	Dados: Blocs B. vernis.	Dados: Beton brut coffr.	Murs: Beton brut coffr.	Murs: Blocs beton	Murs: Blocs vernissés	Murs: Peint	Murs: Epoxy	Murs: Crepi ciment	Murs: Gyproc	Murs: Arborite	Murs: Contreplaqué partiel	Murs: Bois	Plafond: Beton	Plafond: Crepi ciment	Plafond: Gyproc 1/2"	Plafond: Peint	Plafond: Tuile accoustique	Plafond: Suspendu	Plafond: Pontage metal	Plafond: 2'-0" x 2'-0"
S-1	Depôt & concierge	○			non.								○	○									○							
S-2	Clinique	○	○		○			○						○		○			○				○			○				
S-3	Ch. electrique	○			non								○	○														5'-6"		○
S-4	Vestibule	○	○		○									○		○									○	○		"		
S-5	Vestiaire	○	○		○									○		○												"		○
S-6	Vestiaire	○	○		○									○		○									○	○		"		○
S-7	Vestiaire	○	○		○									○		○												"		○
S-8	Maternelle	○	○		○									○		○												"		○
S-9	Maternelle	○	○		○									○		○												"		○
S-10	Maternelle	○	○		○									○		○												"		○
S-11	Toilette	○	○		○									○		○						○						"		○
S-12	Toilette	○	○		○									○		○						○						"		○
S-13	Toilette	○	○		○									○		○						○						"		○
S-14	Maternelle	○	○		○									○		○							○			○				
S-15	Maternelle	○	○		○									○		○							○			○				
S-16	Maternelle	○	○		○									○		○							○			○				
S-17	Vestibule	○	○		○									○		○									○	○		8'-6"		
S-18	Escalier	○	○				○							○		○								non						

School T

TABLEAU DES FINIS INTERIEURS

Nos	Pieces	Plancher: Tuile ceram.	Plancher: Terrazzo	Plancher: Fini ciment	Plancher: Marboleum	Plinthe: Tuile ceram.	Plinthe: Terrazzo	Dado: Tuile	Dado: Rock wall	Mur: Platre	Plafond: Platre	Plafond: Acoustique	Plafond: Suspendu	Plafond: Tuile
101	Classe				●		●		●	●		●	●	●
102	"			●	●		●		●	●		●	●	●
103	"			●	●		●		●	●		●	●	●
104	Escalier		●				●		●	●	●		●	●
105	Classe			●	●		●		●	●		●	●	●
106	Toilette	●				●		●		●	●		●	
107	Classe			●	●		●		●	●		●	●	●
108	"			●	●		●		●	●		●	●	●
109	Passage			●	●		●		●	●		●	●	●
110	Classe			●	●		●		●	●		●	●	●
111	Escalier		●				●		●	●	●		●	
112	Classe			●	●		●		●	●		●	●	●

Figure C.4 Interior finishes for the addition of School L and the original construction of School T. Image source: Schola database, 2018.

Appendix D Additional instrumental and photographic survey results in school settings

Complementary to the findings discussed in Chapter 3, this appendix contains additional instrumental and photographic survey data gathered during the different site visits. Analyses relative to melanopic light, noise exposure, thermal comfort and energy performance in these schools were further addressed by master students in architecture, as part of the research project Schola.ca, using a combination of site measurements and simulations (Carrier, Forthcoming; Darvishi Alamdari, Forthcoming; Saavedra, Forthcoming).

Table D.1 Environmental measurements in School C.

Date	Time	Room	Illuminance (lux)					Temp.	Relative humidity	Sound level
			Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	°C	%	dBA
11 June	9:40	Library	293.8	254.7	472.5	311.0	179.4	27.0	47.0	
	10:20	Gymnasium			495.0			24.7	54.3	
	8:25	Music	611.9	329.6	397.8	712.0	579.3	23.3	52.9	
	12:40	1-064	808.9	762.3	689.5	612.1	982.5	24.5	60.3	
	12:22	1-066	236.7	460.4	318.6	272.5	348.4	23.7	69.0	
		2-125	38.3	99.3	47.2	43.5	47.8	26.4	53.3	
	9:03	2-126	373.3	629.0	843.7	706.2		26.8	49.5	
		2-219	435.2	707.9	672.8	404.3	644.1	27.1	49.2	
13 August	15:20	Outside	16710	29120	16900					
	13:55	Library	498.3	638.4	615.7					
	9:50	Gymnasium	612.5	662.4	811.8	605.9	605.9			
	9:00	Music [1]	35.0	8.5		2.7	16.9			
	9:00	Music [2]	678.0	666.9		595.2	578.4			
	10:15	1-041	29.8	12.8	17.8	558.5	9.8			
	15:20	1-063	651.5	1402.0	427.3	754.6	389.6			
	10:55	1-064	7.9	141.9	73.4	5.8	16.0			
	14:45	2-121	29.1	260.4	44.8	16.6	23.9			
	12:00	2-122	273.2	164.4	186.9	86.0	48.9			
	11:35	2-125	21.4	64.6	31.2	39.1	155.3			
	13:45	2-129	35.3	81.3	114.9	155.7	350.6			
12 March	10:45	1-046	1501.0	5930.0	756.8	696.7	772.1			19.3
		1-106	816.9		909.2					25.1
		1-129			132.5					

[1] Lights off. [2] Lights on.

Table D.2 Environmental measurements in School L.

Date	Time	Room	Illuminance (lux) Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Temp. °C	Humidity %
14 June	14:20	a-s-007	724.2	691	615	585.4	657.7	24.9	56.4
	12:20	a-2-206	952.4	1296	387.7	167.3	191.5	24.7	49.3
	12:10	a-2-207	195.5	441.8	380.8	230.3	327.1	24.6	48.1
	11:45	a-2-208	100.5	1180	249.4	108.8	94		
	11:30	a-3-301	952.6	2168	176.3	1102	1238	26.2	48.4
	11:05	a-3-308	195.7	713.2	21.7	174	132.5	25.1	51.4
	10:45	a-4-409	722.7	165.9	31.5	645	373.9	25.8	
	15:15	Library	100	843.6	136.4	30.4	52.3	24.7	42.1
	15:00	b-1-131	781.6	696.9	754.1	574.9	600.6	25.3	49.8
	14:25	b-1-132	552	872	751.5	690.3	469.1	25.4	49.7
4 July	15:20	a-s-001	1082	1977	1068	507	649	25.9	47.2
	14:35	a-s-007	791.6	2336	1072	604.6	472.2	25.4	55.6
	14:26	a-s-014						25.7	52.8
	14:25	a-s-015	23.5	19.6	27.6	22.9	28.2	24.2	47.1
	14:20	a-s-016	87.1	106.5	68.3	56.2	24.2	24.8	52.1
	13:33	a-1-109						23.8	53.1
	12:30	a-3-301	386.8	440.1	721.2	1709	396.7	27	48.7
	12:10	a-3-305	368.7	2085	520.5	443.6	406.7	27.1	48.5
	11:40	a-3-306	109.5	109.5	93	83.2	69.5	27	46.9
	11:25	a-3-308	398.4	837	469.1	293.6	299.1	27.2	46.3
	11:10	a-3-309	499	1561	945	398.6	701.2	27.1	49.7
	9:27	a-4-402						26.9	46.3
	9:28	a-4-404						26.9	45.9
	9:55	a-4-405	346.7	828.9	655.5	197.9	323.6	26.9	47.2
	9:29	a-4-406						26.9	47.9
	9:40	a-4-407	443.4	1374	513.3	405.4	392.8	26.8	48.6
	9:45	a-4-408	241.3	1222	430.9	197.8	484.9	26.8	51
	9:35	a-4-409	435.8	1102	745.8	405.6	476.7	26.7	49.3
	9:50	a-4-410	54.8	271.4		44	158.7	26.8	49.2
	12:30	Gymnasium [1]	49.4	24.6	22	20.7	29.7		
	12:30	Gymnasium [2]	786.8	757.1	915.7		766		
	15:30	b-1-115	66.2	168.6	123.3	65.5	133.5		
	12:30	Outside	97750	94380	96340	96960			
	11:25	Corridor [3]	52.4	22.1	384.1				
	11:25	Corridor [4]	70	21.6	82.5				
	11:25	Corridor [5]	151.3	54	26.3				

1 Lights off. 2 Lights on. 3 Third floor corridor. 4 Fourth floor corridor, lights off. 5 Fourth floor corridor, lights on.

Table D.3 Environmental measurements in School T.

Date	Time	Room	Illuminance (lux)					Temp.	Relative humidity	Sound level
			Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	°C	%	dBA
16 Nov.	15:05	Outside	8190	16200	19000					
	12:15	107	250.0	1250.0	300.0	95.0	295.0	23.0	41.0	21.0
	12:30	110	120.0	1120.0	184.0	75.0	141.0	24.4	38.6	
	10:05	222	350.0	878.0	380.0	170.0	410.0	21.0	41.0	20.0
	9:45	223	339.0	856.0	370.0	194.0	250.0	21.0	45.0	20.0
10 June	14:15	Outside [1]	5545.0							
	14:25	Outside [2]	8849.0					33.7	25.0	
	14:45	Outside [3]	9140.0					32.9	27.4	
	12:45	Library	453.7	551.9	663.4	583.9	398.7	25.7	38.7	
	11:30	112	104.0	464.1	193.9	165.0	158.3			
	12:10	212	199.6	487.8	208.2	166.2	336.1			
	15:20	221	506.2	974.5	764.9	506.5	742.3	29.1	40.7	
	10:35	226	331.4	714.0	363.0	370.9	213.0			
11 March		221		1082.0	729.6		753.2			
		Corridor [4]								39.5

[1] Facing south-west. [2] Facing north-east. [3] Facing north-west. [4] In front of classroom 221.

Materiality: visual complexity, light uniformity and sound absorption

A variety of interior finishes was observed throughout the three schools. Materials offer the potential to connect people with the earth, foster a sense of geology and emphasise the spirit of place. In School C, the painted cinder block or brick walls were complemented by wooden furniture or storage units in the classrooms. Acoustic ceiling tiles were present in classrooms in School C and School L, perhaps in response to the abundance of reflective surfaces. The surfaces in the classrooms in the addition of School T show the most diversity in terms of colour and type of interior finish.

Figure D.1 Photographs of material textures in a typical classroom in School L (left), School T (centre) and School C (right).

Figure D.2 Visiting School L during the school year and during the summer holidays revealed differences between occupied and unoccupied classrooms.

Migration strategies fostering comfort and nature experiences

Shared spaces, such as libraries, represent a potential space to migrate to during learning activities. The discussion in Chapter 2 raised the possibility for students and school staff to migrate to spaces offering experiences of nature if their regularly occupied classroom only offers limited opportunities to experience nature (for example, small windows or the presence of obstacles outside limiting access to daylight). The libraries in School L and School T offer more diverse sensory experiences than the library in School C. In School L, the library is located on the ground floor and has a door enabling students and staff to access the schoolyard (Figure D.3, left). The reading zones are located near the windows which can be accessed by students to naturally ventilate the space. The library in School T also has a large glazing area and operable windows. However, the height of the space and the windows makes it more difficult for students and staff to adjust them to their desired connection with the outdoor environment (Figure D.3, centre).

Figure D.3 Libraries in School L (left), School T (centre) and School C (right).

The light colours of the walls in the School T library distribute light throughout the space and the nature inspired decoration of the reading corner illustrates a symbolic reference to nature (pattern "biomorphic forms and patterns in Browning et al., 2014). Contrary to School L and School T, the library in School C is located in the core of the building and has no windows or skylights to the outside. While this space has windows to the corridors, the stacks placed in front of them limit the visual connection with the surrounding spaces (Figure D.3, right). Thus, the shared spaces in a school may not always offer more direct experiences of the outdoor climate (such as sun, wind and snow) than the classrooms. This suggests the importance of considering indirect experiences of nature (as defined by Browning et al., 2014; Kellert & Calabrese, 2015) via natural materials, images of nature or plants in addition to experiences of sun, wind and snow.

Quality views from classroom windows

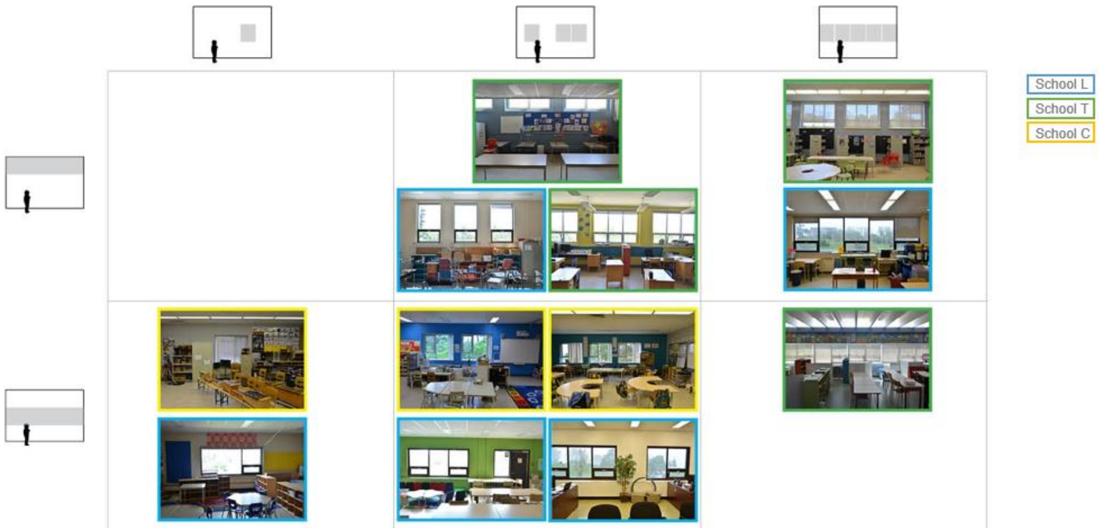


Figure D.4 Classroom windows for daylighting and thermal variability in the three schools.

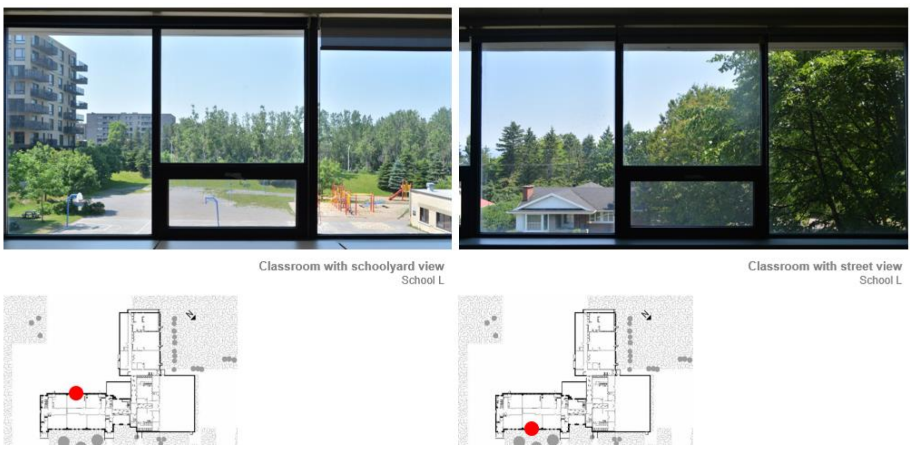


Figure D.5 Diversity of classroom views in School L.

Figure D.6 Obstacles in the field of view from classrooms in School T.

Biophilic and bioclimatic potential of schoolyard surfaces

Site visits during different seasons confirmed that the schoolyard of School C offers a higher variety of potential biophilic experiences than School L and School T. The analysis of the site plans of the three schools (Appendix C) indicated that School C presents more abundant vegetation and less asphalt surfaces than the other schools. However, the site visits revealed that both School C and School L have outdoor seating areas enabling students and school staff to take learning activities outside or to enjoy outdoor meals during warmer months of the year (Figure D.7a and b).

Figure D.7 Schoolyard settings as potential extensions of the learning environment (a) School C outdoor classroom (b) School L outdoor learning and eating area. (c) School L vegetative hill as sound barrier (d) School C surrounded by abundant vegetation (e) School C covered in snow with vegetation marking seasonal processes (f) School T asphalt covered play surfaces (g) School T snow removed to expose asphalt surfaces.

The topography of the School L schoolyard is also designed to act as a sound barrier between the school building and a highway. As this hill is covered in grass and trees, it contributes to the presence of vegetation in the field of view while reducing outdoor temperatures (Figure D.7c). Of the three schools, asphalt surfaces were most abundant in School T while School C offered the most mature vegetation in the schoolyard. Visits during winter revealed that School C continues to offer biophilic experiences as snow naturally accumulates in large portions of the schoolyard and around the tall trees (Figure D.7d and e). Thus, the schoolyard of this school may be perceived as more biophilic during winter as snow covers the asphalt surfaces.[16] On the contrary, School T continues to offer fewer biophilic opportunities during winter as machinery is used to move the snow to portions of the schoolyard, exposing the asphalt below (Figure D.7f and g) rather than natural occurring snow accumulations.

Complementing analyses based on spatial geometry

The site visits revealed differences between the architectural drawings provided by the school boards and the current state of School L, School T and School C. This suggests that certain potential opportunities or challenges for multisensory experiences of nature identified in Chapter 2 may not exist, or no longer exist. For example, in School L, the analysis based on spatial geometry showed that many classrooms in the building addition have doors to the schoolyard. This direct physical to the schoolyard from the classrooms could facilitate outdoor learning in warmer months. However, the site visits revealed that the School L addition has been rented to various organisations for the past few years due to reduced student numbers. Only one space in this addition serves as the school library (Figure D.8).

Figure D.8 Classrooms with direct physical access to the schoolyard facilitating outdoor learning. (a) Exterior view of the two-storey addition with doors to the outside on the ground floor (b) Library with direct physical access to the schoolyard (c) Classroom space rented by exterior organisation.

The site visits also made it possible to validate certain assumptions made in the development of the assessment method based on spatial geometry. For example, given the longevity of school buildings, the notion of "regularly occupied spaces" included rooms in which children or staff could spend most of their school day, such as classrooms, gymnasiums, libraries, child-service offices and administrative offices. As the repeated site visits took place over different school years, it was possible to observe changes in room use. In School T, for instance, the computer room (Summer 2019) became a regularly occupied classroom as student numbers increased the following year (Winter 2020). This confirms the reasoning used in Chapter 2 to study spaces with and without windows not only based on their current use but their potential to become regularly occupied rooms.

[16] The perception of the biophilic qualities of these school settings is further explored in Chapter 4.

Appendix E An integrated approach to biophilic experiences: New frameworks explored through school architecture

This appendix presents the article "An integrated approach to biophilic experiences: New frameworks explored through school architecture" by Mélanie Watchman, Mark DeKay, Claude M. H. Demers and André Potvin. It describes a portion of the work conducted during a research semester at the University of Tennessee, Knoxville. The model of biophilic experiences developed in this article was integrated (as textual fields) in the Biophilic Experience Representation Tool (BERT) presented in Chapter 4.

Résumé

Malgré les développements de la recherche sur le design biophilique et ses avantages pour les enfants, de nombreuses questions demeurent. Qu'est-ce qu'une expérience biophilique ? Comment les enfants vivent-ils la nature en milieu scolaire ? En quoi une expérience de la nature diffère-t-elle d'une expérience architecturale ? Une analyse de la littérature révèle le besoin d'une meilleure compréhension, en termes architecturaux, de l'expérience biophilique. Grâce aux expériences dans les environnements des enfants, cet article développe une réflexion théorique pour mieux comprendre le design biophilique. Nous examinons comment les stades de développement des enfants créent une occasion pour décrire les expériences de la nature. Nous développons un modèle exploratoire pour décrire les expériences biophiliques en matière de sensations, émotions, compréhension et affiliation à la nature. Enfin, nous discutons des implications de valoriser les expériences subjectives de la nature dans la conception architecturale.

Abstract

Despite growing literature on biophilic design and the benefits of nature for children, many important questions remain. What constitutes a biophilic experience? How do children experience nature in school settings? How does an experience of nature differ from an architectural experience? An examination of the literature reveals a need for a better understanding, in architectural terms, of the mood, emotion, experience that biophilic design creates for people. This paper develops a theoretical reflection that explores a new way of understanding biophilic design with a focus on experiences in children's environments. We examine how children's developmental stages create an opportunity to better understand and describe experiences of nature. We further identify gaps in the biophilic literature and show the potential to enrich subjective assessments of biophilic design using an integral approach. We develop an exploratory model to emphasise the descriptions of biophilic experiences through sensation, affect, understanding and affiliation with nature. Finally, we discuss the implications of emphasising the subjective experiences of nature in architectural design.

Introduction

Primary school children generally spend a third of their day at school, where most of their learning activities occur indoors. Children interact less with nature today than previous generations did (Clements, 2004; Louv, 2005; Soga & Gaston, 2016). This growing disconnection from nature, or "extinction of experience" (Pyle, 1978), is concerning because a direct interaction with nature offers multiple health and well-being benefits for children (Beatley, 2011; Chawla, 2015; Gill, 2014; Kahn & Kellert, 2002). It also positively impacts children's cognitive functions and academic success (Bakir-Demir et al., 2019; Brussoni et al., 2017; Dadvand et al., 2015; Faber Taylor & Kuo, 2006; Heschong-Mahone Group, 2003; Ulset et al., 2017; Wells, 2000). Moreover, experiences of nature have been shown to influence people's pro-environmental attitudes and behaviours later in life (Chawla, 2007; Collado et al., 2015; Jensen & Olsen, 2019; Rosa & Collado, 2019). Two major factors facilitate a disconnection from nature: loss of opportunity to interact with nature (e.g., low quantity or quality of nature sites, over-scheduling of children's time) and loss of orientation towards engaging with nature (e.g., less interest for outdoor activities, increased screen time) (Soga & Gaston, 2016). From an architectural perspective, biophilic design has shown the possibility to increase people's opportunities to interact with nature. Biophilic design represents a deliberate attempt to translate the people's innate affinity for nature into the creation of the built environment through the integration of natural elements (Browning et al., 2014; Kellert, 2018; Kellert et al., 2008). Despite growing interest in biophilia from practitioners and researchers across design fields, biophilic design remains an ambiguous notion, at least in terms of experiences of nature. The paper therefore proposes a theoretical reflection to respond to the questions: What constitutes a biophilic experience? How does an experience of nature differ from an architectural experience? Which design decisions foster experiences of nature?

An experience can be defined as "the process of getting knowledge or skill from doing, seeing, or feeling things" or "something that happens to you that affects how you feel" ("Experience", 2020). In their notion of experience of nature, Clayton et al. (2017) explain how this wide-ranging and complex process is embedded in social and cultural contexts. They further argue that experiences of nature are being transformed, rather than extinguished, along with changes in society. Similarly, Crowley (2013) showed that various cultural, ecological and social factors influence the conceptualisation of "loving nature". Thus, reflections on biophilic experiences can be nourished by scholarship from diverse fields, such as psychology, human biology, sociology, climatology and philosophy. In this paper, we propose a framework that captures biophilic experiences from an architectural perspective. As most of human life is lived indoors, buildings become the way nature is or is not experienced most of the time. Particularly in regions where the climate is harsh and seasonally diverse, buildings mediate experiences of nature and can either reduce or enhance people's enjoyment and appreciation of nature in regularly occupied buildings, such as schools.

In the aim of providing a better understanding of biophilic experiences in architecture, we begin with an examination children's developmental stages and their influence on adulthood experiences. We further use an integral approach (Wilber, 2000) to identify gaps in the biophilic literature and show the potential to enrich subjective assessments of biophilic design. Then, we propose an exploratory model relating to the description of biophilic experiences via nested levels of sensation, affect, understanding and affiliation. Finally, we reflect on the implications of emphasising the subjective experiences of nature in the architectural design of primary schools.

Methodology

Two main research questions structured our examination of the literature and proposal of a theoretical model describing biophilic experiences.

- What are the key theories concerning child developmental stages and attitudes to nature that may impact their experience of nature in primary school?
- What are the emerging concepts and descriptions of experiences of nature that are articulated in the biophilic design literature?

The first question aims to understand children's appreciation and understanding of nature in the built environment by examining publications by key authors who have defined stages of child development and environmental values. The second question is designed to identify concepts and descriptions of experiences of nature which may inform architects' understanding of biophilic experiences and ultimately, their design decisions that shape children's learning environments. We used a combined database search strategy and selected relevant publications based on titles, abstracts, keywords and research questions. We began with a database search using Web of Science, Google Scholar and Scopus and keyword combinations including nature, biophilia, biophilic design, experiences, child, child development and school. Based on the publications obtained, we reviewed the references to find additional literature of interest for the research questions. Using an integral approach (DeKay, 2011; Wilber, 2000), this existing knowledge on biophilic experiences was critically examined and organised to emphasise the potential to enrich subjective assessments. Then, building on these experiential descriptors, we developed an exploratory model to better understand and describe biophilic experiences before discussing its implications for the architectural design of children's learning environments.

Child developmental stages and attitudes to nature

Primary schools with children at different developmental stages and levels of understanding of nature and natural processes offers a rich context to study biophilic experiences. "Children progress from *exploring* the world around them, to trying to *manipulate* it, physically, socially and emotionally" (Day, 2007, p. 17). They begin to *use* their environment as awareness of the physical world and the capacity for cause-effect rationality increases. As Kellert remarks (2008, p. 4), biophilia is "is reliant on adequate learning, experience and sociocultural support for it to become functionally robust". Successful learning has been shown to occur through self-discovery and hands-on, interactive play (Bergen, 1998; Copple & Bredekamp, 2008; Piaget, 1952). Particularly in the case of learning environments, "buildings that invite participation can help students acquire knowledge, discipline, and useful skills that cannot be acquired other than by doing" (Orr, 1993). While multiple studies consider adults' connectedness to nature and pro-environmental behaviour, research indicates that experiencing nature during childhood can have profound benefits given children's cognitive plasticity and vulnerability (Wells & Evans, 2003). Early experiences with the natural world can foster a sense of wonder and the development of imagination (Cobb, 1977; Louv, 2005). These experiences can also positively contribute to children's cognitive development by improving language and collaborative skills (A. F. Taylor et al., 1998) and awareness, reasoning and observational skills (Pyle, 2002). Although the desirable outcomes of biophilic settings for children are increasingly documented, biophilic design guidelines do not distinguish environments for adults and children. This makes it impossible to discern which biophilic experiences architects should encourage for different age groups of schoolchildren.

Nature connotes many settings and may be viewed differently by children of various ages. As Kaplan and Kaplan (1989, p. 3) remark, "It is clear that whereas the concept of nature is very much part of the human experience, the language for discussing it is neither rich nor precise". Building on descriptions of nature from Kellert (2018, p. 5), Beatley (2016, p. 13), Browning et al. (2014, p. 9), Chawla (2002, p. 200) and Kaplan and Kaplan (1989, p. 2), biophilic experiences can include ways of experiencing natural forces (such as light, wind and water) and ways to be in contact with living organisms (such as animals and plants). Experiences of these elements can occur in a steady state and/or with daily, seasonal and annual variations. Varying degrees of complexity can also be found in nature, gradually increasing from natural forces to living organisms to living systems (such as landscapes and ecosystems) (Figure E.1). Definitions of nature have also changed through time with research questions and methods. While ethnographic research in the 1970s considered nature as a rich sensory field, nature became an abstraction that can be quantified when the shift to experimental, quasi-experimental, and correlational methods began in the 1990s (Chawla, 2015). Technology is also increasingly transforming experiences of nature through standardised and managed virtual representations and reduced sensory richness (M.-X. A. Truong & Clayton, 2020). This suggests the importance of identifying the most pleasurable and fulfilling components of nature that designers can deploy carefully to create spaces that foster biophilic experiences, particularly for children at different developmental stages.

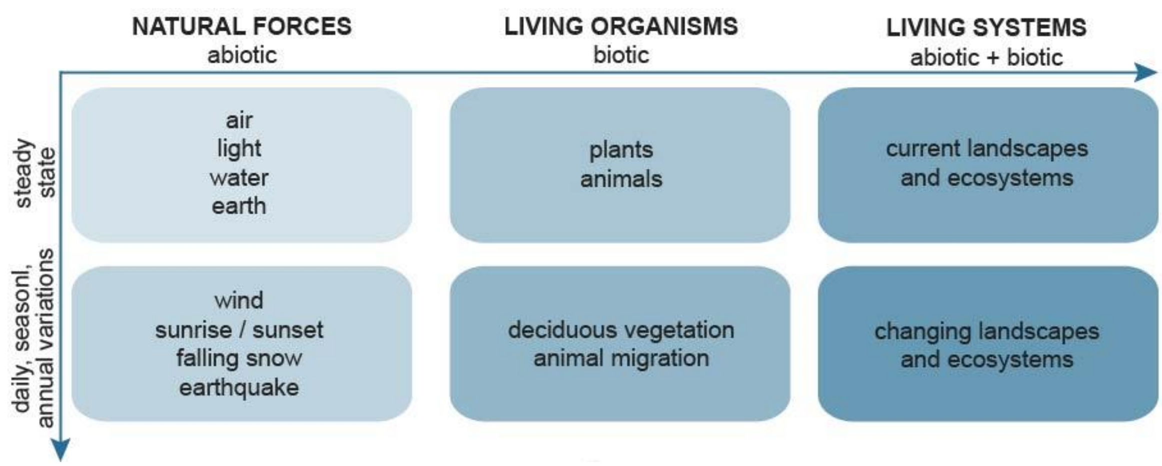


Figure E.1 Complexities in nature, from energy and matter to organisms in their environment.

Multiple lines of child development, such as cognitive, affective, ethical and spatial, may influence how schoolchildren experience nature. Ken Wilber (2000) identifies cognitive development as a precondition for other related lines of development. Based on psychologist Jean Piaget's (1972) stages of cognitive development, primary school children typically begin in the *preoperational* stage, which consists of thinking dominated by perception (4–7 years). Then their thinking becomes more organised and logical while remaining concrete in the stage of *concrete operations* (7–12 years) before entering the *formal operational* stage. In *Spots of Time: Manifold Ways of Being in Nature in Childhood*, Chawla (2002) describes how primary school children typically experience three of philosopher Jean Gebser's (1985) forms of consciousness. The *archaic* level concerns a child's immediate physical experience and is exemplified in activities such as climbing trees, rolling down hills and squatting in mud and water. The *magical* stage helps children develop a silent intuition of the world's power and of their power. At this stage, children are fully immersed in nature. The *mythic* level involves language and symbol. Notions of time appear as does the sense of a group experience and identity. This later leads to the *rational* and *integral* stages. Developmental psychologist Robert Kegan's theory (1994) defines five *orders of consciousness*, which are sequential developmental stages of mental organisation that affect thinking, feeling and relating to self and others. His *second order* of consciousness (the "instrumental mind") generally applies to primary school children who tend to be motivated solely by their individual needs, interests and desires. Children's attitudes to nature may also influence how they perceive biophilic design. In terms of children's development of environmental values and their environmental education, Sobel (1996) and Kellert (2005) identify three basic stages with specific objectives. *Empathy* between the child and the natural world develops during early childhood (ages 3–4 to 7). *Creating bonds* with the earth generally develops in middle grade school (ages 7 to 11). Finally, *social action* contributes to the development of environmental preservation attitudes during adolescence (ages 12 to 17). Kellert (2005) also suggests that the maturation of children's values of nature occurs in three major stages. Humanistic, symbolic and aesthetic values tend to develop during primary school years (roughly ages 6 to 12) as "the child forms basic ideas about nature and gains a rudimentary empirical understanding of the natural world". Figure E.2 aligns the developmental stages and maturation of environmental values proposed by these authors; the patterns revealed have significant implications for architects designing biophilic settings for children.

Age	**Piaget** (1972) *Cognitive line*	**Gebser** (1985) *Structures of consciousness*	**Kegan** (1994) *Orders of consciousness*	**Sobel** (1996) & **Kellert** (2005) *Child environmental values*	**Kellert** (2005) *Values of nature*
0 1	Sensorimotor	Archaic			Utilitarian, doministic, negativistic
2 3	Preoperational (symbolic)		1st Impulsive Mind		
4 5 6	Preoperational (conceptual)	Magic		Empathy	
7 8 9 10 11	Concrete operational	Mythic	2nd Instrumental Mind	Exploration	Humanistic, symbolic, aesthetic
12 13 14 15 16 17	Formal operational	Rational	3rd Socialised Mind	Social action	Ecological, moralistic, naturalistic

Figure E.2 Developmental stages and environmental values from early childhood to adolescence proposed by different authors.

Developmental stages can logically influence design decisions that aim to foster experiences of nature. A simple appreciation of natural forces in early life is essential for the development of later life competencies such as deep affiliation that may lead to activism in service to nature. Specifically, the complexities of ecosystems, while they may be present in their world, cannot be understood by primary school children, having not developed cognitively to Kegan’s third or fourth order. For primary school buildings, this suggests that designs build up from the fundamental levels first and focus mostly on pre-rational experiences. At these fundamental levels, children perceive the tangible physical and living environments characteristic of the concrete design realm. Thus, the organisation of biophilic experiences could be expressed on a spectrum from simplex experiences (e.g., identifying animals and developing a sense of empathy towards them) to complex experiences (e.g., sense of oneness with the natural environment). Children will engage and understand the more complex elements as they develop, a theme that is explored in subsequent sections of this paper. By doing so, it paces architecture, along with its physical and experienced relations with natural elements, as a foundation for the entire life stages of an individual.

Articulation of ideas of nature

Ideas of nature and how people are connected to nature appear deeply and tacitly embedded within biophilic literature. Providing more tangible articulations for the nature of nature could enhance the understanding and integration of biophilia in the design process. Using the Integral Model to examine biophilic design offers insights into the multifaceted experiences of nature that designers can foster in architecture. Integral Theory (Wilber, 2000) suggests that human knowledge and experience can be understood using a four-quadrant grid along the axes of individual and collective phenomena and objective and subjective ways of knowing. Each quadrant in Figure E.3 represents a fundamental perspective on human knowledge and uses different methods, reveals phenomena differently and employs different criteria for value. Viewing sustainable design through an integral lens, DeKay (2011) terms these four perspectives as *experiences* (self and consciousness), *behaviours* (science, mechanics and performance), *cultures* (meaning, worldviews and symbolism) and *systems* (social and natural ecologies and contexts). In the context of biophilic design, perhaps the most important gap is the missing linkages among experiences (*philia*), natural elements (*bio*), spatial configurations and natural contexts (*eco*) via operative shared understandings of nature (*storge*) (Figure E.3). Building on the Greek definitions, *philia* means friendship, a strong bond, the love between friends while *storge* is the fondness, empathy, affection that grows from familiarity (such as love for one’s country). In biophilic design, this corresponds to subjective experiences of nature at an individual or collective level. Meanwhile, the natural elements (*bio*) and contexts (*eco*) that foster this fondness and friendship reflect more tangible, measurable components of the equation that architects can deploy.

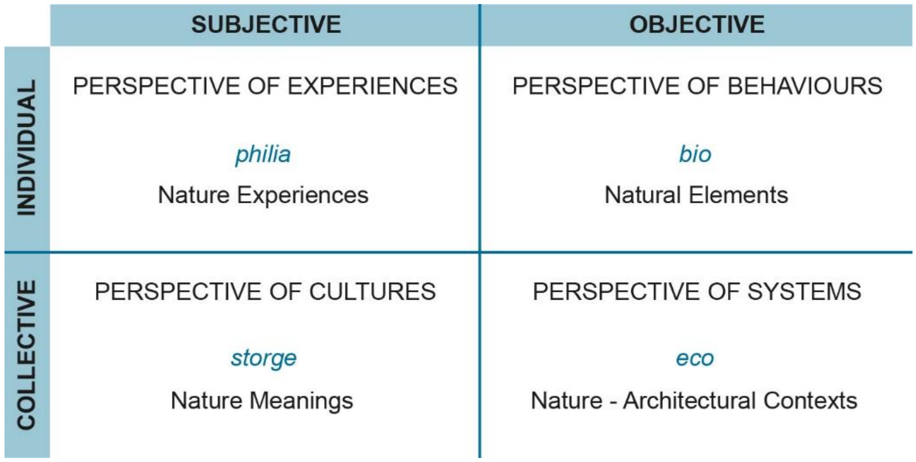


Figure E.3 Mapping of philia, bio, eco and storge within the Integral Theory quadrants articulated by Wilber (2000) and perspectives as termed by DeKay (2011).

Figure E.4 compiles biophilic design strategies, patterns and principles from selected publications in each of the four quadrants, revealing a similar gap. The analysis reveals more objective than subjective biophilic design elements and more individual than collective elements. Most of the literature takes the behaviours perspective (individual-objective quadrant). In contrast, the cultures perspective (collective-subjective quadrant) appears underdeveloped by biophilic researchers. Most of the literature does not offer a clear explanation of what "nature" means, an idea that when present is expressed from the perspective of cultures. For example, a modernist view might be that of "nature as resources", while a more postmodern view can be understood as one of "nature as a community, the web-of-life." Yet some research (such as prospect-refuge theory) refers to human evolutionary development when nature might have been considered as wilderness, as a (or "the") garden (DeKay, 2011). One explanation for the missing critical perspective could be that particular ideas of nature and of connection to nature are tacitly accepted by proponents or are too deeply embedded in biophilic literature. The clear articulation of biophilia's operative worldview and its idea(s) of nature could enhance the integration of biophilic responses in the design process.

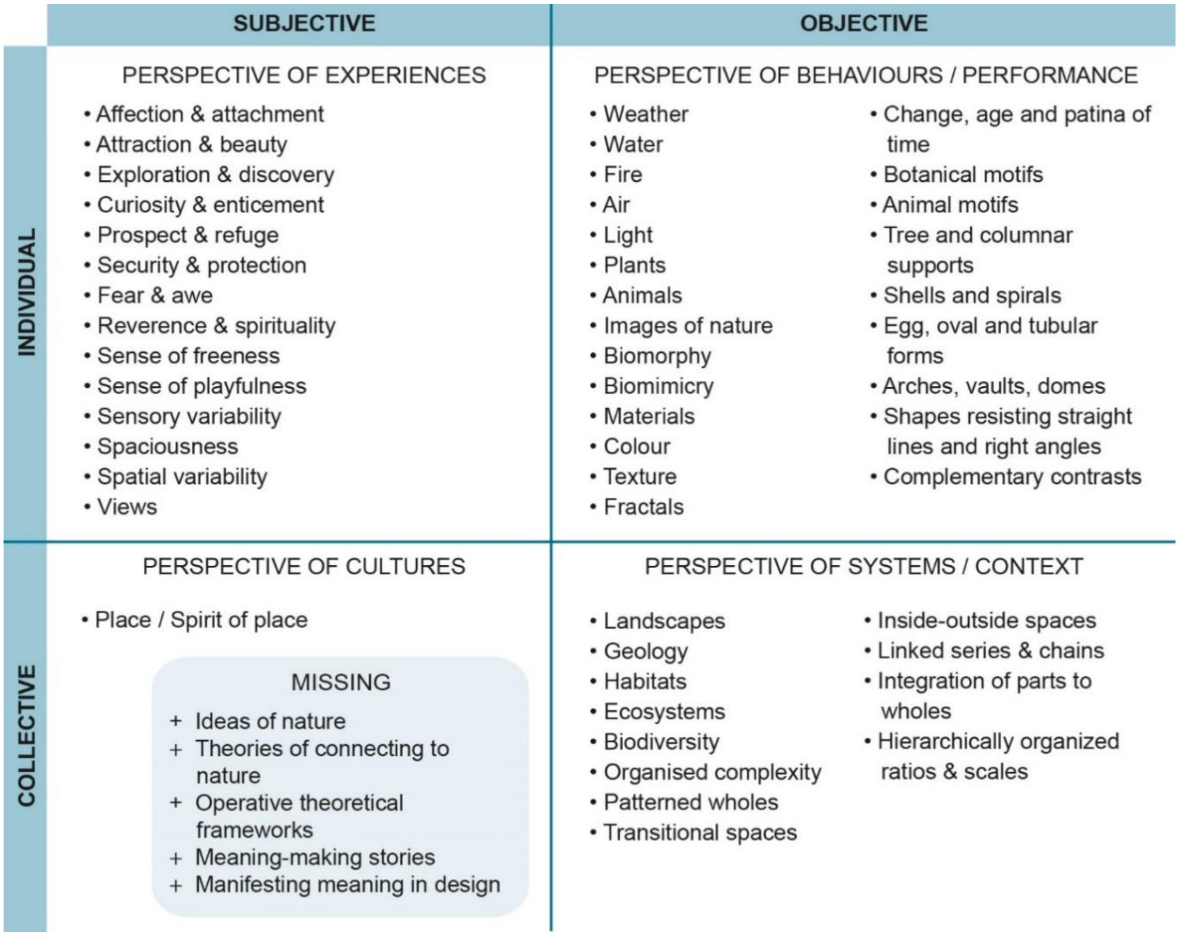


Figure E.4 Biophilic design principles described by Browning et al. (2014), Heerwagen and Gregory (2008), Kellert (2018), Kellert and Calabrese (2015) and Kellert et al. (2008) within the Integral Theory quadrants articulated by Wilber (2000) and DeKay (2011).

Biophilic design literature and canons as mostly objective about the objective

Approaching nature and its impacts for people through various measurements and prediction strategies documents the objective dimensions of biophilic design. While useful, such "measure & weigh" outcomes transfer poorly to promoting subjective experiences. Studies about the benefits of biophilic design generally focus on measurable health, performance and economic outcomes. Biophilic design is not being evaluated for subjective and individual experiences of the *philia* (mapped in Figure E.3), but for other criteria that may or may not be associated with subjective human affiliative experiences of nature. They are asking the question, *What are the impacts of biophilic design?* While some research has identified natural elements that affect well-being, measures of contact with nature that can directly inform architectural design account for the smaller portion of this research. Metrics already used by the client, such as absenteeism, perceived comfort or test scores, are currently suggested to help architects understand and assess biophilic design (Browning et al. 2014). In school settings for example, test scores have been used as indicators of the impact of the built environment on learning progress (Barrett et al., 2015; Heschong-Mahone Group, 2003). Surveys are also used to assess biophilic design by evaluating occupants self-assessed health and well-being as well as their preferences for certain settings (e.g., Matusiak &

Klöckner, 2016; Shu & Ma, 2018). Measures of physiological responses are further employed to provide information on the efficacy of implemented biophilic design strategies (e.g., Kelz et al., 2011). However, these objective measures do not offer more than potential correlation with subjective experiences. Overall, evidence gathered using client-based metrics, self-assessed measures and physiological indicators does not assess the *philia* in biophilia.

To better assess and design spaces that foster experiences of nature, there is a need for an enhanced understanding, in architectural terms, of the mood, emotion, experience that biophilic design creates for people. Figure E.5 adapts DeKay's "six essential lines of design awareness" (2011, pp. 165–171), shown in all caps text, to the current problem of biophilic design, shown in the lower-case text. A "line" in Integral Theory is a capacity for human development, such as cognition or kinesthetics, along which a person may develop through stages. Among the best-known lines are those covered in Howard Gardner's (1983) "multiple intelligences", which include interpersonal, logical-mathematical, naturalistic, and more. Five of DeKay's lines are reordered to inform and shape the sixth, HUMAN EXPERIENCE, which becomes expressed as the *philia* in biophilia. This shows the numerous essential design considerations that can shape and affect human experience.

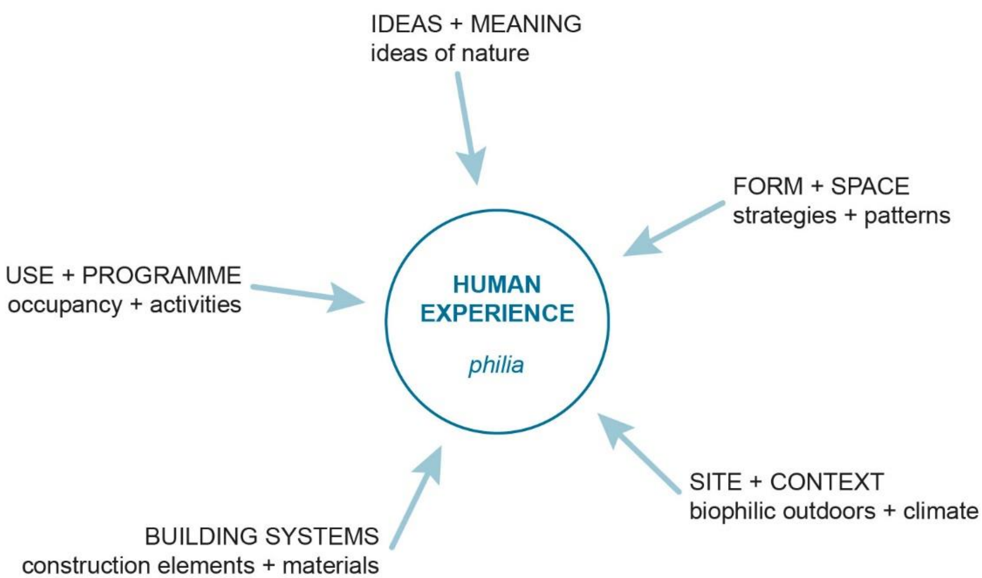


Figure E.5 Human experience in context based on DeKay's (2011) six lines of design awareness.

Experiences in biophilic settings

Architecture can stimulate the senses and may give rise to feelings or emotions. Information is essential to human functioning and in many situations, this relationship with information is far from neutral (Kaplan & Kaplan, 1989). An experience of architecture can be pleasant and foster a positive response (e.g., music in sacred spaces). However not all enjoyable experiences create an affiliation with nature. Variations in building systems, such as electric lighting, that mimic natural patterns or processes, could be considered as simulated biophilic experiences. Nonetheless, the immediate experience of architecture is affected by previous sensations and also conditioned by the anticipation of experiences to come (Cousin, 1980). Thus, the effect of environmental variables on people's experience will depend on a combination of internal sensations and external influences.

The biophilic design literature claims a variety of experiences, such as sensory, psychological, or social, as opportunities for an affiliation with nature. Descriptions of biophilic experiences tend to convey positive sensory and affective elements that contribute to an understanding of natural patterns and also an affiliation with nature. In Kellert's words, "Biophilic design encourages engagement and immersion in natural features and processes" (2018, p. 19), although these are the precursors of an experience. The biophilic experiences that Beatley (2016) describes include curiosity, care, awe, engagement and celebration of the diversity of life, the latter being less an experience than, typically, a social action. Browning et al. (2014) also allude to a sense of exhilaration and curiosity towards nature, indicating that such individual experiences can be states of mind. In the logics of Integral Theory, *states* are temporary experiences, while *stages* (levels of development) are permanent acquisitions. Heerwagen and Gregory (2008, p. 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." Such a statement, common in the literature, conflates the physical characteristics of places (behaviours and systems perspectives) with human responses to them (experiences perspectives), yet importantly distinguishes more transient emotional conditions (states) from more permanent attitudes and affects (qualities of developmental stages).

Building on these experiential descriptors, we developed an exploratory model to better understand and describe biophilic experiences. The organisation draws on the dynamic relationships among environmental stimuli, feelings and thoughts, knowledge and previous experiences and the development of close relationships with nature (Figure E.6). To reflect the increasing complexity and interconnectedness that children grasp at different levels of development, we regroup biophilic experiences as nested levels of sensation, affect, understanding and affiliation.

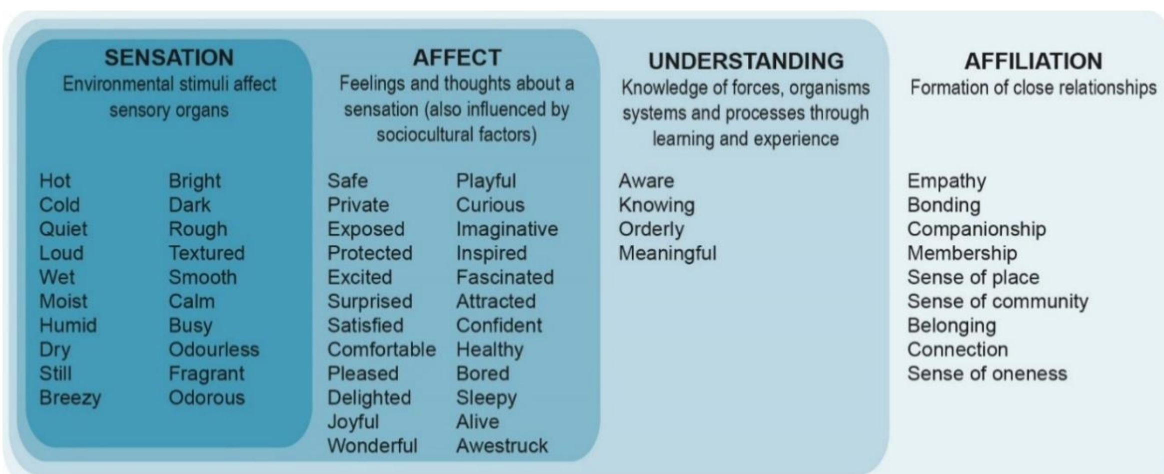


Figure E.6 Some biophilic experiences as nested levels of sensation, affect, understanding and affiliation based on Kellert (2018), Beatley (2016), Browning et al. (2014), Heerwagen and Gregory (2008).

"Sensation" is the immediate response to environmental stimuli prior to thought or interpretation. It can be understood as the fundamental level of experience, or as defined by Merleau-Ponty (1962), the basic unit of perception. This appears particularly important in the design of children's environments, because "the child is assumed to be more sensually engaged than the adult who is more intellectual" (Bartos, 2013, p. 91). Considering sensation as the basic level of nature experiences further aligns with Deleuze's (2003) theory of sensation. According to Deleuze, sensation, as irreducible to organic life, is a fundamental capacity of any organism or living system. Building on this theory, Ash (2015, p. 123) offers a helpful distinction between sensation and affect: sensation is "the rhythmic organization of organic and inorganic forces and the transmission of these forces. Affects can be understood as the encounter of those organized forces with other bodies, which in turn shapes what these bodies are and the sensations they can generate". Thus, in the proposed model of biophilic experiences, affect is used to mean feelings about sensations. As identified by Nemorin (2017), affect "encompasses conscious/preconscious shared moods, feelings, and emotions such as attachment, affection, excitement, fear, ease, or wellbeing". In terms of experiences of nature, affect can also include terms such as comfortable, delightful, safe or exposed to the elements.

"Understanding" natural forces and processes includes an awareness, such as of weather forces, species identification and characteristics, and at higher stages, a knowledge of processes such as water cycles, ecosystems, habitats, climatic patterns or sun movements. This understanding can emerge from formal learning opportunities, such as environmental education programmes in schools. Environmental education develops an awareness, a sensitivity, knowledge and understanding of the environment and environmental challenges (United States Environmental Protection Agency [US EPA], 2018). As Wilson (1993, p. 32) remarks, biophilia is "relevant to our thinking about nature, about the landscape, the arts, and mythopoeia, and it invites us to take a new look at environmental ethics". An understanding of nature also encompasses informal observations and reflections. For example, children may have a greater understanding of solar rhythms as they enjoy recess in the shade of a school building in the morning and a sun-filled schoolyard in the afternoon. "Affiliation" means a range of relationships with nature, increasing in depth and meaning, which can become manifest as empathy or a sense of community with the natural world, for example. Affiliation with nature can be understood as a process that shares certain similarities with the notion of "place". Always in transformation, places and people's relationships with place are temporary and changing (Bartos, 2013). From the Integral view, we can understand this as both a temporary state, but also as a characteristic of stages that has different qualities at each level. As Kellert et al. (2008) suggest, people's affiliation with nature develops through experience, learning and cultural construction.

Thus, presented as nested levels, the model expresses the view that describing sensory experiences of nature is a fundamental component. It suggests that complementary descriptors relating to affect, understanding and affiliation with nature can help better understand and describe biophilic experiences. It further recognises that the adaptive opportunities provided to building inhabitants contribute to the experience of diverse and changing environmental conditions (Demers & Potvin, 2016). In turn, this influences how biophilic architecture can encourage experiences of nature. We suggest a corollary precept that the purpose of biophilic design is to provide solid replicable state experiences of sensation and affect—the hypothesis being that individuals might build upon these to experience temporary "next-stage" *states* of mind (understanding) and being (affiliation) that eventually lead to the development of permanent *stages* characterised by increasing depth of relatedness to nature.

Design implications for biophilic experiences in schools

Analysing biophilic experiences in school settings brings an awareness to child developmental stages and the level of biophilic experience that changes as children grow. Building on the reflections presented above, this section discusses design implications identified to help architects set the conditions for potential biophilic experiences.

Architecture may be experienced or understood differently by schoolchildren at different periods of their life. In a canopy place that moderates natural forces from above while connecting occupants to the horizon, a kindergartener may sense and enjoy the diverse colours and fragrances of outdoor vegetation. During this *magical* stage (Gebser, 1985), children are fully immersed in nature in this space. A third grader may appreciate this space during rain-day recess or the delight of choosing to read in sun-filled or shaded areas, illustrating a schoolchild's focus on individual interests and desires as expressed by Kegan's *second order* of consciousness (1994). By sixth grade, a student may have a greater understanding of solar rhythms and times during which direct sunlight will enter the space. This can contribute to the development of child environmental values, particularly as they explore and create bonds with the environment (Kellert, 2005; Sobel, 1996). Teachers using this space may embrace the seasonal planting rituals and understand their contribution to the larger ecosystem of the schoolyard. Thus, architectural design features may foster a variety of biophilic experiences for all ages.

Hands-on experiences and children's learning happen in various places besides the classroom. As curious and active learners, children benefit from immersive and open-ended experiences that are based on their developmental stages (Copple & Bredekamp, 2008). In transitional spaces, such as entrance halls and corridors, opportunities for such experiences of nature can be created. For instance, incorporating plants in a generous circulation space may encourage children to learn about gardening and botany, even during winter. Interior courtyards can encourage the use of outdoor gardens and dining areas in warmer months. Sheltered learning spaces can further offer different degrees of engagement with nature. From a covered outdoor classroom area, nature in the schoolyard landscape can be experienced at a distance during structured teaching activities. When in this space, children are incidentally in the presence of nearby nature. Moreover, the diversity of materials, vegetation and animals in the schoolyard can encourage the active manipulation of nature during structured or unscripted outdoor activities. Such opportunities for biophilic experiences reveal the role of the architectural programme to support a diversity of activities, whether in indoor, semi-enclosed or outdoor spaces.

Spatial diversity sets the distributions of conditions as the field in which sensations, affect, understanding and affiliation with nature can arise. As advocated by Potvin (1996) and Steemers and Steane (2004), the diversity of environmental conditions contributes to meeting a diverse set of human wants and needs. For example, window placement has the potential to influence schoolchildren's experience of dynamic lighting. The strategic placement of windows and skylights enables students to sense and understand sun paths throughout the day. It also offers selected views of outdoor vegetation and the sky, providing cues on environmental conditions. Moreover, a design solution that varies the types of connection between a courtyard and interior spaces encourages people to feel safe and protected from harsh winds while remaining in contact with gentle breezes. By intertwining the building with the forces and social patterns present on the site, occupants can develop a sense of place, a deep relation between the building and the site. These inexhaustive design examples illustrate how a diversity of spatial, contextual, material and programming design considerations set the distributions of conditions as the field in which sensations, affect, understanding and affiliation with nature can arise.

Conclusion

This paper reflected on experiences of nature in architecture, particularly as they pertain to children in school environments. Bringing the notion of developmental stages to the study of biophilic experiences suggests building up from the fundamental levels of nature experiences. In primary school-age children's environments, design decisions that focus mostly on pre-rational experiences build a foundation for later stage experiences. This paces architecture and its physical and experienced relation with the natural elements as a foundation of the entire life stages of an individual. Using an integral lens to view biophilic design from four fundamental perspectives, this article also identified current shortcomings of biophilic design literature. Ideas of nature were shown as deeply and tacitly embedded within biophilic literature; "nature" was rarely and poorly defined, as if the common meaning is known. Moreover, it was noted that the current focus on measurable outcomes makes for a difficult transfer to understanding the subjective experiences of nature. This revealed the potential to articulate and clarify the architectural elements that give rise to subjective and individual experiences.

An exploratory model was developed to better understand and describe biophilic experiences. This model enriches the discussions on the relative importance of individual and subjective experiences in biophilic architecture. At its core, the model expresses our demonstration that describing experiences of nature in terms of sensations only represents one level. This opens a new opportunity to consider feelings, understandings and affiliations with nature. The benefits that could arise are significant, particularly in children's environments as primary schools that encourage children to learn and interact actively with nature may be most effective and engaging when based on children's developmental stages (Copple & Bredekamp, 2008).

Multiple spatial configurations can set the distributions of conditions as the field in which sensations, affect, understanding and affiliation with nature can arise. In school architecture, diverse biophilic experiences can be fostered for children (and adults) of different ages and developmental stages. As their level of sensory awareness and understanding of natural processes increases, design elements can express or incorporate more complex phenomena. Hands-on experience opportunities of nature in a school setting can contribute to immersive and active learning. Whether in classrooms, transitional spaces or the schoolyard, designers set the conditions for children to interact with a diversity of tangible natural elements. In addition, design decisions relating to window placement or the form of the building, for example, influence the relationship between the site and the building, impacting the variety of sensations, affect, understanding and affiliation with nature people can experience.

These reflections on biophilic experiences provide powerful and clear directions for relatively unexplored future research. Studying experiences of nature in architectural terms provided some clarity on this vast question that would benefit from complementary scholarship and concepts from other fields of research. This could enhance and refine the model of biophilic experiences, which would help design professionals further incorporate these principles in the design process. Future research in architecture might also investigate:

- How these experiences are influenced by other design aspects such as materials, window placement, facade design, garden design indoors and outside, relationships between indoor, in-between and outdoor spaces, and building systems for heating, cooling and lighting, among others.
- How different developmental levels experience nature in general and nature as mediated by biophilic architecture in particular. Levels of biophilic design in each quadrant could be hypothesised and tested.
- How Integral Theory might be further employed to develop correlations among given levels in each quadratic perspective.

Further, mapping the universe of potential states for experiencing nature and biophilic design at different levels of complexity (much less how to create them) remains largely unexplored. As the nature of the “Nature” to which biophilic design intends to connect people is imprecise, different definitions and conceptualisations of nature will surely require different biophilic designs. By incorporating subjective experiences into the understanding and application of biophilic architecture, it becomes possible to complement the current dominant focus of measuring the quantifiable impacts with engendering and assessing the *philia* in biophilic buildings.

Appendix F Additional experiences documented using BERT

Appendix F presents additional representations of biophilic experiences using the Biophilic Experience Representation Tool (BERT) discussed in Chapter 4.

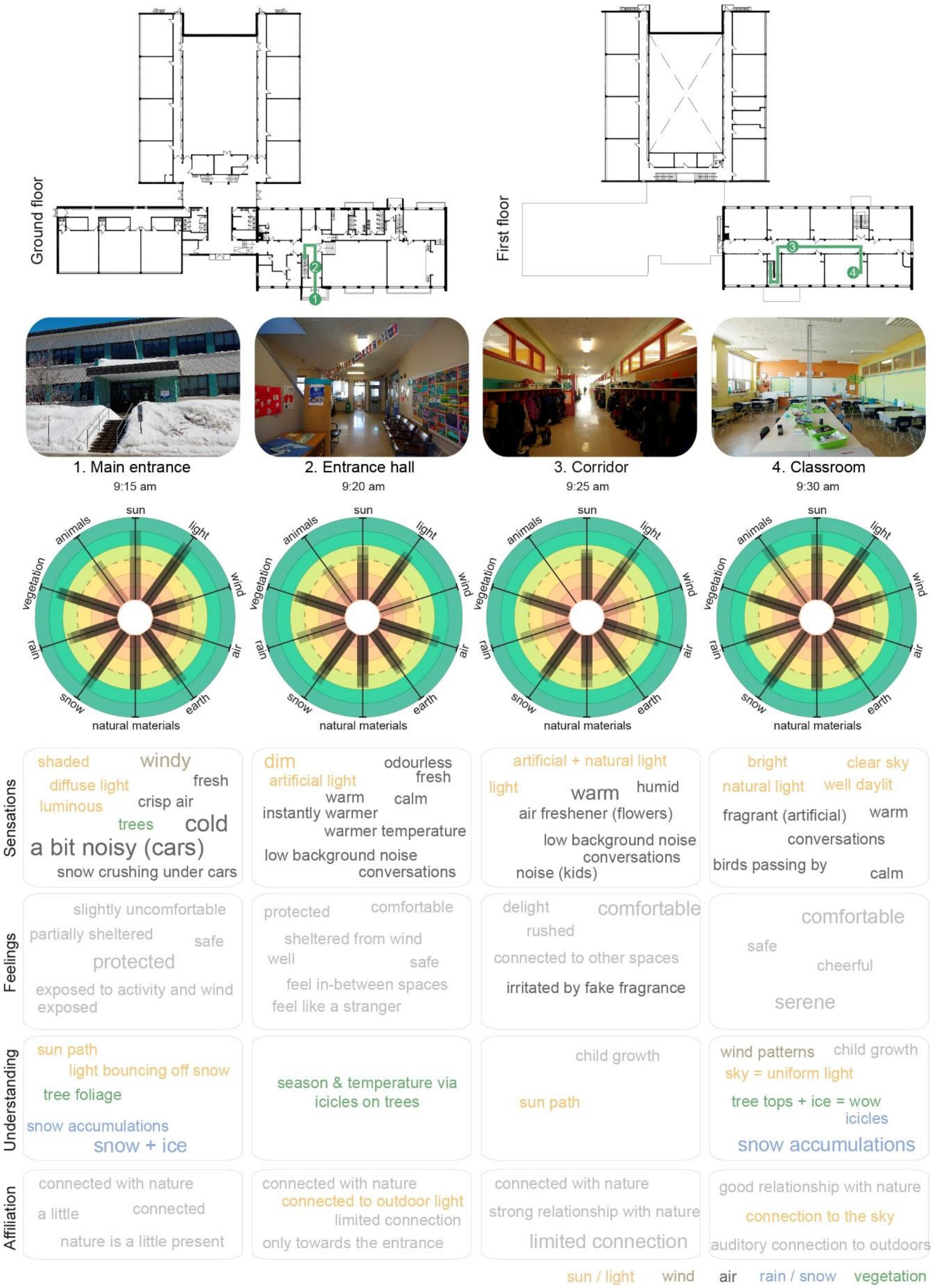


Figure F.1 BERT illustrating experiences from the main entrance to a classroom in School T.

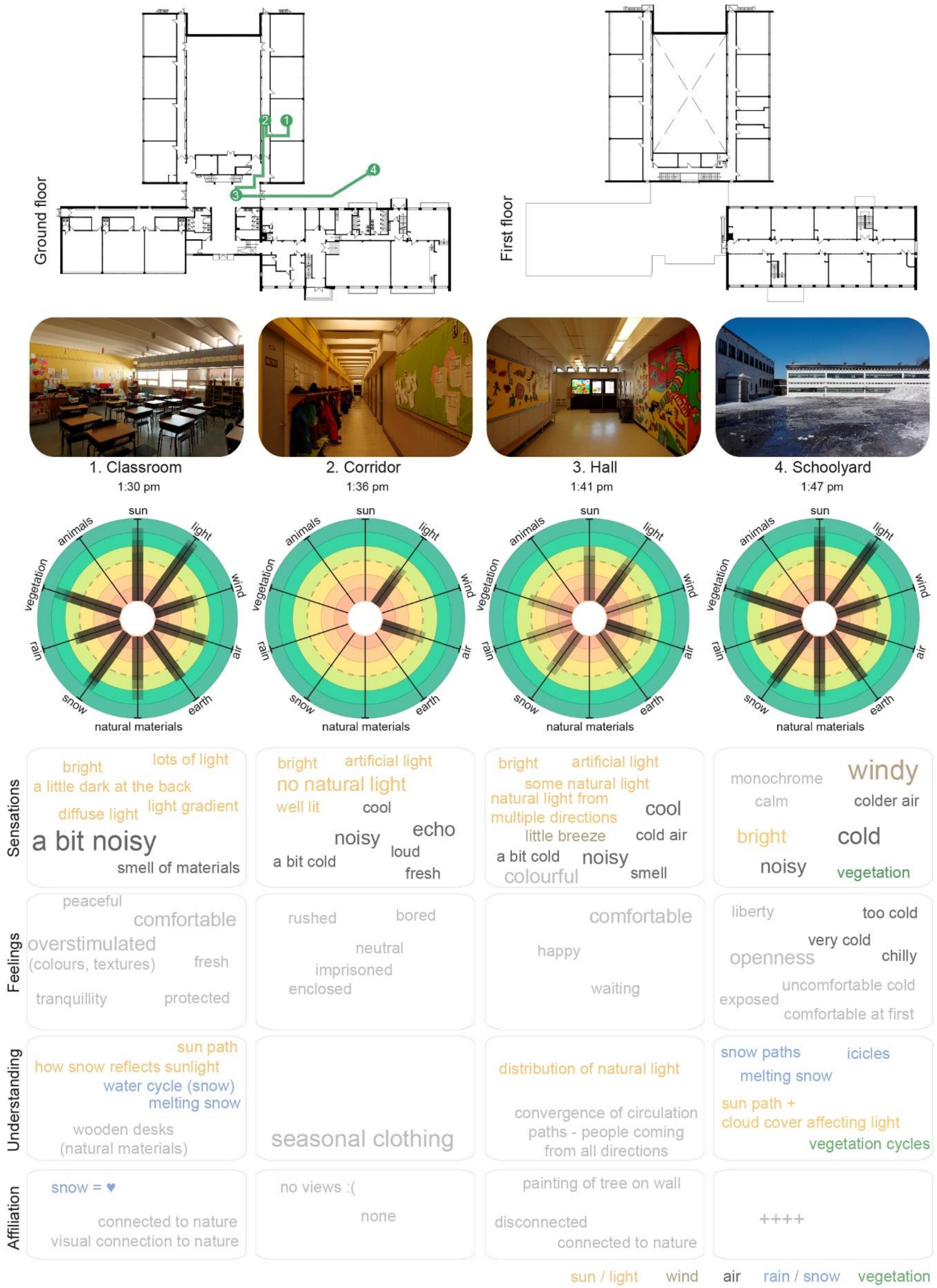


Figure F.2 BERT illustrating experiences from a classroom to the schoolyard in School T.

Figure F.3 BERT illustrating experiences from the gymnasium to a classroom in School T.

Figure F.4 BERT illustrating experiences from the main entrance to a classroom in School C.

Figure F.5 BERT illustrating experiences from a classroom to the schoolyard in School C.

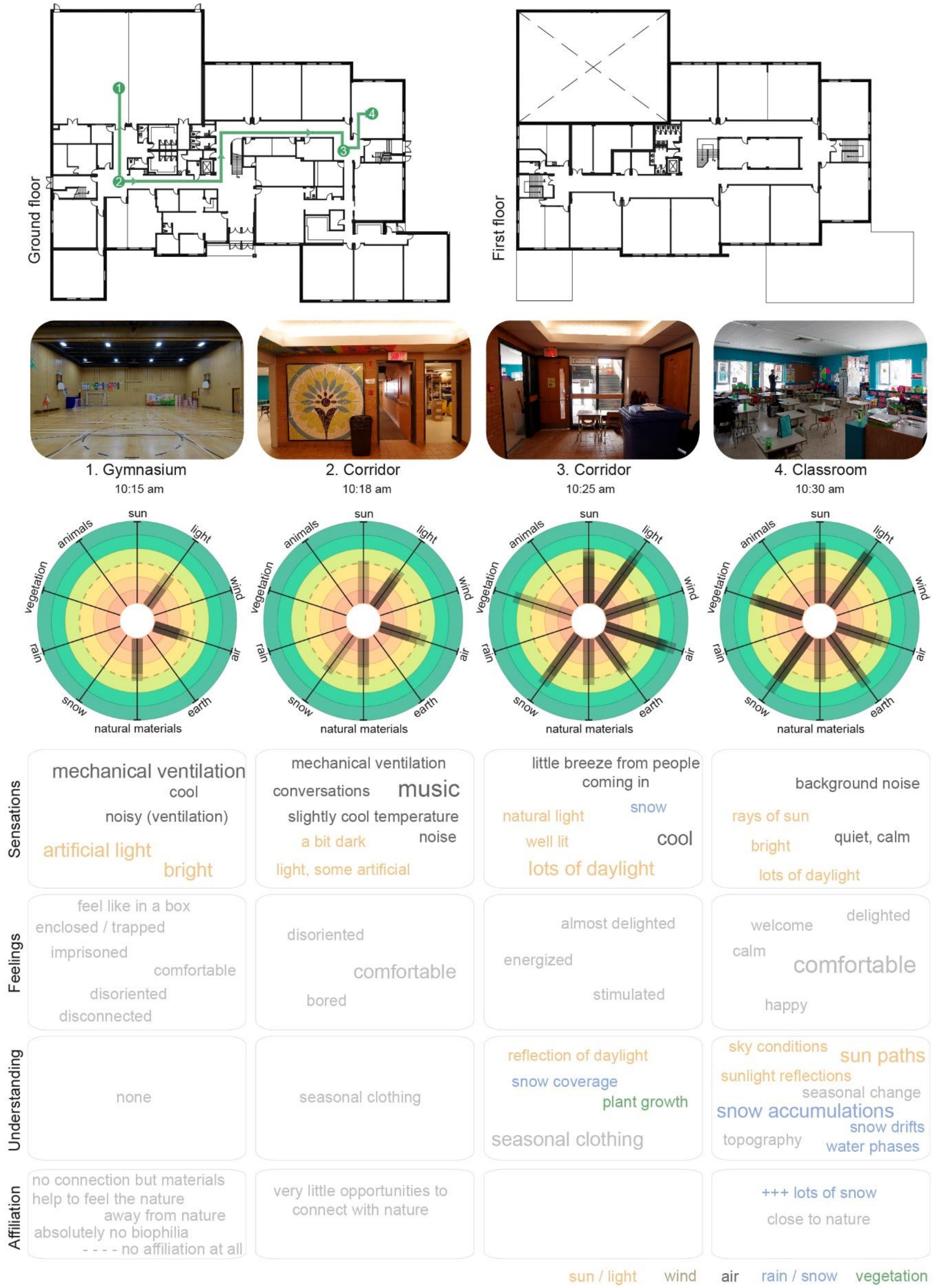


Figure F.6 BERT illustrating experiences from the gymnasium to a classroom in School C.

Appendix G Extended adjacency matrix for the biophilic design vocabulary

Appendix G presents an extended matrix for the theme *adjacency* presented in the biophilic design vocabulary in Chapter 5. Figure 5.4 considered horizontal combinations of space types to generate three spatial configurations: *alignment*, *interposition* and *containment.* Figure G.1 adds four complementary configurations to the matrix and represents both their horizontal and vertical combinations.

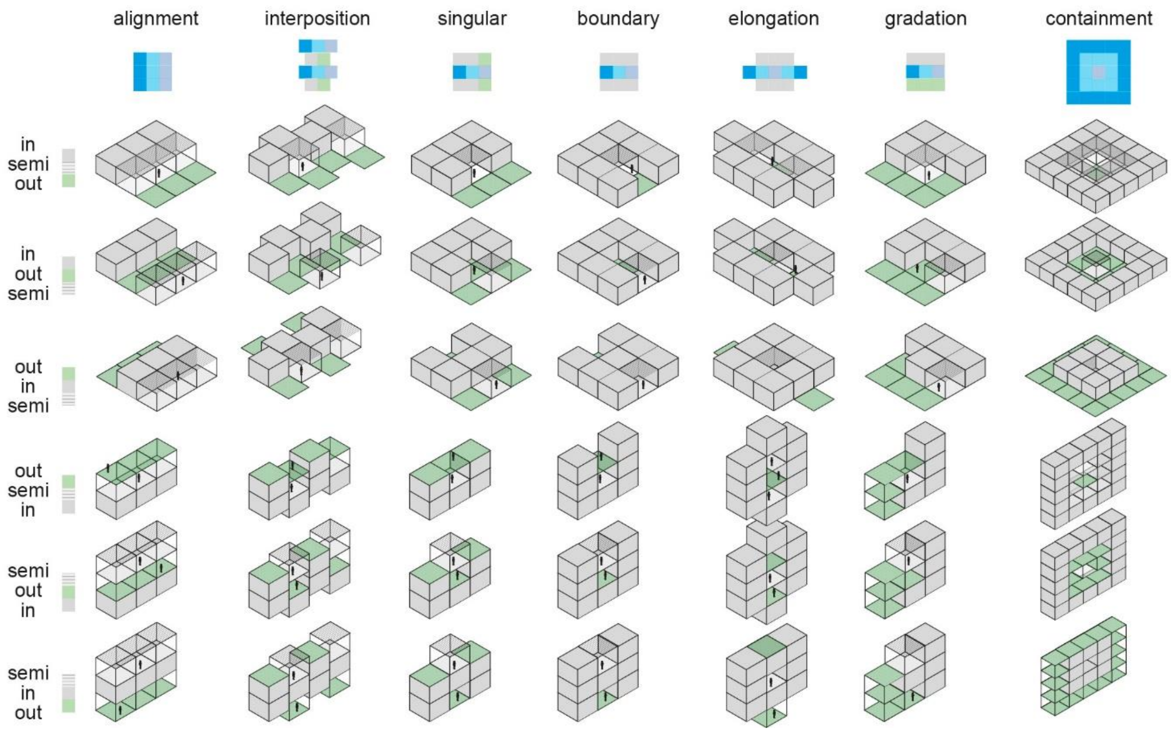


Figure G.1 Extended version of the adjacency matrix presented in Figure 5.4.

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 or vertically. This offers a higher diversity of semi-enclosed spaces, now partially enclosed laterally.

The *singular* configuration is delimited by a sequence of two built spaces and one outdoor space. This highlights the unique position of the semi-enclosed space in each of the variants.

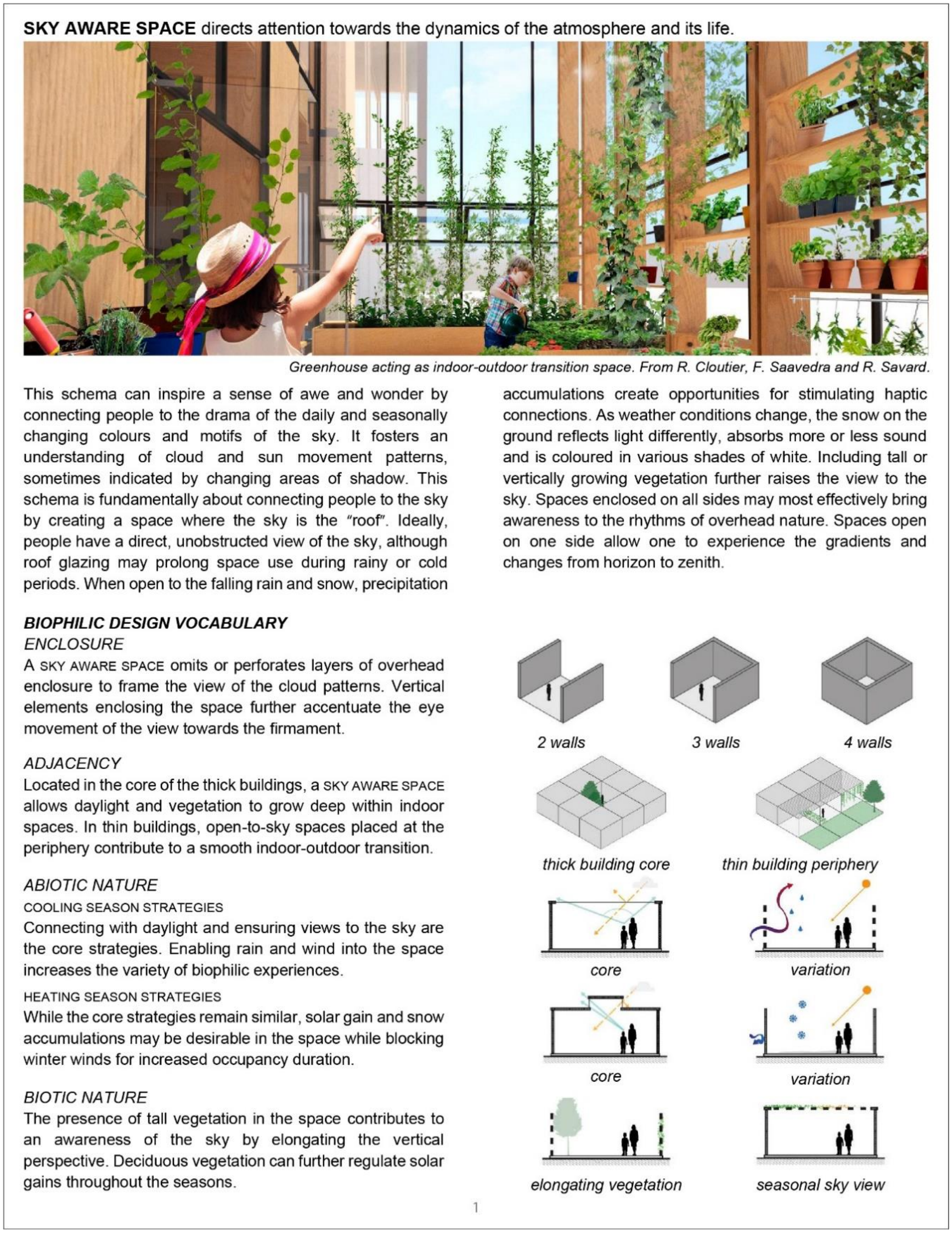
The *boundary* configuration is delimited by two fully built sequences which completely border the sequence of indoor, semi-enclosed and outdoor spaces. This configuration is further complexified in *elongation*. In addition to the two fully indoor sequences delimiting either side of the sequence, the middle sequence is mirrored from the centre in the elongation configuration.

The *gradation* configuration is characterised by a sequence of three outdoor spaces on one side and sequence of three indoor spaces on the other side. This renders the central sequence a soft or abrupt transition among the three space types.

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.

Appendix H Biophilic design schema "SKY AWARE SPACE"

Appendix H offers a detailed description for the schema SKY AWARE SPACE prepared after the preparation of the article presented in Chapter 5. The information is organised according to the anatomy of a biophilic design schema presented in Figure 5.15.



SKY AWARE SPACE directs attention towards the dynamics of the atmosphere and its life.

Greenhouse acting as indoor-outdoor transition space. From R. Cloutier, F. Saavedra and R. Savard.

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.

BIOPHILIC DESIGN VOCABULARY

ENCLOSURE

A SKY AWARE SPACE omits or perforates layers of overhead enclosure to frame the view of the cloud patterns. Vertical elements enclosing the space further accentuate the eye movement of the view towards the firmament.

ADJACENCY

Located in the core of the thick buildings, a SKY AWARE SPACE allows daylight and vegetation to grow deep within indoor spaces. In thin buildings, open-to-sky spaces placed at the periphery contribute to a smooth indoor-outdoor transition.

ABIOTIC NATURE

COOLING SEASON STRATEGIES

Connecting with daylight and ensuring views to the sky are the core strategies. Enabling rain and wind into the space increases the variety of biophilic experiences.

HEATING SEASON STRATEGIES

While the core strategies remain similar, solar gain and snow accumulations may be desirable in the space while blocking winter winds for increased occupancy duration.

BIOTIC NATURE

The presence of tall vegetation in the space contributes to an awareness of the sky by elongating the vertical perspective. Deciduous vegetation can further regulate solar gains throughout the seasons.

1

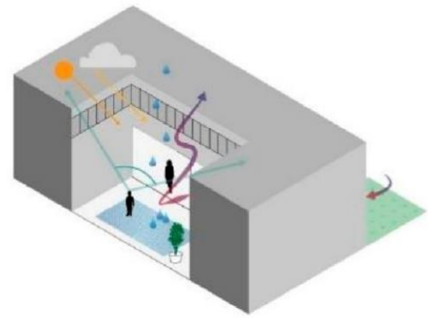
Figure H.1 SKY AWARE SPACE schema, page 1.

FORMS AND SPATIAL CONFIGURATIONS

An example of a SKY AWARE SPACE is the courtyard of the D1 Kindergarten and Nursery designed by HIBINOSEKKEI + Youji no Shiro Architects in Japan.

Situated in the core of the building, the courtyard offers a high degree of freedom to the children and their educators for playground and learning activities that stimulate their creativity.

Rain that falls into the space gathers in a basin, which freezes in winter and serves as a skating rink for the children. Adjacent to the food preparation area, the open-to-sky space can also host lunch activities on warm sunny days.



This selection of design precedents illustrates various spatial configurations of a SKY AWARE SPACE. The combination of horizontal and vertical components forms different strategies to foster experiences of natural forces and living organisms.

The precedents are organised top-to-bottom based on their suggested sense of protection. As the layers of overhead enclosure are less perforated, the view of the sky diminishes and the sense of interiority increases.

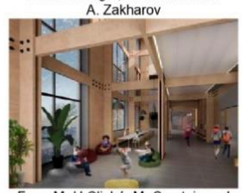
The left-to-right organisation illustrates the experience of living organisms. Whether in the SKY AWARE SPACE or in its immediate field of view, tall vegetation contributes to elongating the vertical perspective.

Experience of living organisms →

← Sense of shelter, protection

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

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



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

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

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

From L-M Caron, C. Parisé and A-A Porlier

DESIGN GUIDELINES

- A SKY AWARE SPACE is fundamentally about connecting people to the sky by creating a space where the sky becomes the "roof".
- The absence or perforation of an overhead structure creates an unobstructed view of the sky.
- Enabling rain and/or snow accumulations may be desirable within the space to enhance visual and tactic experiences of natural elements.
- In cold climates with heavy snowfall, the placement of glazing in the roof design is key to ensure a sustained view of the sky throughout the winter.

FUTURE RESEARCH

- To what extent does the location of a SKY AWARE SPACE in a building influence people's use and appreciation of the space?
- How does the area and height of the space affect people's experience of sky?

2

Figure H.2 SKY AWARE SPACE schema, page 2.