NATURE NURTURES

Architectural Greenery Systems to Support Healing in Canadian Hospitals

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

How can living plant systems be combined with healthcare facility architecture to increase beneficial interactions with nature, while still maintaining healthcare standards of safety, efficiency, and control? Nature can provide healing benefits to hospital occupants by lifting their spirits and by counteracting the difficulties of fighting illness. Architectural designers can help to create more positive hospital environments by utilizing vegetation as a building material and in building systems. Vertical and raised greenery systems such as living walls, green façades, and green roofs can deliver more accessible green spaces in dense, urban hospital sites. Greenery systems can also create synergistic relationships between plant life and functional healthcare programs.

This thesis analyzes the benefits, costs, and challenges of greenery system typologies and their various construction types. Demonstrated are architectural designs for key patient and visitor spaces in a hypothetical patient tower on an existing Canadian hospital redevelopment site. Within this design, greenery systems support long-term care patients of specialty units like rehabilitation, palliative care, acute elderly care, and mental health. By providing knowledge about the application of architectural greenery systems, this thesis promotes a sustainable design of greenery systems and a plant-based philosophy to the way hospitals are envisioned, and health care is achieved.

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List of Abbreviations

AD	Anno Domini
AGS	Architectural greenery systems
ART	Attention restoration theory
BC	British Columbia
CO_2	Carbon dioxide
CSA	Canadian Standards Association
FC	Foot-candles
DB	Decibel
HCF	Health care facility
GF	Green façade
GR	Green roof
GW	Green wall
LED	Light-emitting diode
NBI	Nature based interventions
NAI	Nature assisted interventions
O_2	Oxygen
PBR	Photobioreactor
PM	Particulate matter
PV	Photovoltaics
PVC	Polyvinyl chloride
QSCH	Quirónsalud Sagrado Corazón Hospital
ROI	Return on investment
SQ FT	Square feet

SQ M	Square meters
SRT	Stress reduction theory
TDS	Total dissolved solids
TV	Television
UV	Ultraviolet
VGS	Vertical greenery system
VOCs	Volatile organic compounds
WWI	World War I
WWII	World War II

Part 1: Vegetation in Healthcare Facilities

1-1 Spectrum of nature interactions, shown in section

INTRODUCTION

My thesis seeks to find a symbiotic relationship between two complex subjects: hospital architecture, and vegetation as a living building system and design material. Grüntuch-Ernst calls the combination of vegetation and building design, 'hortitecture', which mixes the Latin word for garden, 'hortus', and the word, architecture.[1] *Hortitecture* includes architectural greenery systems (AGS) like vertical gardens, green façades, and green roofs, and offers new methods of bringing nature into the healthcare facility (HCF). Despite nature's healing benefits, integrating greenery into the sterile hospital environment can be a challenge. My thesis asks, how can greenery systems be integrated into healthcare buildings to increase our connections with nature and improve occupant health, while still maintaining healthcare standards of safety, efficiency, and control?

Although scientific studies indicate that gardens and plants lead to positive

1 Almut Grüntuch-Ernst and Technische Universität Braunschweig, eds., *Hortitecture: The Power of Architecture and Plants* (Berlin: Jovis, 2018).

occupant and organizational outcomes, existing HCFs continue to be designed with minimal green spaces, and innovation is often challenged by strict policies and regulations. Nature immersive spaces are often too far away from healthcare program to be easily accessed by patients and visitors. Typically, building greenery is low in intensity and in the form of loose chattels found in lobbies and atriums, or outside healthcare buildings in the form of landscape at the parameter of building sites. For these reasons, residents may only have short and unmeaningful exposure to plant life. Rarely are living organisms given significant space within the architecture of healthcare environments for occupants to reap potential healing benefits. Figures 1-1 and 1-2 show a spectrum of nature interactions that occupants typically experience in current HCFs. My thesis argues for a shifting of these nature interactions inwards with the goal of bringing about more views and access to nature immersive environments. By using greenery systems in HCF design, greater access to various types of nature interactions like nature views and nature immersion can be achieved.

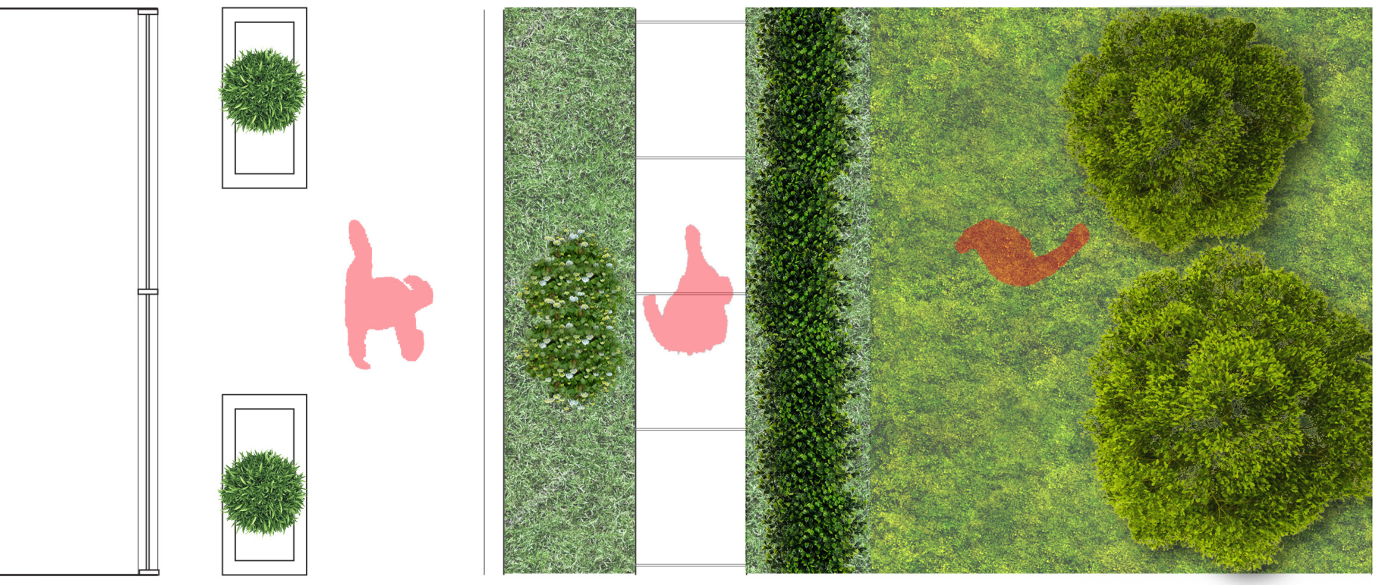
1-2 Spectrum of nature interactions, shown in plan

THESIS STRUCTURE

This thesis is divided into three main parts. Part 1 introduces the concept and role of nature in HCF design, theories, and practices. Part 2 is a technical guide on the fundamentals of AGS. Part 3 demonstrates how nature can assist healthcare functions through a design of green spaces in a hospital site located in British Columbia, Canada.

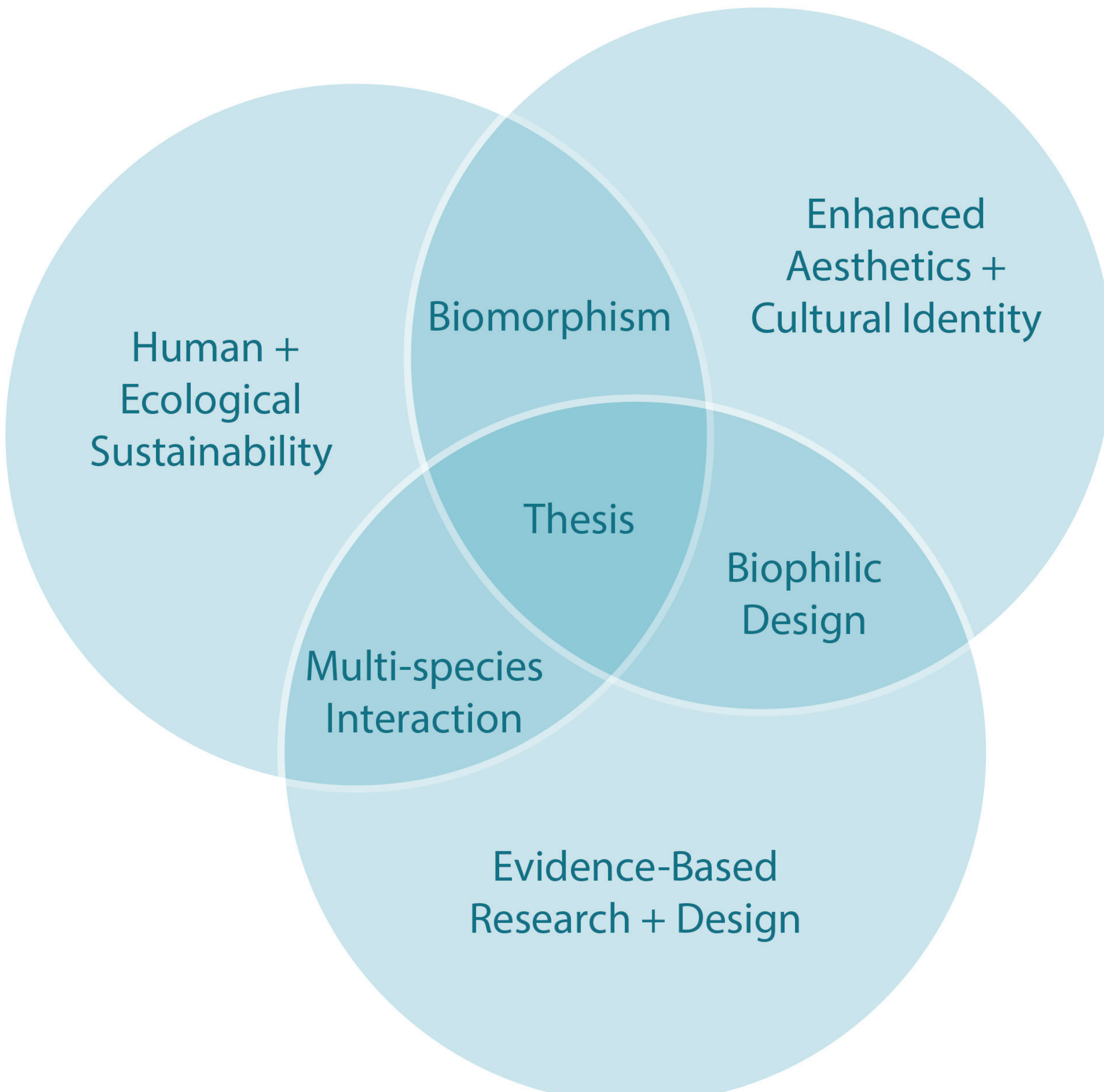
The introductory essay in Part 1 covers current trends in HCF design and discusses the role of nature in the evolution of western hospitals from ancient to current times. This essay explains the benefits of plants through the lens of three current healthcare design movements: 1. enhanced aesthetic and cultural identity, 2. evidence-based research and design, and 3. human and ecological sustainability (refer to Figure 1.3).[2]

2 These movements are similar to the hospital design movements as stated by Stephen Verderber in *Innovations in Hospital Architecture* (New York: Routledge, 2010).



Sensory Environment   Landscape / Garden   Nature Immersion

This thesis is intended to be a handbook to guide designers on how to apply AGS in healthcare spaces to transform the look and feel of them for occupant wellbeing. This handbook demonstrates how plants can create synergies with healthcare functions and building systems. In doing so, HCF design norms will be challenged through innovative methods of harnessing the benefits of nature within therapeutic healthcare environments.



1-3 Thesis drivers and heathcare facility design movements

ENHANCED AESTHETICS AND CULTURAL IDENTITY

BIOPHILIC DESIGN ATTRIBUTES AND VALUES

Why are people inherently attracted to plants and other natural systems? The theory of 'Biophilia' by naturalist Edward O. Wilson states that human beings have an innate urge to affiliate with other life forms stemming from human biology having evolved over millennia in interdependence with natural systems and processes.[3] I believe that human bodies, cultures and traditions have also evolved through connections and entanglements with other natural organisms. Nature offer so many benefits that are essential to our development and livelihood. We value vegetation for everything from creating the oxygen we breathe to providing comfort in the spaces we inhabit. Not only do plants and trees provide food, medicine, and other resources, they are healing and essential to our wellbeing in so many other ways. Figure 1-4 categorizes various biophilic values showing how humans benefit from natural systems like plant life.

Biophilic design enhances aesthetics and cultural identity in the HCF because it provides individuals with experiences and interactions with nature. Biophilic design has the potential to increase human connections with nature and improves public health and productivity in constructed environments.[4] Architect and researcher, Stephen Kellert, describes how biophilic design elements and attributes in the built environment can increase human connections with nature.[5] Figure 1-5 shows a condensed set of twenty-five biophilic attributes, as provided by Kellert, grouped into three categories: direct experiences, indirect experiences, and place-based experiences.[6]

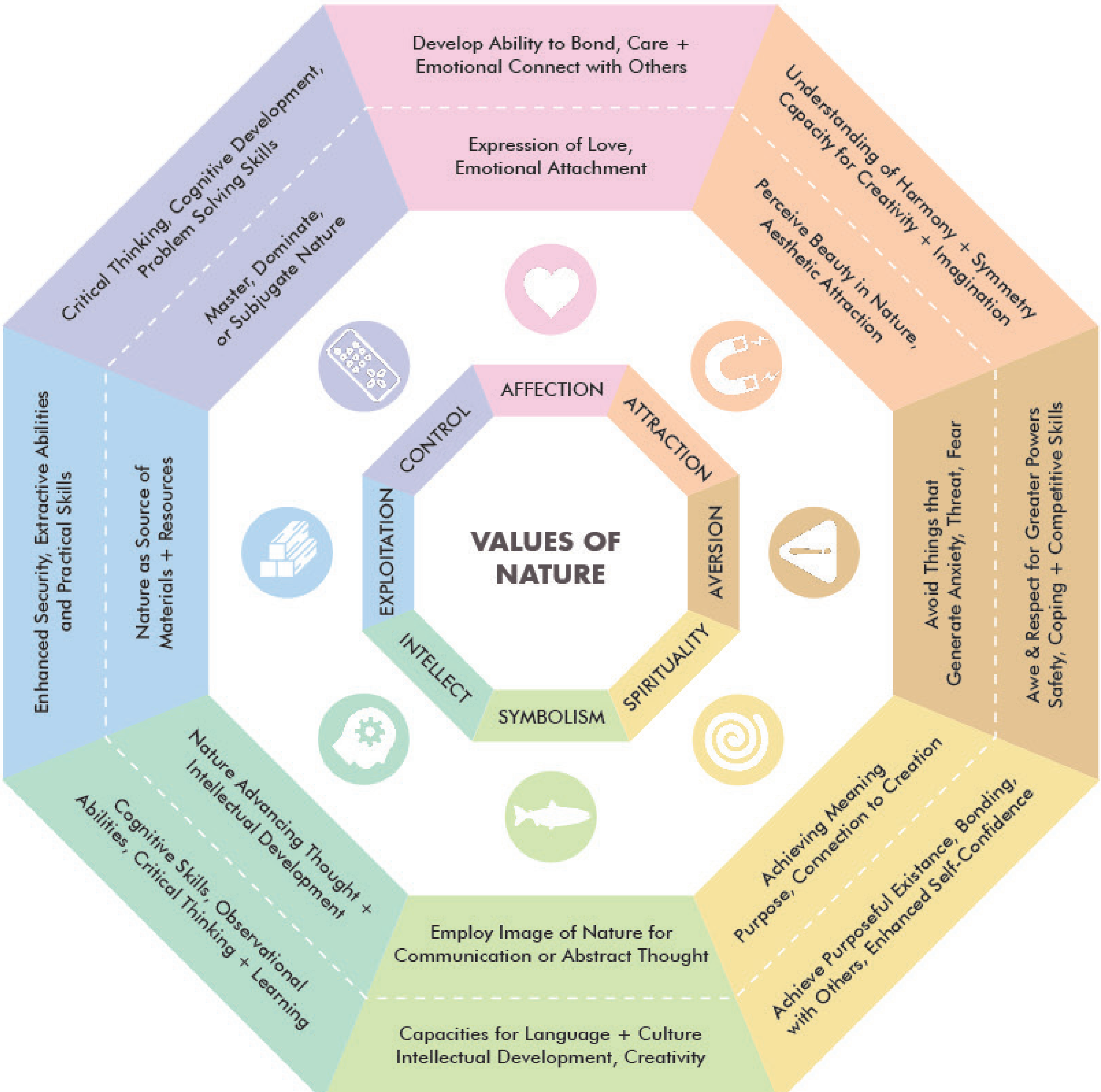
Successful use of biophilic design attributes depend on their relationship to site conditions such as environmental features, location history, and building

3 Stephen Kellert, *Nature by design: the practice of biophilic design* (New Haven: Yale University Press, 2018)..

4 Kellert, *Nature by Design,* 7.

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

6 Kellert, *Nature by Design*, 26-27.



1-4 Biophilic design values

DIRECT NATURE	INDIRECT NATURE	SPACE & PLACE
LIGHT	REPRESENTATIONS OF NATURE	PROSPECT & REFUGE
AIR	NATURAL MATERIALS	CURIOUSITY & ENTICEMENT
WATER	TEXTURE & COLOUR	TRANSITIONAL SPACES
PLANTS	SHAPES & FORMS	SENSE OF PLACE
ANIMALS	INFORMATION RICHNESS	SPATIAL ORGANIZED COMPLEXITY
GEOLOGY & LANDFORMS	CHANGE, AGE, PATINA OF TIME	INTEGRATING PARTS WITH WHOLE
WEATHER	SIMULATED LIGHT & AIR QUALITIES	RISK / PERIL
VIEWS	NATURAL GEOMETRY & PATTERNS	
FIRE	BIOMIMICRY	

1-5 Biophilic design categories and attributes

programme.[7] Indirect biophilic elements like colour and natural materials are being used more often in HCF design as healthcare practitioners and designers begin to appreciate the healing benefits of natural features. Direct experiences of nature on the other hand are more difficult to facilitate in health care spaces, especially indoors. I believe biophilic design is most successfully applied to design of healthcare environments in a mix of direct, indirect, and place-related biophilic experiences appropriate to the site. A compelling example of direct experience of nature is a living wall. Including living plants is one of the most effective attributes for stimulating biophilic values.

The Lady Cilento Children's Hospital in Australia promotes wellbeing through stress reduction and connections to nature (see Figure 1-6).[8] Designed like a 'living tree', the hospital extensively uses biophilic and biomorphic attributes that mimic trees, birds, and insects, to engage and distract young patients.[9] The building incorporates AGS with a large green roof, green walls, and other plantings. The design promotes health in the community by providing positive and stimulating architectural environments.[10]

7 Kellert, *Nature by Design*.
8 "Lady Cilento Children's Hospital," Archello, accessed April 27, 2021, https://archello.com/project/lady-cilento-childrens-hospital.
9 Ibid.
10 Ibid.

1-6 Lady Cilento Children's Hospital, Brisbane, Australia

Biophilic design in complementary to sustainable building design. The film, *Biophilic Design: The Architecture of Life*, argues that while sustainable architecture focuses on low environmental impact by reducing building energy and material usage, biophilic design showcases the occupant's beneficial connections with nature, something that green buildings may still neglect.[11] According to Totaforti, true sustainable design should consider both the building's environmental impact as well as the building's ability to increase mutually beneficial connections between humans and the environment.[12] The goal of integrating plants into healthcare architecture is to create attractive and nature immersive spaces that can lift one's spirit and counteract the challenges of fighting and treating illness. The introduction of AGSs in healthcare architecture would bring greater care and emotional connection to our surrounding environment, including the buildings themselves.

11 *Biophilic Design: The Architecture of Life*, DVD (Bullfrog Films, 2011).

12 Simona Totaforti, "Applying the Benefits of Biophilic Theory to Hospital Design," in *City, Territory and Architecture* 5, no. 1 (December 2018): 1.

1-7 Baubotanik Plane-Tree-Cube, Nagold, Germany

BIO-UTILIZATION

AGS is a form of bio-utilization. Bio-utilization in architecture involves the direct use of living things within architectural, mechanical, or structural systems.[13] If occupants can experience authentic natural qualities or interact with the living material within these systems in a positive way, then bio-utilization in architecture is a way to increase wellness in healthcare spaces. An example of a direct use of living systems within buildings systems is Dr. Ferdinand Ludwig's 'Baubotanik' living plant constructions, which involves inosculation of plants into building structure (see Figure 1-7). Another example of bio-utilization is the use of algae photobioreactors (PBR) within building facades, partitions, or mechanical systems, like Imhof and Gruber's project, "Growing as Building (GrAB)".[14] The phenomenological quality produced by these bio-utilization systems within architecture can be healing if combined with interactive and educational features that help facilitate human fascination, interaction, and understand of biological processes. In

13 Michael Pawlyn, *Biomimicry in Architecture*, Second edition (Newcastle upon Tyne: Riba publishing, 2016), 2.

14 Petra Gruber and Barbara Imhof, "Patterns of Growth—Biomimetics and Architectural Design," *Buildings 7,* no. 4 (April 4, 2017): 32.

this way, nature immersive spaces in buildings can enrich the healthcare environment and reduce patient stress.

BIOMORPHISM

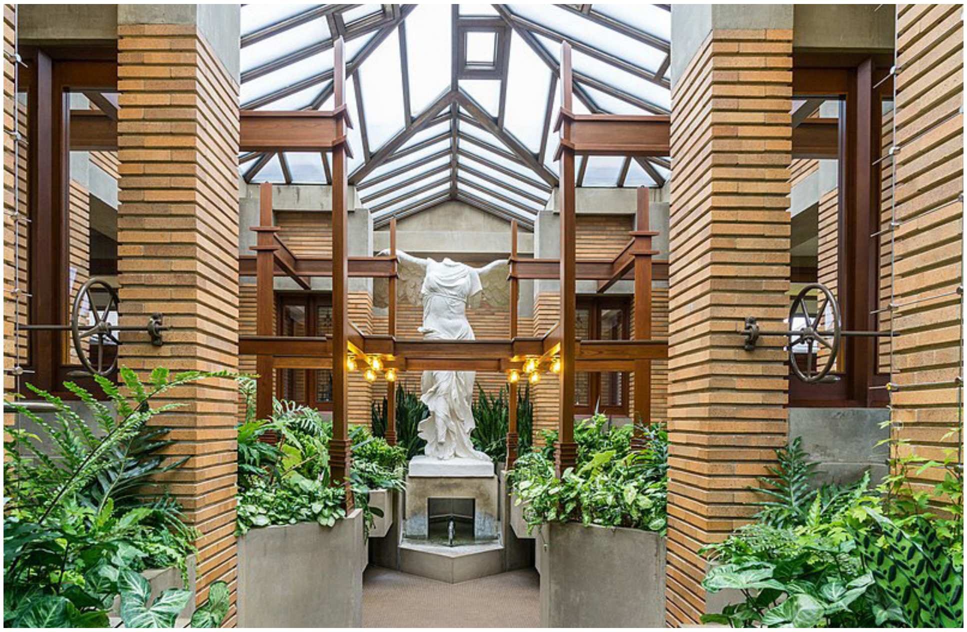
Biomorphic architecture is a form of nature analogue, which relies on indirect experiences of nature through a simulation of nature shapes, forms, patterns, textures, and colors for aesthetic and therapeutic effects. Biomorphism in architecture can lead to biophilic feelings of awe, spirituality, and affection. The book, *Inspired by Nature: Plants*, provides examples of how architects have been inspired by qualities in plants such as their spatial arrangement, temperature control, and water control. Architects have morphed their buildings, components, or spaces to mimic these attributes of plant organisms.[15]

There is evidence of biophilic and biomorphic design in classical, vernacular, and organic buildings. Art nouveau architecture utilize flowing lines and organic shapes, often in an ornamental way. The philosophy of organic architecture includes ideology about the relationships between humanity and natural environment. Organic architecture connects individual experience with nature and assists in reconciling building with site. One of the aims of organic architecture is to design tranquil spaces in harmony with its surrounding site. It uses natural materials and colours to expose nature's inherent qualities. The overall effect aims to fit the preferences and desires of the inhabitants, and the qualities of the site. The ornament in Frank Lloyd Wright's architecture emerged from the characteristics and detail of its form and structure like in nature itself. These characteristics also produce a spiritual quality and sense of depth to the architecture as can be seen in Wright's Darwin Martin House (see Figure 1-8). The project combines living plants with natural wood and brick finishes.

IDENTITY OF HOSPITALS

Medical care involves all stages of our lives: at the beginning of life, for life

15 Alejandro Bahamón, Patricia Pérez, and Alex Campello, *Inspired by Nature: Plants: The Building/Botany Connection* (New York: W.W. Norton, 2008).



1-8 Hall of Frank Lloyd Wright's Darwin Martin House, Buffalo, NY

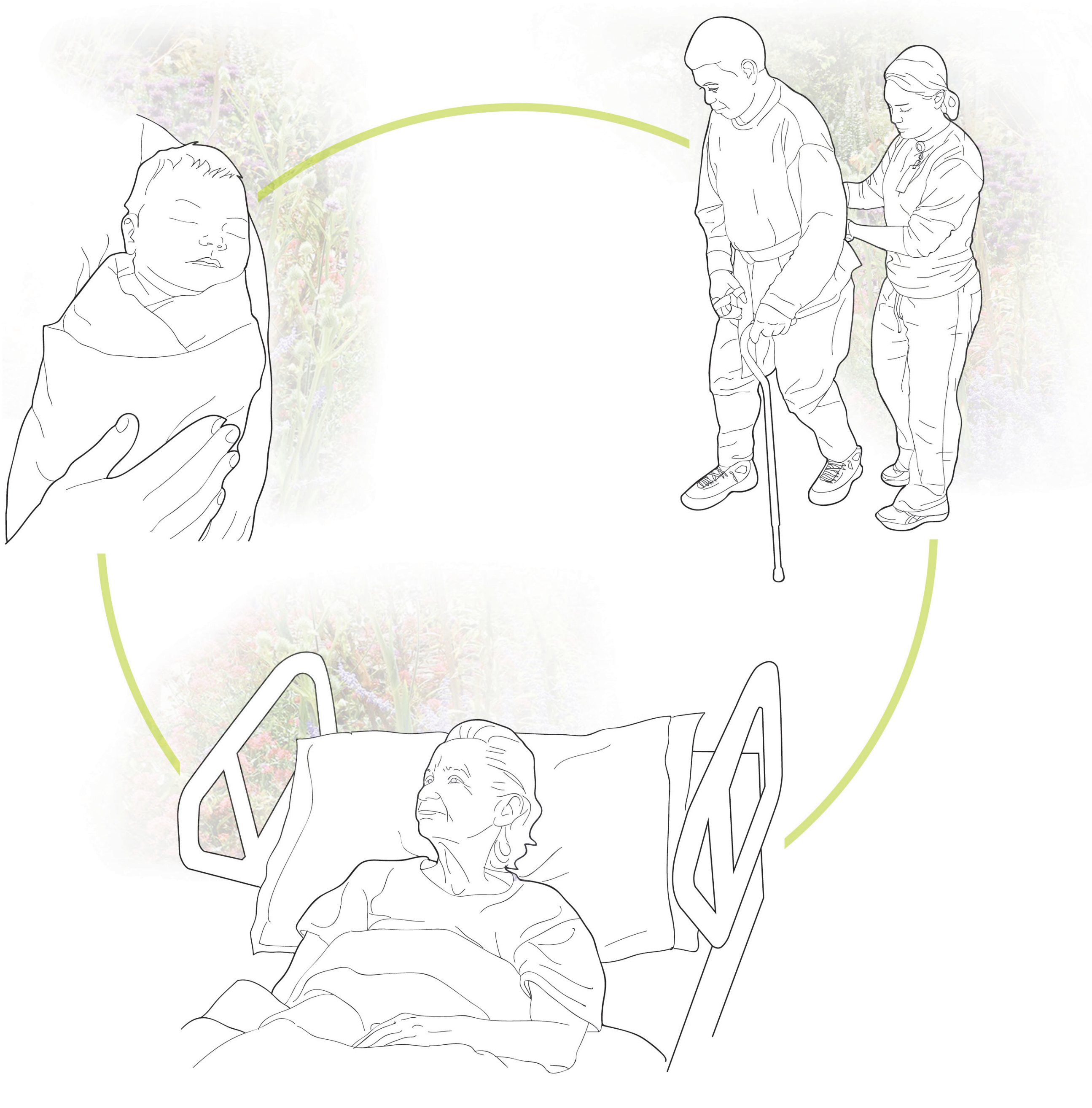
extension, and at the end of life (see Figure 1-9). Despite the advances of medical technology, people may resist going to a hospital for treatment or to visit or care for others, citing fear of pain, ill feelings, infection risk, and for not being treated like a human being. Surveys show that most Canadians would prefer to die at home than in a hospital because they would feel more comfortable dying in a familiar environment surrounded by family.[16] We are moving towards healthcare architecture that is patient-centered, concerning the whole health of the patient as well as the environment. Simona Totaforti says that the "humanization of healthcare spaces and contact with nature can empower the patient and have a positive impact".[17] She also concludes that further studies and a new approach to healthcare which considers human needs in their entirety is needed.[18]

Combining plants and architecture decreases anxiety surrounding hospitals. By introducing living nature and by mimicking nature's harmonious complexity, hospitals could be conceived as beautiful and sacred like nature, rather than mechanical and sterile. Maggie's Centres across the United

16 Canadian Institute for Health Information, *Access to Palliative Care in Canada* (Ottawa, ON: CIHI, 2018).

17 Totaforti, "Applying the Benefits of Biophilic Theory to Hospital Design," 1.

18 Ibid., 1.



1-9 Greenery systems aid healthcare functions for every stage of life

1-10 Maggie's Centre in Oxford, England

Kingdom offer a non-clinical environment for those affected by cancer. Although the centres are built on hospital grounds, Maggie's Centres have been called the antitheses of hospitals.[19] Hospitals, on the other hand, can be disorienting and confusing places due to their enormous size, busyness, and primary focus on medical treatment and efficiency. The intention of Maggie's Centres is to provide support and advice for people dealing with cancer in comfortable, residential-like and small-scale spaces that are outside of the hospital environment.[20] All locations contain gardens and green spaces where visitors are encouraged to participate in the care of plants. The existence of many Maggie's Centres indicate that hospitals could do better in balancing efficiency with patient comfort. Hospitals would benefit from characteristics like those of Maggie's Centres, including a friendly and domestic aesthetic, and garden landscapes. Therefore, rather than depending on a secondary facility, hospitals should offer serenity and spaces within their own walls where patients and their families can unwind.

19 "Maggie's Architecture and Landscape Brief" (Maggie's Keswich Jencks Cancer Caring Trust (Maggie's)), accessed November 3, 2020, https://www.maggies.org/about-us/how-maggies-works/our-buildings/, 6.
20 Ibid., 6.

EVIDENCE-BASED RESEARCH AND DESIGN

HEALING NATURE

Hospital architecture is healing if it reduces occupant stress or improves their mental and physical health. Plants in healthcare environments can improve quality of life and reduce suffering, but according to Health Canada, designing with nature should be supported by evidence-based research and avoid expensive and ineffective measures that do not actually improve occupant quality-of-life.[21] Scientific studies indicate that greenery in HCFs reduce recovery times, stress, and use of pain medications. This suggests that building design can play an active role in patient healing and wellbeing. Many theories such as the biophilia hypothesis (Wilson, 1984), and Attention Restoration Theory (Kaplan & Kaplan, 1989) relate the use of plants in environmental design with health benefits.[22] These scientific theories and studies support the use of living plants in healthcare environments and that vegetation contributes positively to human health.

Views of gardens and plants improve occupant outcomes. Studies have shown that pain and recovery times are reduced when patients have a window view of nature, rather than a view of a buildings. One of the first studies relating window views and patient outcomes was completed by Roger Ulrich in the 1980's. It compared post-operative outcomes of gallbladder surgery patients between those with a window view of a brick wall and those with a window view of trees (refer to Figure 1.11).[23] The patients with tree views had shorter hospital stays of an average of one full day, took less pain medication, and received fewer negative evaluations from nurses.[24] What if the patients facing the brick wall had a view of a green wall or green façade outside their window? It would not be hard to believe that they would have enjoyed similar kinds of benefits as the study group with a view of trees. Such a fusion between plants and hospital architecture could

21 Canada and Health Canada, *Framework on Palliative Care in Canada*, 2018, http://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2018/18-49/publications.gc.ca/collections/collection_2018/sc-hc/H22-4-16-2018-eng.pdf, 16.

22 Rachel Kaplan and Stephen Kaplan, *The Experience of Nature: A Psychological Perspective* (Cambridge ; New York: Cambridge University Press, 1989).

23 Roger S. Ulrich, "View through a Window May Influence Recovery from Surgery," *Science*, New Series, 224, no. 4647 (April 27, 1984): 420-21.

24 Ibid., 420.

1-11 Comparison of inpatient window view of trees versus brick wall

allow all the recovering patients to experience nature's healing benefits.

This kind of design research evolved into a field called evidence-based research and design, which links attributes of the physical healthcare environment to effects on hospital care outcomes. Ulrich et al. created an evidence-based design model of healthcare design variables that could affect various participant and organizational outcomes.[25] Figure 1-12 illustrates some relationship of architectural design variables on participant and organizational outcomes in healthcare environments.[26] Subsequent studies tested the effects of many biophilic attributes including colourful murals, natural materials, potted plants, organic shapes and forms and found that these features resulted in lower stress levels and aggressive behaviors.[27]

Ulrich et al. references studies showing that direct and soothing exposures to nature, like trees and serene water, seem to have the strongest positive effect in reducing stress, reducing pain and medication, and speed recovery.[28] More recent evidence-based design studies surveyed the effects of gardens in healthcare settings and found that hospital gardens resulted in decreased

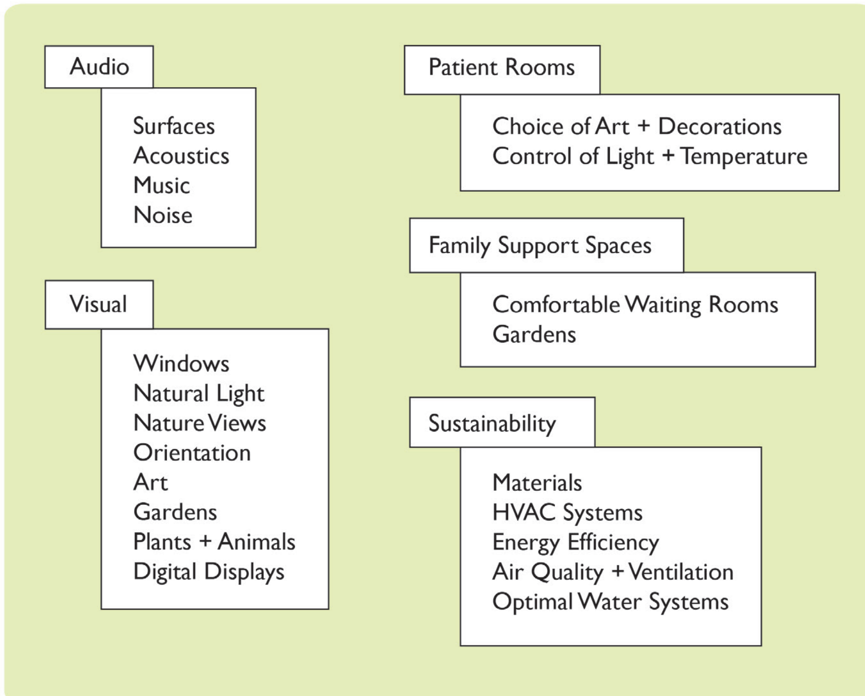
25 Roger S. Ulrich et al., "A Conceptual Framework for the Domain of Evidence-Based Design," *HERD* Vol. 4, no. No. 1 (Fall 2010): 95–114.

26 Ibid., 98-99.

27 Roger S. Ulrich, "Health Benefits of Gardens in Hospitals," 2002, 1-11.

28 Ulrich et al., "A Conceptual Framework," 100.

ARCHITECTURAL DESIGN VARIABLES

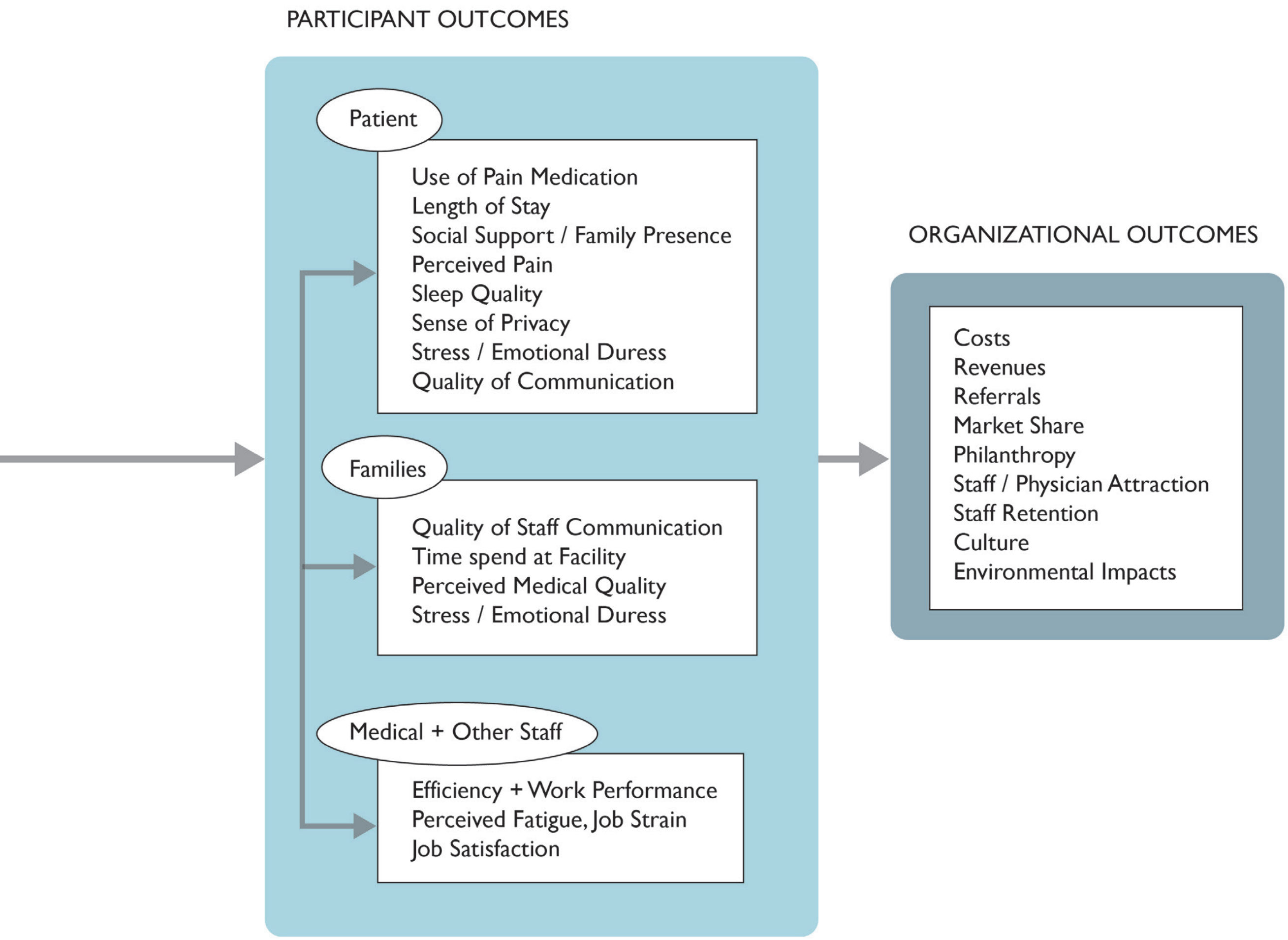


1-12 Participant and organizational outcomes in HCF environment

stress, improved clinical outcomes, and increased satisfaction from patients, staff, and visitors.[29] Therefore, plants are nature's healers, and gardens provide effective therapeutic environments.

Peter H. Kahn, Jr. conducted experiments testing the possible health benefits of 'technological nature' as opposed to real nature. His study uses a 'technological nature window' and concludes that a digital display of nature is more beneficial than no view of nature, but less beneficial than a window with real nature views.[30] As simulated nature becomes more like real nature, I agree that more psychological studies are needed with the right

29 Ulrich, "Health Benefits of Gardens in Hospitals," 9.
30 Peter H. Kahn Jr., "Technological Nature and Human Well-Being," in *Oxford Textbook of Nature and Public Health :The Role of Nature in Improving the Health of a Population* (Oxford: Oxford University Press, Inc., 2018), 161–62.



benchmarks to hold "technological nature to the same standards" as real nature, and to see if technological replacements provide "the same physical and mental benefits as interacting with its actual nature counterpart".[31] These studies demonstrate how emerging technology might play an ever more significant role in the future of architectural design and healthcare spaces. As Sternberg says, "a happy balance can be established between intuitive design and technological advances, to improve health, mood, and cognition and to foster a sense of well-being in hospital patients and staff".[32]

31 Kahn Jr., "Technological Nature and Human Well-being," 162.

32 Esther M. Sternberg, *Healing Spaces: The Science of Place and Well-Being* (Cambridge, Mass.: Belknap Press of Harvard Univ. Press, 2009), 215.

ENVIRONMENTAL PSYCHOLOGY THEORIES

Cognitive and environmental psychology theories like prospect-refuge theory by Jay Appleton, and arousal theory by Daniel Berlyne offer ideas about how architectural spaces can mimic those found in nature. Similarly, stress reduction theory (SRT) and attention restoration theory (ART) provide insights into understanding restorative environments that could help with mental fatigue and healing. [33] According to ART, nature provides opportunities for occupants to experience soft fascination, which is defined as "a more moderate form of involuntary attention that leaves room for thought and self-reflection".[34] This is because natural systems and processes are inherently complex in multi-sensory stimulation but do not over demand attention (refer to Figure 1-13). Think of the sounds and movement of water, or the play of light and shadows filtered through a canopy of trees. Soft fascination is suggested to be highly supportive of mental fatigue and stress reduction.[35] Not only does nature provide sensory experiences (visual, tactile, auditory, gustatory, and olfactory), nature can evoke memories and emotions, as well as provide cognitive, social, and physical stimulation. Therefore, nature can be used in passive and active enrichment strategies to create a restorative environment within a healthcare setting.

Patients have stated that they prefer to have positive distractions, spaces for socialization and control and input in regards to the design of their healthcare environment.[36] However, one of the challenges of translating an enriched environment into the clinical setting is that there is a wide range of personalities, experiences, and preferences for interactions.[37] Furthermore, motivation to be engaged in certain types of activities varies greatly between individuals. The key is to provide greater access to suitable forms of passive and active environmental enrichment and individual choice

33 Stephen Kaplan, "The Restorative Benefits of Nature: Toward an Integrative Framework," *Journal of Environmental Psychology* 15, no. 3 (1995): 169–82.

34 Agnes E. van den Bosch and Henk Staats, "Environmental Psychology," in *Oxford Textbook of Nature and Public Health :The Role of Nature in Improving the Health of a Population* (Oxford: Oxford University Press, Inc., 2018), 51–56

35 Heidi Janssen, Julie Bernhardt, and Frederick R. Walker, "Environmental Enrichment: Neurphysiological Responses and Consequences for Health," in *Oxford Textbook of Nature and Public Health :The Role of Nature in Improving the Health of a Population* (Oxford: Oxford University Press, Inc., 2018), 71–78.

36 Ibid., 75.

37 Ibid., 74.

1-13 Exposure to nature in gardens

over levels of engagement. Uses of vegetation and natural systems can be subtle. The REHAB Basel centre for spinal cord and brain injuries is a good example of a rehabilitation facility that It does not look or feel like typical health care facilities because of its usage of natural materials, natural daylight, and air ventilation, as well as gardens and terraces to aid patient recovery (Figure 1-14).[38]

HEALTHY BUILDINGS AND PATIENT-CENTERED CARE

The relationship between architectural design and therapeutic environments is an expanding field of study and interest. Alongside sustainable and green building practices for environmental concerns is a growing trend towards health and wellness in building design as indicated by building certifications from Planetree International Inc. and WELL Health-Safety rating, which is

38 Verderber, *Innovations in Hospital Architecture*, 250–57.

1-14 REHAB Basel Centre for spinal cord and brain injuries, Basel, Switzerland

a performance-based system for buildings to be developed with people's health and wellness as a primary focus of design.[39]

Similarly, palliative care is a growing approach to improve the quality of life of people and their families dealing with life-limiting illnesses.[40] It focuses on supporting patients and their families' physical, psychosocial, emotional, and spiritual needs.[41] Nature-rich hospital spaces could support palliative care in Canada. For example, hospital architecture could help improve the integration and ease transition of palliative care from hospitals to a more permanent residence, like long-term care homes or hospices, by holistically designing spaces that provide appropriate treatment.[42] Palliative care and patient-centered care new approaches developing in healthcare that considers human health needs in their entirety.

39 "International WELL Building Institute," International WELL Building Institute, 2021, https://legacy.wellcertified.com/en.

40 Canadian Institute for Health Information, *Access to Palliative Care in Canada*.

41 Ibid.,14.

42 Ibid., 51.

HUMAN AND ECOLOGICAL SUSTAINABILITY

URBAN BENEFITS

Colin Ellard, a professor of neuroscience at the University of Waterloo, studies the effect of urban design on human physiology. He argues that urban designers and architects can do more to improve urban surfaces by increasing their permeability and sensory complexity.[43] Ellard says that boredom causes people to excrete more of the stress hormone cortisol, which is bad for human health.[44] Looking to the natural world, Ellard believes that building façades should be designed with intermediary levels of complexity, with engaging "patterns, symmetry, and curvature" to positively affect our physiology.[45] Therefore, hortitecture is a contemporary solution to many environmental and health pressures that urban development generates.[46]

Plants engage our tactile, olfactory, visual, gustatory, and auditory sensory systems. Proportional harmonies can be seen from a plant's overall form right down to its microscopic details. Therefore, AGS in a healthcare setting can provide visual appeal from both afar and up close, attracting positive attention. As occupants come closer, they experience more sensory qualities of the system, such as a cooler and more humid atmosphere, freshly scented air, sounds of water and chirping birds, and the gentle movements of plants. In these ways, greenery systems can improve the aesthetic appeal and experience of HCFs. AGS increase visual and physical contact with plants, which can lead to direct health benefits. They create a 'greener' surrounding in built-up areas and provide a healthier and enjoyable feature in both private and social healthcare spaces.

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43 Rawe, Anna, "Colin Ellard – How Urban Design Is Making Us Unhappy," Salzburg Global Seminar, November 22, 2018, https://www.salzburgglobal.org/news/publications/article/colin-ellard-how-urban-design-is-making-us-unhappy.

44 Ibid.

45 Ibid.

46 Erik van Zuilekom, "Guidelines for Going Green," in *Going Green with Vertical Landscapes*, ed. Vo Trong Nghia and Takashi Niwa (Mulgrave, Victoria, Australia: Images Publishing Group Pty Ltd, 2017), 22.

Hortitecture can assist with current ecological and human sustainability goals like reducing greenhouse gases, increasing natural and biodegradable material use, and improving public health and wellness. Cities experience urban problems like a lack of green spaces, air pollution, and overheating. Architectural greenery improves public health by creating calming and relaxing green spaces, which reduce stress and decrease mortality rates. Urban greenery also improves air quality because plants increase oxygen levels and trap air pollution and particle matter (PM). They provide social, economic, and environmental benefits for surrounding city.[47] Including a variety of native plant species will increase biodiversity and improve site sustainability. Through living plant material in architecture, we can improve human experience of urban environments.

AGS make hospitable space for friendly plants species in the urban environment. As Zuilekom describes, our built environments can be thought of as urban canyons, with opportunities for plants to lay claim to constructed cliffs, ridges, and plateaus.[48] The bare surfaces of buildings and the deep urban "canyons" between them can be transformed into productive gardens and lush habitats through greenery systems and climbing plant species.[49] As urban communities grow in density, building footprints decrease in size, and building heights increase. With taller buildings, vertical building façades and interior walls become the largest surface areas of buildings, but they are often devoid of life and can separate occupants from views of greenery and fresh air.[50] Vertical gardens are one response to the increasing building heights and the increase of underground construction, that often lead to lifeless spaces created by iatrogenic urban development. AGS including living walls, green façades, and green roofs, can provide healthcare residents with healing views of nature with minimal footprint area. VGS support vegetation in locations that would be too dark or small to support other typical plantings.[51] Prior to this, buildings expanded horizontally, and roofs represented the largest exterior surface of buildings.[52] Therefore, green roofs have a longer history than vertical greenery systems.

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47 van Zuilekom, "Guidelines for Going Green," 27.

48 Ibid.,22.

49 Ibid., 22.

50 Ibid., 24.

51 Jialin Tong and Wenwen Yin, *Living Wall: Jungle the Concrete 2* (London: Design Media Publishing, 2017), 8.

52 van Zuilekom, "Guidelines for Going Green," 24.

Vegetated buildings provide a transitional zone between inside and outside. Ashizawa calls it "a moment of reconciliation between the built and natural environment".[53] Moreover, he says when buildings become a living and breathing part of the landscape, they are no longer at odds with the scenery.[54] Artificial building materials, so ubiquitous on hospital sites, cannot impart the same healing benefits that AGS can. Although site greenery and green roofs have become a more popular practice across hospitals, vertical greenery systems (VGS) like living walls and green façades are less familiar territory for many architectural designers. Vegetation can be employed as a eco-friendly design material, like other building finishes. The HCF architect's objective can be to increase the amount of greenery in buildings to improve occupant health, building aesthetics, and ecological position.

BIOMIMICRY

Nature has many biological role models that may offer design solutions. Through evolution, organisms have evolved highly efficient and effective physical forms and properties. Biomimicry utilizes biological role models to find highly efficient and effective design solutions, that are adapted to the natural environment. Biomimicry in architecture seeks to harness or mimic the forms and properties of natural systems through building technology, materials, and systems design, often with ecological benefits. With a focus on environmentalism, architects have used methods of biomimicry to find sustainable design solutions. Through sustainable designs, biomimetics can help prevent diseases, and illnesses, and thereby contribute to human health. Designs modeled from biology can also be beautiful due to their adaptation of harmonious biological forms.

Biomimicry in architecture is not necessarily biomorphic or biophilic. It does not need to have anything natural looking about it. AGS is not considered a form of biomimicry. Although it mimics ecological systems, hortitecture is more like bio-utilization because it directly incorporating living organisms, rather than mimics their forms and processes. Nevertheless, AGS is complementary to biomimicry. They share many of the same values, namely

53 Ryuichi Ashizawa, "Guidelines for Green Façades and Roof Gardens," in *Going Green with Vertical Landscapes,* ed. Vo Trong Nghia and Takashi Niwa (Mulgrave, Victoria, Australia: Images Publishing Group Pty Ltd, 2017), 15.
54 Ibid., 15.

1-15 Sidney & Lois Eskenazi Hospital, Indianapolis, IN

the appreciation of biological systems and processes, and the greater aim of human and ecological sustainability.

IMPROVED BUILDING PERFORMANCE

Vegetation in buildings supports sustainable building practices and standards. It can help a HCF meet LEED Healthcare credits in the areas of surrounding sites, water management, and environmental air quality. Moreover, AGS assists in providing comfortable indoor and outdoor environments for occupants and reduce cooling loads in a building. Many systems offer thermal benefits to reduce solar heat gain in the summer. Organic matter also performs well as thermal and acoustic insulation.

AGS can integrate with other buildings systems like stormwater collection, and ventilation systems. As a building material, vegetation is a renewable and biodegradable product. There is no harmful dust during construction and demolition. The organisms are oxygen producing and carbon sequestering, they absorb VOCs and capture pollutants, all of which improve air quality. Plants can be used in gray water filtration, or in indoor air purification.

Green roofs (GRs) can both improve building performance and provide other health care functions. The Sidney and Lois Eskeazi Hospital in Indianapolis, has a 35,000 square feet GR that can be expanded by an additional 46,000 sq ft, and has the capacity to collect 40,000 gallons of rainwater that is used to irrigate the site's many landscaped gardens (see Figure 1-15).[55] The hospital has a series of accessible and therapeutic gardens for different populations on the campus, as well as two prominent outdoor spaces. The 'Sky Farm' is a food producing GR that provides on-site food production for the hospital itself. The hospital's site is designed to be porous, allowing stormwater runoff to enter bio-filtration swales and aquifer before going back into the environment. This stormwater management protects nearby rivers.[56]

The diversity of AGS available allows them to satisfy a range of building design challenges. As well, multiple systems can be combined on a single project.[57] More benefits are being studied and supported by evidence. Radic et al. identifies thirteen vertical greenery systems (VGS) construction types, comprised of four types of green facades and nine types of living walls.[58] The literary review identifies ten VGS benefits, with thermal performance having the most exploration and empirical evidence.[59] According to the literary review, other benefits such as "improvements in air quality, reduction of noise, positive effects on hydrology, and visual benefits need much further empirical testing, as the current supporting data is mostly descriptive".[60]

The Palomar Medical Center in California utilized greenery systems (GS) for building performance benefits has a 1.5-acre extensive GR that controls stormwater runoff and helps to mitigate heat island

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55 Robin Guenther and Gail Vittori, Sustainable Healthcare Architecture, Second edition (Hoboken, New Jersey: John Wiley & Sons, Inc, 2013), 72.

56 Ibid., 72.

57 van Zuilekom, "Guidelines for Going Green," 27.

58 Mina Radić, Marta Brković Dodig, and Thomas Auer, "Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits," *Sustainability* 11, no. 17 (August 23, 2019): 4579, https://doi.org/10.3390/su11174579.

59 Ibid.

60 Ibid., 1.

1-16 Typical hospital corridor and waiting area

effect.[61] The green roof contains native herbs and grasses that create habitat for birds and improves views from the patient tower. The tower also has planted terraces on each patient floor for visitors to enjoy and the terraces have double height spaces and deep planting beds to accommodate trees.[62] These VGS improve air quality, reduce heat gain through seasonal shading and thermal insulation, and improve occupant comfort.

PUBLICITY BENEFITS

Despite being decorated in natural looking colours and finishes, HCF rooms are typically bland and devoid of living nature and landscape views (refer to Figures 1-16 and 1-17). AGS are still somewhat a novelty in Canadian HCF, and therefore they can generate interest in-of themselves. Decorative objects and art pieces can be included in the AGS to great effects. Greenery

61 "Palomar Medical Center," Archello, n.d., https://archello.com/it/project/palomar-medical-center.

62 Ibid.

1-17 Typical patient bed without nature view

systems can be integrated into the hospital's art program. Art installations enhance interior and exterior environments by generating positive reactions and making the healthcare site more beautiful and enjoyable. In this way, hortitecture can attract community interest and participation, volunteers, and monetary donations, by injecting vitality, social, and aesthetic benefits for the surrounding community.

Additionally, media and publicity attention from GS can provide financial gains for HCFs. A study completed by the Urban Greening and Biosystems Engineering Research Group in Spain at Quirónsalud Sagrado Corazón Hospital (QSCH) assessed its living wall's return on investment (ROI) in relation to publicity and assessed the green wall's impact on the attitudes of hospital occupants. QSCH's green wall is installed on an exterior façade facing the hospital's main hall and can be viewed through the main hall's large windows and from some patient rooms. The living wall was very profitable in terms of increasing publicity as installation costs were recovered six-fold.[63] The study concluded that most of the participants surveyed, including

63 Luis Pérez-Urrestarazu, Ana Blasco-Romero, and Rafael Fernández-Cañero, "Media and Social Impact Valuation of a Living Wall: The Case Study of the Sagrado Corazon Hospital in Seville (Spain)," *Urban Forestry & Urban Greening* 24 (May 2017): 141–48.

patients, visitors, and staff thought that the green wall produced positive feelings and promoted psychological wellbeing.[64] Overall, participants agreed with the hospital's investment in the greening system.[65] Thus, being a relatively new technology in HFC design, vertical gardens can generate large publicity and media benefits.

CHALLENGES AND THREATS

The benefits of using vegetation as a building material are vast and include everything from improving building sustainability to improving occupant health outcomes. Despite this, architects rarely think of vegetation as a building material. One reason is because living materials have very different characteristics from your typical building material. Conventional building materials are static, stronger, and homogeneous throughout. Plant matter on the other hand is dynamic, heterogeneous, and environmentally responsive, which can make it more difficult to work with. Furthermore, architects are more comfortable specifying stable and inert building materials. There are certainly challenges and risks associated with working with living plant material in the context of healthcare facilities.

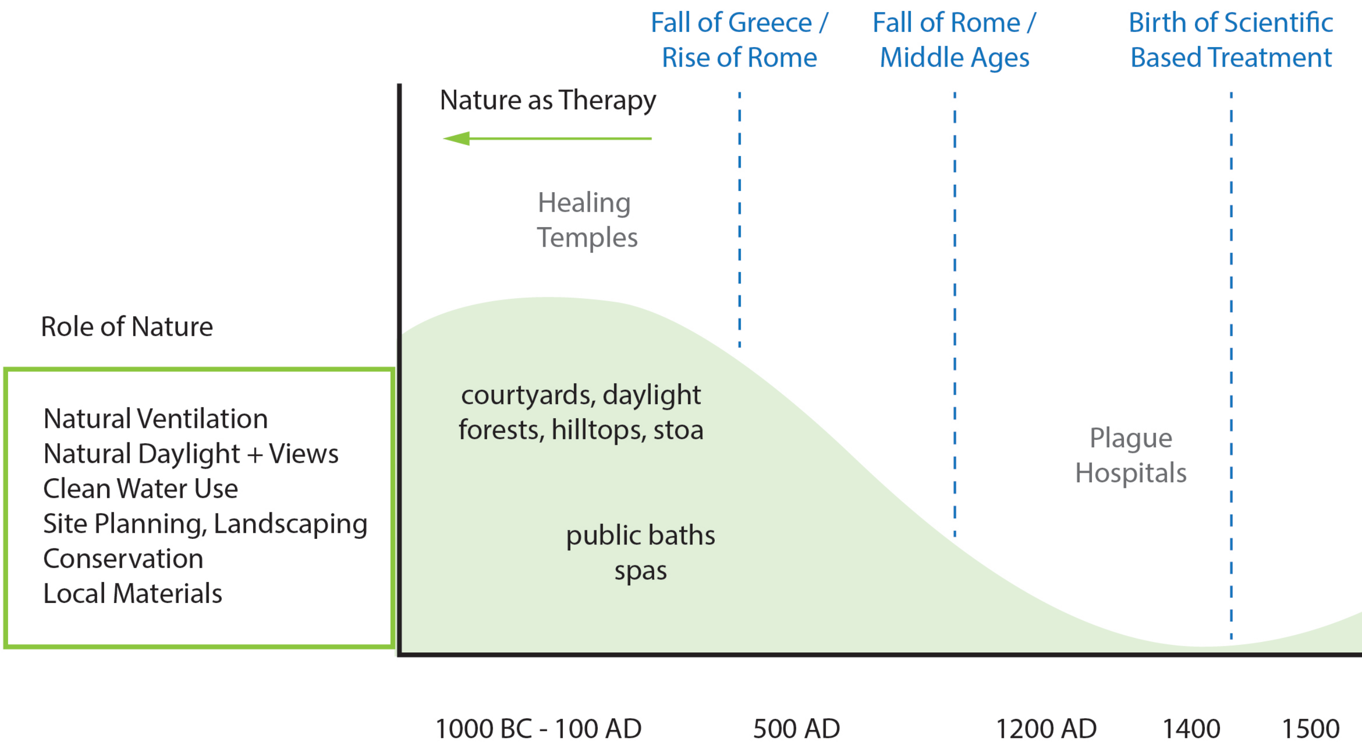
The heterogeneous properties and dynamic behaviours of living materials are the unique qualities that provide environmental benefits, and occupant fascination leading to physical wellness. With all their potential benefits, one of the great challenges for architects is how to use these properties of biological building material to positively affect building design. As Andrea Ling asks, how can we "take advantage of the dynamism of the material and accommodate the unpredictable while still maintaining design influence?"[66] For success, hortitecture should to be part of design vision from the project onset. The more integrated AGS are to achiving the project goals and vision, the less likely the systems will be cut out from the design as the project progresses. As designers of human-constructed environments, architects would benefit from understand the possible interactions and intra-actions among humans and plant matter in buildings.

64 Pérez-Urrestarazu, Blasco-Romero, and Fernández-Cañero, "Media and Social Impact Valuation of a Living Wall."
65 Ibid., 144.
66 Andrea Ling, "Design by Decay, Decay by Design" (Massachusetts Institute of Technology, 2018), 26.

However, vegetation on buildings can suffer from some stigmas. AGS might be viewed as a form of 'greenwashing' or green labeling.[67] In this case, the focus of the greenery system is merely to brand the project as sustainable. The effect may be counter-productive and fuels a capitalist green economy. Financial gains and promotional benefits for a healthcare facility can be achieved more effectively through a focus of achieving actual benefits in building function and performance.

Similarly, because the act of building into the earth with natural materials has such a long history, vegetation on buildings may be perceived as a form of regression in design.[68] Parts or all the building might be hidden if plants are left to grow intensely. This may be the intension of the designer and effectively add mystery and intrigue to the building site. Alternatively, the system may be seen as messy or a hood to hide bad design. Furthermore, choosing the wrong construction type, plant species, or location can lead to poor plant growth, diseases, and pests. Therefore, an understanding of plant species, greenery systems and how they work together would help designers successfully integrate vegetation into healthcare architecture.

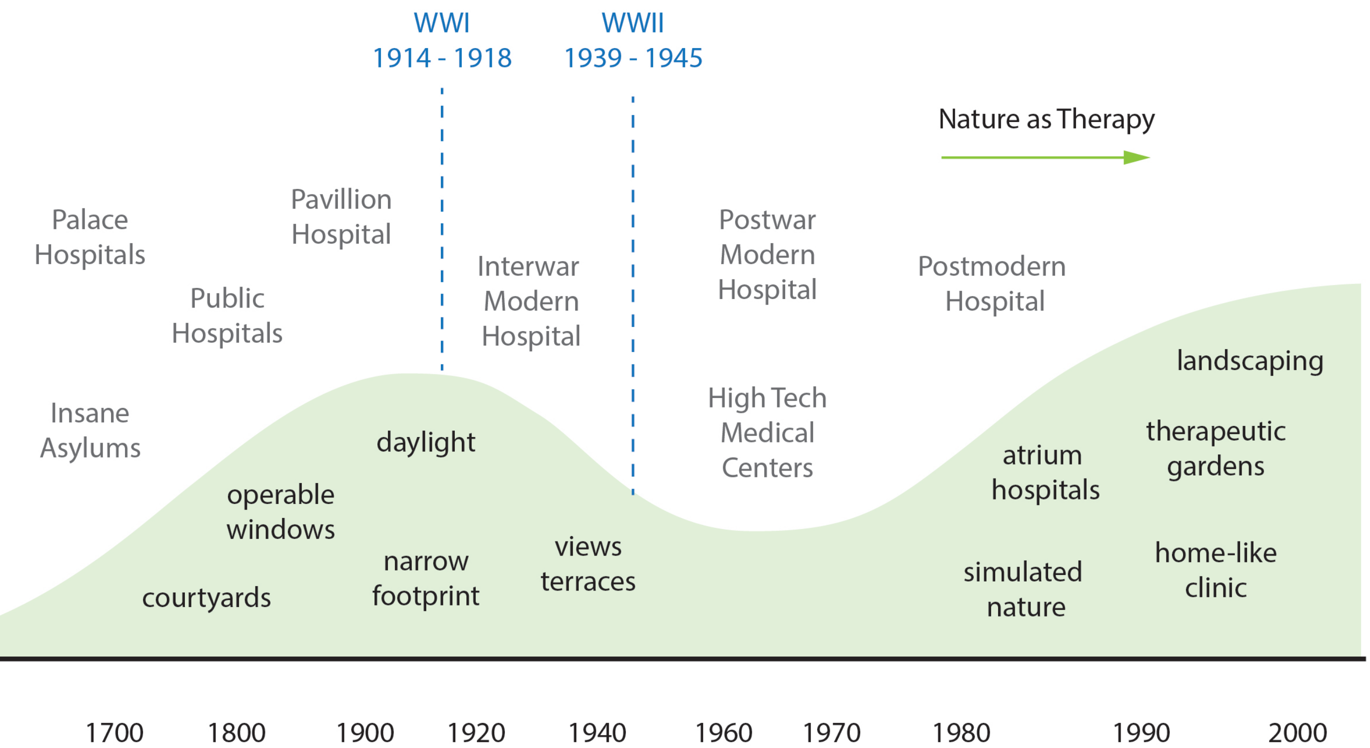
67 Grüntuch-Ernst and Technische Universität Braunschweig, *Hortitecture*.
68 Ibid.



1-18 Role of nature in the history of western hospital design

HISTORY OF NATURE IN HOSPITALS

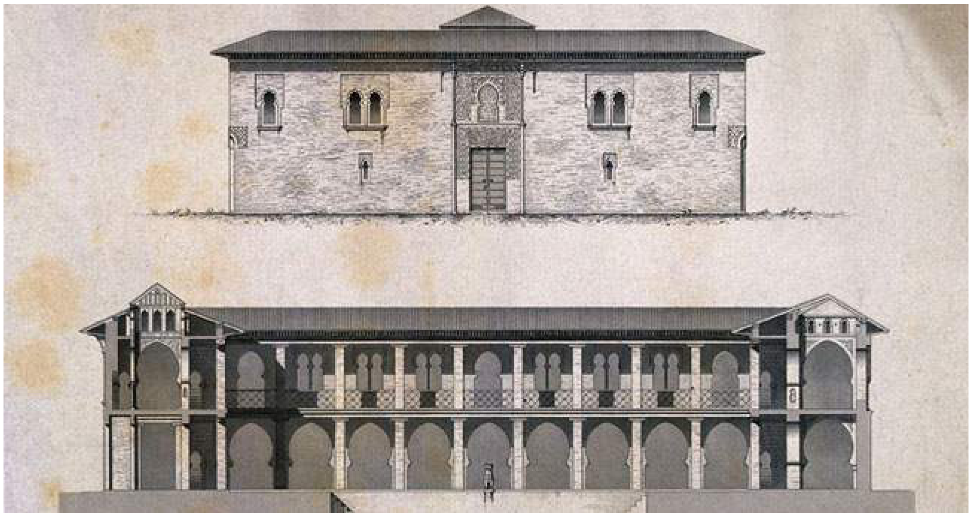
Throughout history, natural systems and processes of the surrounding site influenced the design of healing spaces and had important therapeutic functions. These natural features include daylight, nature views, natural ventilation, clean water, and renewable materials. Figure 1-18 is a timeline of healthcare architecture indicating the degrees to which natural systems supported HCF design. The architecture of hospitals has taken many forms throughout history. In this section, the term 'hospital' is used to refer to a range of historical care facilities that provided aid to large numbers of sick and injured peoples, including soldiers, slaves, and poor. These facilities can be considered architectural precursors to modern day hospitals. This architectural history about the role of natural systems in hospitals provides some insights and lessons about relationships that can form between nature and the design of healing spaces.



ANCIENT HEALING SPACES

From the earliest of times, the cave was a place of refuge for the care and treatment of the sick and dying.[69] In early Neolithic settlements, it became a common practice to separate the ill from the mainstream community in a 'sick house' where family members provided most of the care in a home-like setting.[70] According to Verderber, patterns of discrimination occurred throughout Europe where the impoverished, insane and terminally ill were segregated into sick houses and death houses.[71] Nevertheless, ancient scholars in both eastern and western parts of the world understood the impact of site and micro-climatic conditions on health. There are many ancient examples of healing facilities that utilized the healing qualities of natural systems.

69 Verderber, *Innovations in Hospital Architecture*, 10.
70 Ibid., 10.
71 Ibid., 10.



1-19 Nasrid Bimaristan of Granada, Spain

Urban hospitals in ancient Middle East and Asia were more advanced compared to those in Europe at the time.[72] The earliest known hospitals were found in Middle Eastern countries like Iraq, Iran, Egypt, and Turkey.[73] There, ancient healthcare buildings contained landscaped courtyards and strong relationships with nature through water features and fountains (see Figure 1-19). Healthcare buildings in Japan and China included secular and spiritual types.[74] Care of the sick and ill in East Asia was primarily done in the private dwelling by family members.[75] For example, younger family members would provide care for elderly within multi-generational households. Health care in private homes centered around maintaining balance in the body through food and herbal soups.

The ancient Greeks and Romans also understood the therapeutic benefits of nature, as seen in imperial bath complexes like the Baths of Diocletian (Figure 1-20). The Greek physician, Hippocrates, spoke of the impact of seasons, clean water supply, and site orientation on human health outcomes.[76] The open halls of healing temples in ancient Greece were positioned on hillsides where there was the freshest water, and oriented

72 Verderber, *Innovations in Hospital Architecture*, 10.

73 Joel Montague, "Hospitals in the Muslim Near East: A Historical Overview," *Mimar 14: Architecture in Development*, 1984.

74 Verderber, *Innovations in Hospital Architecture*, 10.

75 Ibid., 10.

76 Ibid., 10.

1-20 Rendered cross-section of the Baths of Diocletian in Rome

buildings to take advantage of sunlight and breezes.[77] Ancient Greek temples, called Asklepieion, devoted to Asclepius, the demigod of healing, provided hospitality and healing spaces for the masses.[78] They were designed to promote physical and spiritual recuperation through healthy food, bathing rituals, and restful sleep.[79] Similarly, the Roman valetudinarium, from the first and second centuries AD, were facilities for the rehabilitation of military soldiers or slaves of affluent families.[80] Modeled after Persian architecture, they were inwardly focused buildings featured four wings and a peristyle surrounding a central courtyard or garden.[81]

MEDIEVAL EUROPE

The use of nature and landscape diminished in European hospitals during the Middle Ages. It would not re-emerge in the West until the natural spring

77 Guenther and Vittori, *Sustainable Healthcare Architecture*, 66.

78 Guenter B. Risse, *Mending Bodies, Saving Souls: A History of Hospitals* (New York: Oxford University Press, 1999), 45.

79 Ibid., 57.

80 Verderber, *Innovations in Hospital Architecture*.

81 Risse, *Mending Bodies, Saving Souls*, 46.

1-21 Hôtel-Dieu of Tonnerre, France, former hospital converted to museum

wellness retreats of the nineteenth century.[82] Deadly epidemics swept through communities in Medieval Europe killing near entire populations of people. For example, during the bubonic plague in the mid-1300s, masses of sick people were housed inside dirty, dark, and poorly ventilated buildings. In Medieval Europe, charitable medical care was provided by Christian religious orders through networks of monastic hospitals based on cross-ward plans.[83] These open ward plans had miserable conditions because they were poorly heated and provided minimal natural daylight and ventilation.[84] Cross-ward monastic hospitals like Hôpital Notre-Dame de Fontenilles in Tonnerre, France, had small drainage holes in the stone walls beneath each window or ventilation holes drilled into the wooden slat ceilings (see Figure 1-21).[85] The concept of care was based on allowing patients to hear mass everyday and focused on their proximity to the alter.[86] The hospice complexes that first appeared in the middle ages provided better conditions than the chapel-ward buildings because they provided contact

82 Verderber, *Innovations in Hospital Architecture*, 17.
83 Ibid., 17.
84 Ibid., 18.
85 Ibid., 18.
86 Ibid., 17.

with terraced gardens and landscapes.[87]

Nevertheless, one sustainable aspect of the monastic hospitals in feudal Europe was their self-sufficiency in food production. The monastic medical centers operated farms onsite that raised livestock and agriculture to produce all their daily necessities.[88] Furthermore, many of these hospitals also had their own cisterns.[89] This self-sufficiency was important during times of war, famine, and social upheaval.[90]

The insane asylum was a new building type for the mentally ill and for social outcasts. Although some lunatic asylums were large with courtyards, the typical institution had poor air quality and very little to no natural light. The insane asylums that were later built in Europe and North America were also self-sustaining in terms of on-site food production. This practice of agricultural practice with acres of land farmed by inmates and patients was continued in many lunatic asylums up until the twentieth century.[91]

EIGHTEENTH AND EARLY NINETEENTH CENTURIES

The architecture of pre-modern healthcare buildings seems to follow the course of history about the knowledge of germ theory and infectious diseases, starting with the enlightenment and industrial revolution.[92] The industrial revolution brought with it further developments in anesthesia, surgery techniques, and medical treatments.[93]

In the 1700s, western aristocrats redesigned their countryside to fit landscape ideals of the time.[94] These tranquil, pastoral landscapes were seen as the healing remedy to unhealthy conditions of urban life during the industrial revolution.[95]

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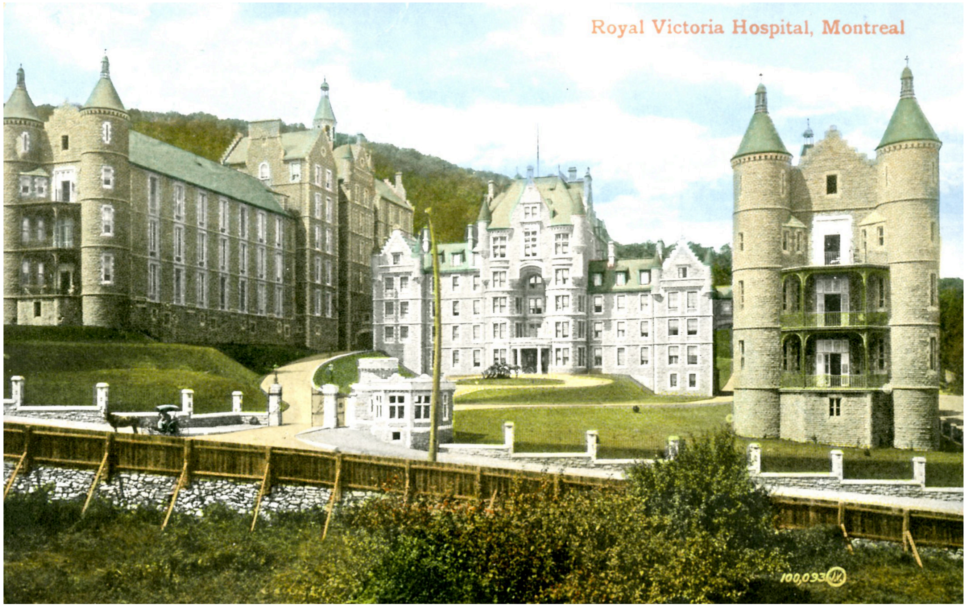
87 John D. Thompson and Grace Goldin, *The Hospital: A Social and Architectural History* (New Haven: Yale University Press, 1975), 56.
88 Verderber, *Innovations in Hospital Architecture*, 18.
89 Ibid., 18.
90 Ibid.,18.
91 Ibid.,19.
92 Sternberg, *Healing Spaces*.
93 Guenther and Vittori, *Sustainable Healthcare Architecture*, 66.
94 Ibid., 70.
95 Ibid., 70.



1-22 Royal Victoria Hospital, Montreal

NIGHTINGALE MOVEMENT

In the 1800's, Florence Nightingale, a British nurse and social reformer, helped transform western hospitals from dark and dirty "death-traps" to spacious "pavilion-plan" hospitals that utilized daylight and cross ventilation to prevent infection.[96] The "pavilion-plan" hospital of Nightingale, like Montreal's Royal Victoria Hospital of 1893 shown in Figure 1-22, provided plenty of space, natural light and ventilation.[97] Hospital buildings again focused on healing through sustainable building design features like landscaped courtyards, nature views, and access to clean water.[98] Design specifications like open wards and large windows next to patient beds ensured abundant fresh air and daylight could flow through the spaces.[99] To access greater amounts of daylight, nature views and fresh air, the early nineteenth century pavilion hospitals were often situated away from dense urban environments.[100]

96 Annmarie Adams, "Canadian Hospital Architecture: How We Got Here," *Canadian Medical Association Journal* 188, no. 5 (March 15, 2016): 370–71, https://doi.org/10.1503/cmaj.151233

97 Ibid.

98 Guenther and Vittori, *Sustainable Healthcare Architecture*, 66.

99 Ibid., 66.

100 Ibid., 66.

SPA MOVEMENT AND SANITARIUMS

In North America during the nineteenth century, the use of nature for healing began to deviate away from critical care buildings. Hospitals before World War II (WWII) looked more like schools or town halls.[101] However, nature-based healing features continued to flourish in alternative types of healthcare buildings in North America, such as the nineteenth century spa resorts.[102] In the nineteenth century, writers Ralph Waldo Emerson and Henry David Thoreau, argued for a return to nature through authentic contact with wilderness, which lead to the development of national public parks in America.[103]

Tuberculosis sanitariums were another HCF type that maintained relationships with landscape and gardens. Disease outbreaks occurred in cities as they grew and became more polluted with industrial sites. Affluent individuals retreated to hot and humid vacation locations where conditions were healthier. Nineteenth century spa retreats are a precursor to contemporary health facilities like wellness centres, hot springs, and spa retreats in vacation hotels.[104] Adams describes the building types between the wars to be like aristocratic housing with smaller rooms and other hospital practices like surgeries and morgues in separate specialized places.[105]

POST-WAR MODERN HOSPITAL

While some types of HCF like resort spas and tuberculosis sanatoriums retained their focus on healing landscape features, hospitals in the early twentieth century distanced itself from restorative aspects of nature in pursuit of "mastery over nature".[106] The unsustainable mega hospital characterized healthcare buildings after the second world war into the twenty-first century.[107] Post WWII hospitals featured wider corridors and

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101 Adams, "Canadian Hospital Architecture."
102 Verderber, *Innovations in Hospital Architecture*, 28.
103 Guenther and Vittori, *Sustainable Healthcare Architecture*, 70.
104 Verderber, *Innovations in Hospital Architecture*, 29–30.
105 Adams, "Canadian Hospital Architecture."
106 Guenther and Vittori, *Sustainable Healthcare Architecture*, 66.
107 Verderber, *Innovations in Hospital Architecture*, 38.

1-23 Vancouver General Hospital Centennial Pavilion

housed large technological equipment.[108] Hospital architecture of this period like Vancouver General Hospital Centennial Pavilion (Figure 1-23) took on an international style modernism with functionality and efficiency at its forefront.[109] Tiled walls connected to tiled floors, and countless stainless-steel surfaces were utilized because of they were easier to wash and keep sterile. While the need for sterile environments took hold, hospitals became high-tech medical centres, notorious for their hard and cold surfaces and long white corridors flanked by countless number of examination and treatment rooms. The plethora of hard surfaces reflecting noises, and views of medical equipment and paraphernalia caused residents further anxiety.

The industrialization of medical technology led to further distancing from biological systems. Medical technology became more aggressive in fighting diseases.[110] As the medical and pharmaceutical industries progressed, North American healthcare buildings lost their connections with nature

108 Adams, "Canadian Hospital Architecture," 370.

109 Ibid., 371.

110 Guenther and Vittori, *Sustainable Healthcare Architecture*, 65.

1-24 McGill University Health Centre, Montreal

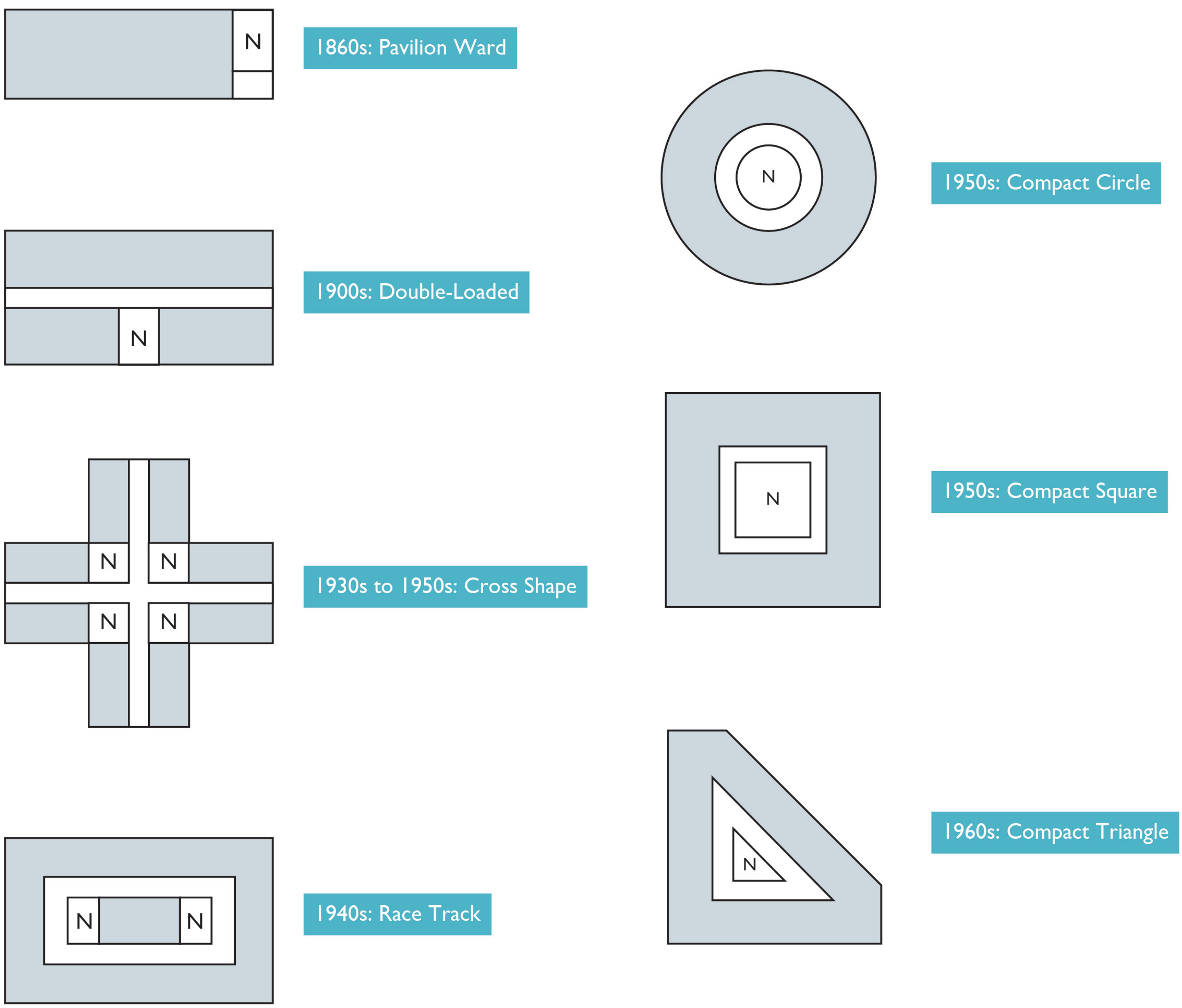
and became more sealed and artificial environments.[111] Nature is often perceived as a source of infections and in opposition to the battle against illness, which Guenther argues is reflected in North American hospital architecture today.[112]

Knowing the health benefits of nature, planners after the World Wars located community hospitals at the outskirts of cities where they would be surrounded by greenery and provide healing nature views for patients.[113] During suburban sprawl post-WWII, hospitals were sited in suburban areas where there were plenty of access to exterior green spaces. However, suburban sites soon became engulfed by urban development. As cities grew, many of these hospitals found themselves surrounded by dense urban settings. Therefore, calming views of natural landscapes outside of windows became congested views of neighbouring buildings, surface parking, or above ground parkades.

POSTMODERN HOSPITAL

By the late twentieth century, the restorative and healing effects of nature was discovered again in hospital architecture. Architects became more aware of the therapeutic effects of nature and views, and the negative

111 Guenther and Vittori, *Sustainable Healthcare Architecture*, 65.
112 Ibid., 65.
113 Verderber, *Innovations in Hospital Architecture*, 38.



1-25 Nursing-unit forms

effects of the cold and sterile designed hospitals of the mid-twentieth century.[114] Postmodern architecture appeared in the 1980s and hospitals like McGill University Health Centre became more colourful and spread out horizontally (see Figure 1-24).[115] Anxiety inducing views of medical equipment and technology were hidden and separated from patient and visitor circulation. Hospital streets, focused on consumerism, were lined with shops, restaurants, and cafes. The resulting hospitals resembled little towns, airports, and shopping malls with many interconnected buildings and large glass atria. Many design features like therapeutic gardens, atria, and retail spaces were added to de-institutionalize the hospital and make them feel more familiar.

NURSING UNIT CONFIGURATIONS

Nursing units have also evolved in form by locations of patient beds relative to one another and nursing service areas. Many plan forms have been tried over the past couple of centuries, as can be seen in Figure 1-25. The pavilion ward, starting in the 1860s, housed multiple patients together in open wards with minimal circulation corridors. The single-bed room pre-WWII The double-loaded plan with rooms containing multiple beds was introduced in the 1900s and became the most dominate configuration for hospitals throughout the 1950s.[116] The racetrack plan was created by pulling apart rooms to fit a center core containing support amenities and service rooms. The racetrack plan took over as the leading configuration by the 1960s in the US.[117] Although highly efficient for the day, the double-corridor, racetrack plan could cause problems with high travel distances from end to end during staffing shortages.[118] Hospitals after WWII that still exist today were normally comprised of two-bed patient rooms with shared toilets and showers. The compact square, circle, and triangle plans emerged because of concerns about inefficient traffic patterns between departments,.[119] The compact circular plan arrayed beds around a central nursing station, reducing distances to work cores. The compact triangle

114 Adams, "Canadian Hospital Architecture," 371.

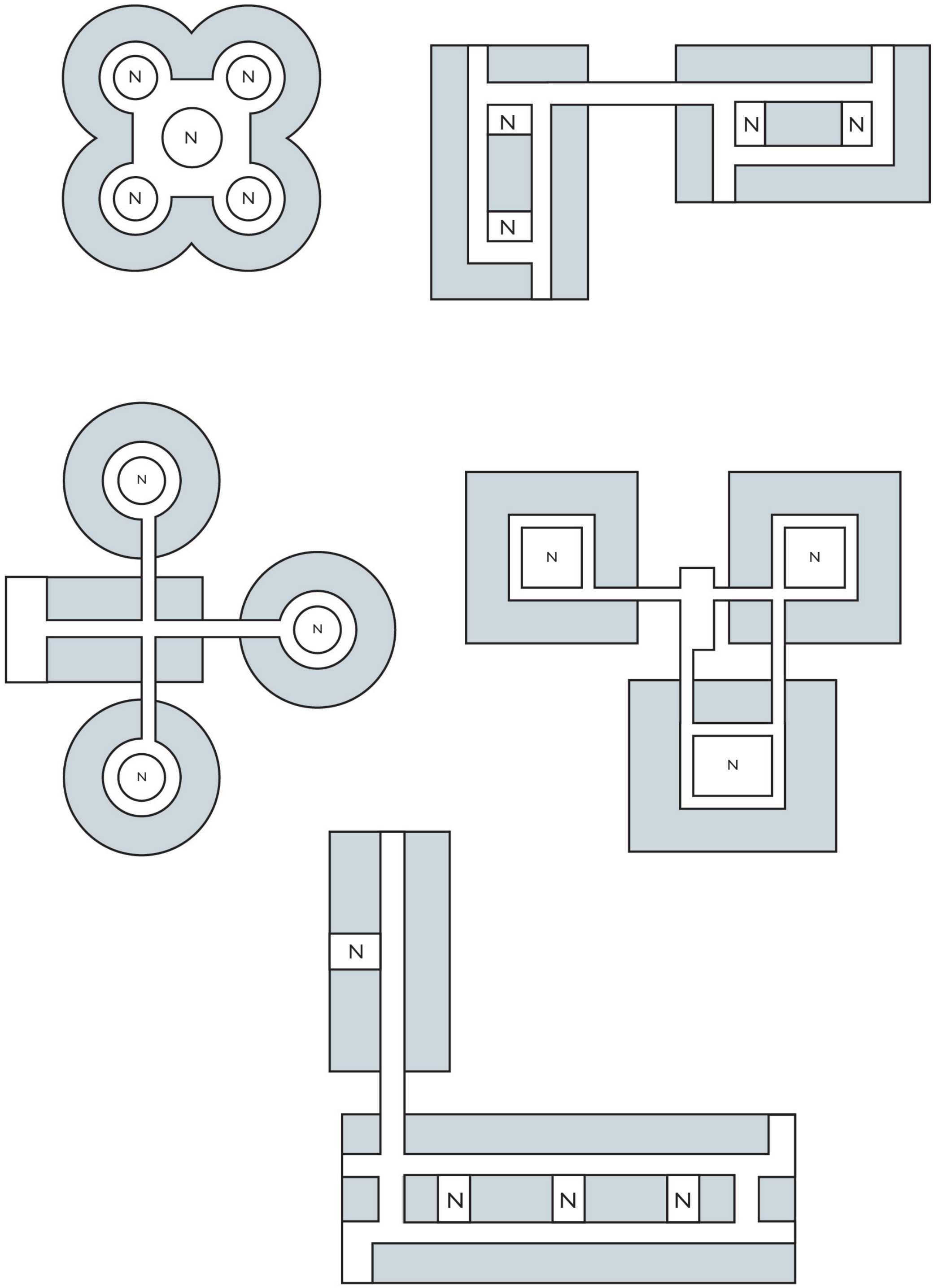
115 Ibid. ,371.

116 Richard L. Kobus, ed., *Building Type Basics for Healthcare Facilities, 2nd ed,* Building Type Basics (Hoboken, N.J: J. Wiley, 2008), 187.

117 Verderber, *Innovations in Hospital Architecture*.

118 Kobus, *Building Type Basics for Healthcare Facilities*, 188.

119 Ibid., 188.



1-26 Example nursing-unit configurations plan combined the circular plan's ability to radiate outwards and connect with existing building, with the cost efficiency of linear wall construction.[120] These compact units make very efficient floor plans when clustered into concentric groupings (refer to Figure 1-26).

CONTEMPORARY PATIENT ROOM

Patient accommodation in nursing units progressed from totally open spaces, to eight-, six-, four-patient wards and two-bed patient rooms with shared toilet and bathing facilities, to the private single-bed rooms with individual toilet and shower.[121] Nursing units with all single-patient rooms is widely accepted today.Advantages of single bed per room hospitals include increase privacy and control, reduction of medical errors from less patient moves, and the ability for hospitals to achieve100 percent room occupancy.[122] Other changes to patient rooms include identical same handed rooms, universal room designs, and relocation of toilet and bath facilities to the periphery of the room to improve visibility.[123] Universal rooms are a single type of room that can support patients through changing levels of acuity including the most intensive care, thereby reducing the number of patient transfers in the case the patient condition worsens or improves.[124]. Many facilities have several nursing substations, each with access to medical records, medications and supplies, or nursing workstations dispersed across patient rooms, for improved monitoring of patients. Nurse travel times have been reduced due to advances in mobile supply carts, and computerized medical records. Patient rooms are equipped with computer charting stations at the bedside, and there are increases in bedside treatments. Patient room sizes have therefore increased to accommodate more equipment, family support spaces, and utilities.[125]

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120 Stephen Verderber and David J. Fine, *Healthcare Architecture in an Era of Radical Transformation* (New Haven, CT: Yale University Press, 2000), 41.
121 Kobus, *Building Type Basics for Healthcare Facilities*, 191.
122 Ibid., 192.
123 Ibid., 192.
124 Ibid., 193.
125 Ibid.,194.

CSA Z8000-18, National Standard of Canada, Canadian Health Care Facilities

The OASIS Principles

5 key design objectives of requirements set forth in the Standards

- Operations (effectiveness + efficiency)
- Accessibility
- Safety + Security
- Infection Prevention + Control
- Sustainability

1-27 CSA standard for Canadian Health Care Facilities OASIS principles

HEALTHCARE FACILITY DESIGN STANDARDS

The design of HCF environments is the result of requirements set forth in the *CSA Z8000-18*. Key objectives are expressed by the OASIS Principles, which stands for operation efficiency and effectiveness, accessibility, safety and security, infection prevention and control, and sustainability (refer to Figure 1-27).[126]

These objectives do not seem like they would create a healthcare environment like an actual OASIS, that is a fertile and peaceful place for safety and sustenance. However, lines within the operations portion of the standards, speak about designing an environment of care that promotes healing and wellness (see Figure 1-28).[127] It includes objectives to reduce

126 Canadian Standards Association, *Z8000-18 Canadian Health Care Facilities*, 2nd ed. (Toronto: CSA Group, 2018).
127 Ibid.

4.2 Operations

Notes:
1) Operations considerations include

a) an environment of care that promotes healing and wellness, and is sensitive to the needs of individuals;

4.2.2 Environment of care

4.2.2.3 To promote a safe and effective environment of care, the HCF should be designed to achieve the following objectives:

a) reduced stress for patients and their families, visitors, and staff;

...

i) sensitivity to the cultural beliefs and expectations of the expected patients where appropriate (e.g., selection of colours or materials that are associated with healing);

j) promotion of a healing environment through design and choice of materials for interior furnishings and finishes; and

k) foster a sense of control over the environment by giving patients access to information, navigation, and environmental preferences through the use of technology

1-28 Lines from CSA Z8000-18, Standard for Canadian Health Care Facilities stress, to promote a healing environment through design and material choice, and to select colours or materials that are associated with healing.[128] Given that there is scientific evidence to support that vegetation promotes healing, architectural greenery could fit within these guidelines as a smart material choice that would help organizations achieve operational effectiveness and efficiency. Therefore, it would be a logical decision to utilize AGS wherever possible within environments of care.

THE FUTURE OF NATURE IN HOSPITAL DESIGN

Canada is moving towards smaller community-based facilities, reserving hospitals for acute and specialist care.[129] Both community-led healthcare facilities, and large regional hospital sites could benefit from more living greenery systems in architecture, supported by models of patient-centered care and evidence-based research. Over the last several decades, nature has regained attention for its therapeutic qualities and benefits in healing. Consequently, many healthcare architects seek to bring biophilic elements into medical sites, especially in the case of women's and children's hospitals, but often designers do not seek to integrate much living nature into these spaces. AGS are not yet utilized to full capabilities in the design of a HCFs. A new model is needed, one that does not look like contemporary office buildings, or shopping malls. Let us not go back to the sealed buildings of the mid-twentieth century hospitals.

An ecologically holistic and long-term approach to health care needs to be taken. Contemporary wellness centres and organic residential architecture might offer ideas on how healthcare architecture can create more comfortable spaces that relate to nature. However, I believe it could be taken further by including ideas about entanglements with non-human partners and ecological sustainability. According to Adams, innovation in Canadian hospital design is restricted because only a few design firms have the hospital design expertise to design them, and there is a lack of healthcare design being taught in Canadian architecture schools.[130] I believe a revolution in hospital design is needed to avoid pitfalls that have beset hospital designs historically.

128 Canadian Standards Association, *Z8000-18 Canadian Health Care Facilities*, 2nd ed.

129 Canadian Institute for Health Information, *Access to Palliative Care in Canada*.

130 Adams, "Canadian Hospital Architecture," 371.

Architectural vegetation should not be a design afterthought or left to the hands of subconsultants. Instead, the integration of nature should be included in the hospital design vision as early as possible. The synthesis of vegetation and architecture will create calming spaces that are comfortable for patients within, with the larger goal of being more humanly and ecologically sustainable for the earth in the long term. This takes medical care beyond solely treating disease, to a salutogenic approach to wellness that supports the health of humans and non-humans alike. Utilizing natural systems, not only as inspiration, but as active agents in the therapeutic healthcare environment and in building systems will advance the aesthetics and concept of hospitals in the community. Furthermore, the social and aesthetic benefits of AGS can make health care environments become a central space for community investment, involvement and gathering.

Part 2 : Greenery System Technical Guide

SYSTEM TYPOLOGIES

DESIGN PRINCIPLES

What benefits are gained by elevating vegetation to the heights of buildings? Moreover, what greenery systems are available and how can designers apply them to healthcare spaces? The following section provides key information and considerations about various architecture greenery systems (AGS). The aim of this section is to provide a fundamental understanding of a selection of greenery system construction types, how they work, and how they can achieve the goals of HCF projects.

There are many approaches to vegetating buildings. Common AGS typologies are green façades, green walls, and green roofs. Each typology has multiple construction types with unique benefits. AGS technologies can provide benefits to healthcare design projects ranging from small to large scale, and from retrofits to new constructions. The diversity of AGS construction types available allows designers to fulfill a range of building design challenges.[1]

This section organizes common AGS construction types for designers to apply them effectively in healthcare architecture projects. What greenery systems to use on a healthcare project depends on existing site conditions and project design goals. Designers should carefully consider the technology and variations of each system for the most efficient and functional benefits for the healthcare facility.[2]

1 van Zuilekom, "Guidelines for Going Green," 27.
2 Ibid., 27.

SITE ANALYSIS

A site analysis should investigate the following: climate and seasonal variations, surrounding vegetation and environment, structural load bearing capacity, drainage discharge points, irrigation water sources and storage, existing structure and area, as well as maintenance access and storage.[3] It is important to analyze both the macro and micro scale environmental conditions to fully understand the nature of the site.[4] Understanding the regional ecosystem and adapting to the site's natural environment helps designers create an environment of coexistence and symbiosis with nature. Research of site conditions for an exterior project can include studies of topography, geography, soil, regional materials, and surrounding ecosystem. Climatic elements like wind speeds, temperature, precipitation, humidity, and sunlight levels all greatly influence plant growth. Matching system technology and plant species with these ecological conditions will reduce energy use and maintenance levels.

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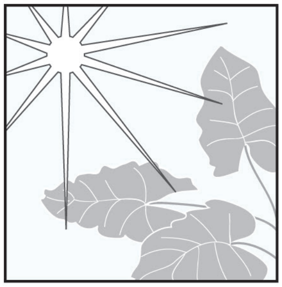
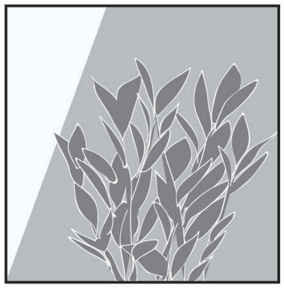
3 Tong and Yin, *Living Wall: Jungle the Concrete* 2, 10.

4 Ashizawa, "Guidelines for Green Façades and Roof Gardens," 16.

USE HARDY PLANTS WITH HIGH...

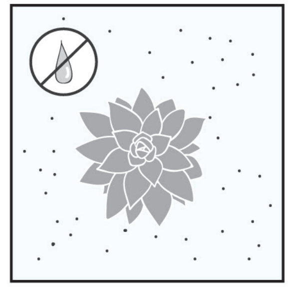


Sun tolerance



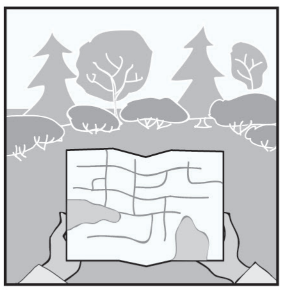
Shade tolerance

Wind tolerance



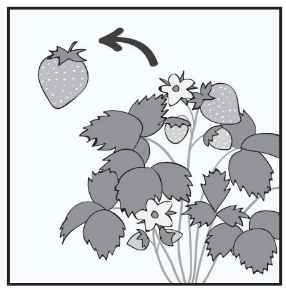
Drought tolerance

LOOK FOR PLANTS THAT...



Thrive locally

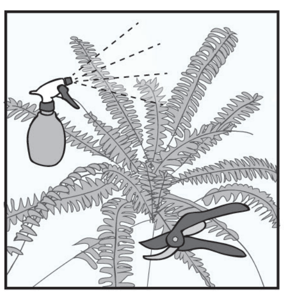
Attract wildlife



Produce food

Provide seasonal colour and texture

AVOID SPECIES THAT ARE ...



High maintenance

Poisonous or toxic

Spiky or thorny

Prone to pests and diseases

2-1 Ideal plant characteristics for architectural greenery systems

PLANT SPECIES SELECTION

Plant selection is one of the most critical steps in designing a successful AGS. Different VGS will be more appropriate than others for different plant growth habits, such as clumping, scrambling, cascading, creeping, or upright.[5] Plant species selection depends on the site conditions, project goals, and the system type. For example, green walls can accommodate a wide range of plant species, from shade loving ferns, to dry loving succulents, to nutrient hungry edible plants. Common characteristics of AGS plants are hardiness, slow growth, as well as shallow and fibrous roots. Some species provide added benefits like air or water purification, or have attractive blooms, fragrant scents, or edible parts.

PLANTS TO SATISFY PROJECT GOALS

Plant selection can help achieve your project's goals, whether that be increasing sustainability by choosing native plant species, attracting beneficial wildlife, or producing food (refer to Figure 2-1). Foliage color, leaf texture, and flowering times are all considered in creating the desired composition. This creates greater therapeutic qualities through higher levels of cognitive and sensory interest at various distances from the system, and at different times of the year. If a project's goal is to increase biodiversity and site sustainability, consider including a variety of plants that attract wildlife. Species that attract wildlife have features like fruits and nectar-producing flowers.[6] These outdoor species provide insects, bees and birds with food, nesting material, and protection from predators. Man-made bird houses and bee boxes can also be integrated into greenery systems.

Plants can only prosper in their ideal environment; therefore it is important to do a site analysis before selecting the types of plants you will use. A successful VGS will contain reliable and robust species. Good candidates are species that perform well in challenging conditions. Exterior gardens should contain species that thrive in the area's temperatures, winds, and

5 Tong and Yin, *Living Wall*, 20.
6 Ibid., 11.

precipitation levels.[7] Sunlight and wind conditions can vary at different heights of a multi-storey exterior systems, with the tops, corners, and sides generally having the greatest wind exposure. [8] Extremely robust species naturally have high wind and sun tolerances and would therefore do well in GWs in these highly exposed locations. Consider that a system can develop its own working ecology as plants mature. Larger plants may grow to provide shade, wind protection, or conserve humidity for smaller plants. Vigorous species can be used to create protective microclimatic niches for sensitive plant species.[9]

Many tropical species make suitable plants for indoor GW. Most 'house plants' are tropical rainforest plants, which are accustomed to shady and warm conditions very similar to our indoor human environments.[10] See Appendix A for a selection of low-light and bright-light tropical plant species. Appendix B offers a selection of outdoor green wall plant species, as well as a selection of climbing plant species that can be used on GF systems. These outdoor plants vary in their hardiness zones. Therefore, some species are more suitable than others for cold Canadian climates.

PLANT CHARACTERISTICS TO AVOID

Most AGS providers will avoid species that are prone to nutrient deficiency, pests, diseases, or weeds.[11] They will also avoid species with spikes or thorns. Some healthcare occupants, like children and mental health patients, may ingest parts of plants. Therefore, avoid using species that cause skin irritations or are toxic if ingested in areas where occupants can reach plants. Some indoor spaces where occupants spend large amounts of time, such as waiting rooms and reception areas may also want to avoid using species that can cause allergic reactions, such as ferns with spores.

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7 Tong and Yin, *Living Wall*, 13.

8 Ibid., 20.

9 Ibid., 20.

10 "How to Choose Plants for Living Walls," Plants on Walls: Florafelt Living Wall Systems, accessed May 12, 2021, https://www.plantsonwalls.com/guides/how-to-choose-plants-living-walls/.

11 Tong and Yin, *Living Wall*, 13.

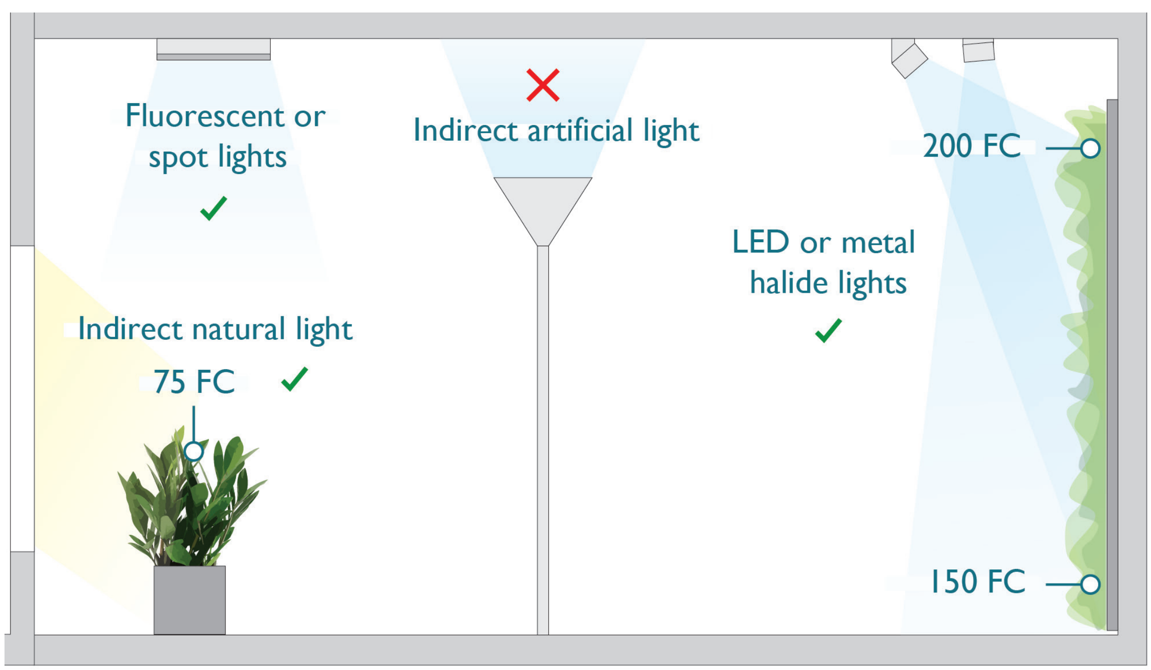
Duration:
10 - 12 hrs / day

Colour Temp = 4,500 K - 6,000 K

Even distribution of light from above to avoid eye glare, design for comfort

Brightness:

Low-light	50 - 100 FC
Med-light	100 - 250 FC
High-light	250+ FC
Green wall	150+ FC



2-2 Interior architectural greenery lighting requirements

LIGHTING

Another big component of AGS is lighting (refer to Figures 2-2 and 2-3). Exterior greenery systems may employ low light tolerant species for deeply shaded, urban canyons and high light tolerance in exposed and elevated settings. South, east, and west facing green walls are most common because plants receive the most direct daylight exposures. GW providers can also suggest plant species that will thrive in less exposed north facing installations as well.

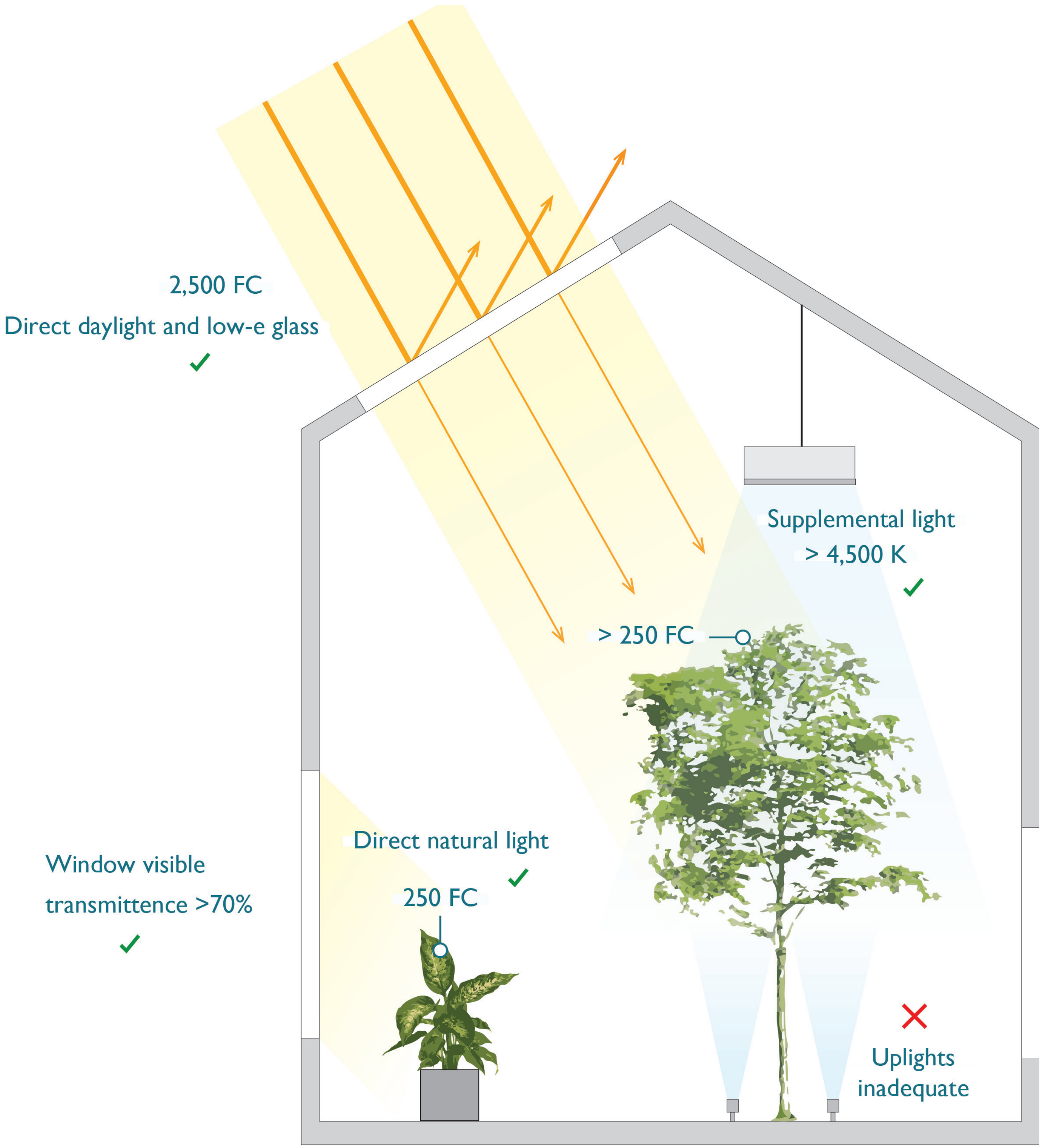
Plants require very specific lighting quantities and qualities to grow. In artificial indoor settings, plants need white light for at least ten to twelve hours a day.[12] The minimum light intensity or illuminance required, measured in foot-candles (FC), depends on whether you are using low, med, and bright light plant species. Indoor bright light plants and atrium trees need a minimum of 250+ FC.[13] Refer to Appendix A for a list of low-light and bright-light tropical plant species.

Often direct or indirect daylight from facing windows or skylights can provide adequate natural illumination. As a reference, daylight from windows range in intensity from 100 – 5,000 FC. Where there is not adequate natural light from windows, supplementary lighting can come from LED, metal-halide, spotlights, or fluorescent artificial lighting.[14] For GW, even distribution of light is necessary, and several rows of lights may be required to achieve this. Consideration should be made to avoid eye glare and design for human comfort, especially in healthcare projects.

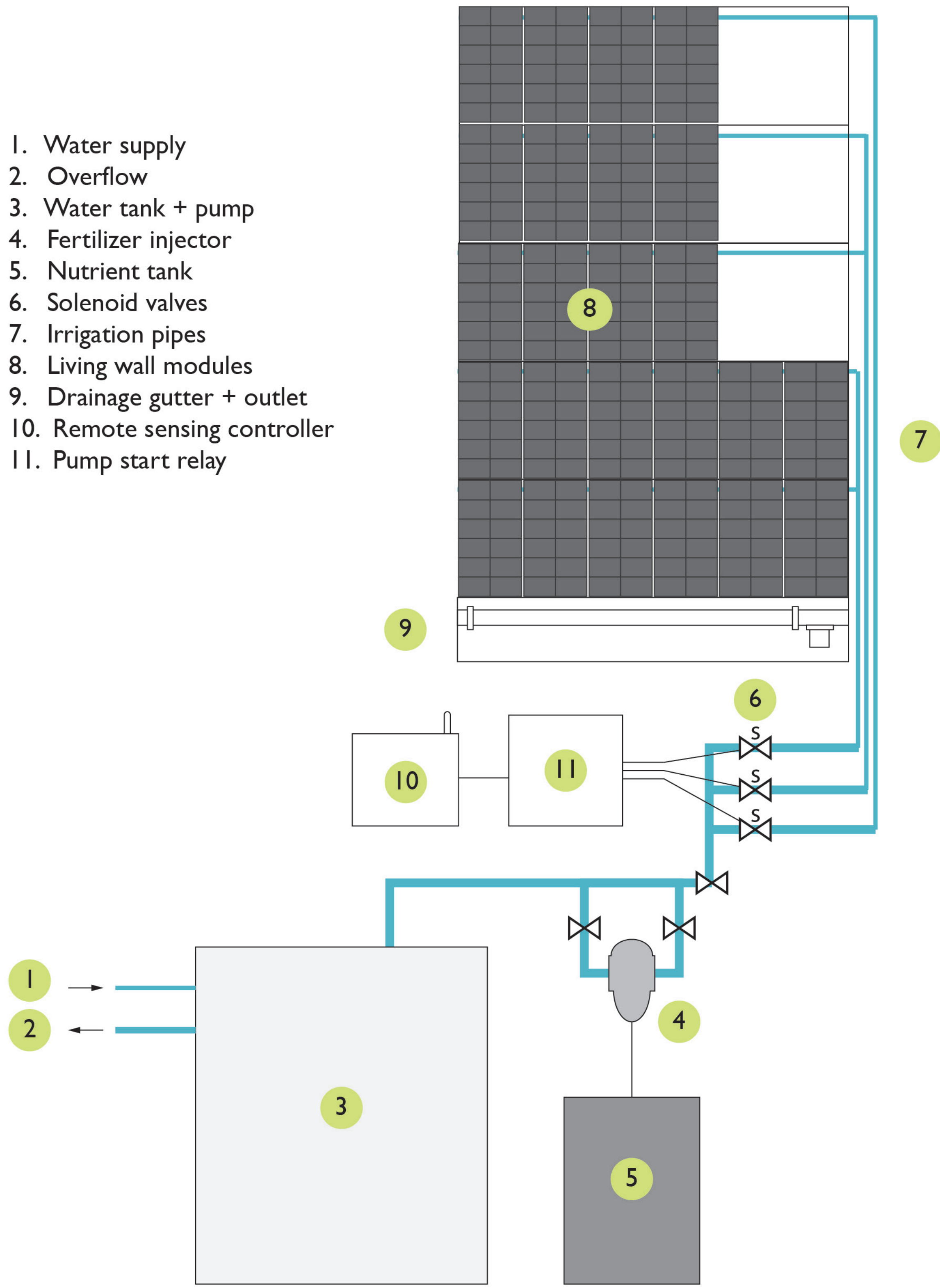
12 Shane Pliska, "Planterra Lighting Guide for Interior Landscape Design" (Planterra Corporation, 2019), www.planterra.com/light, 14.

13 Ibid., 14.

14 Ibid., 14.



2-3 Interior architectural greenery lighting requirements



2-4 Typical green wall irrigation system

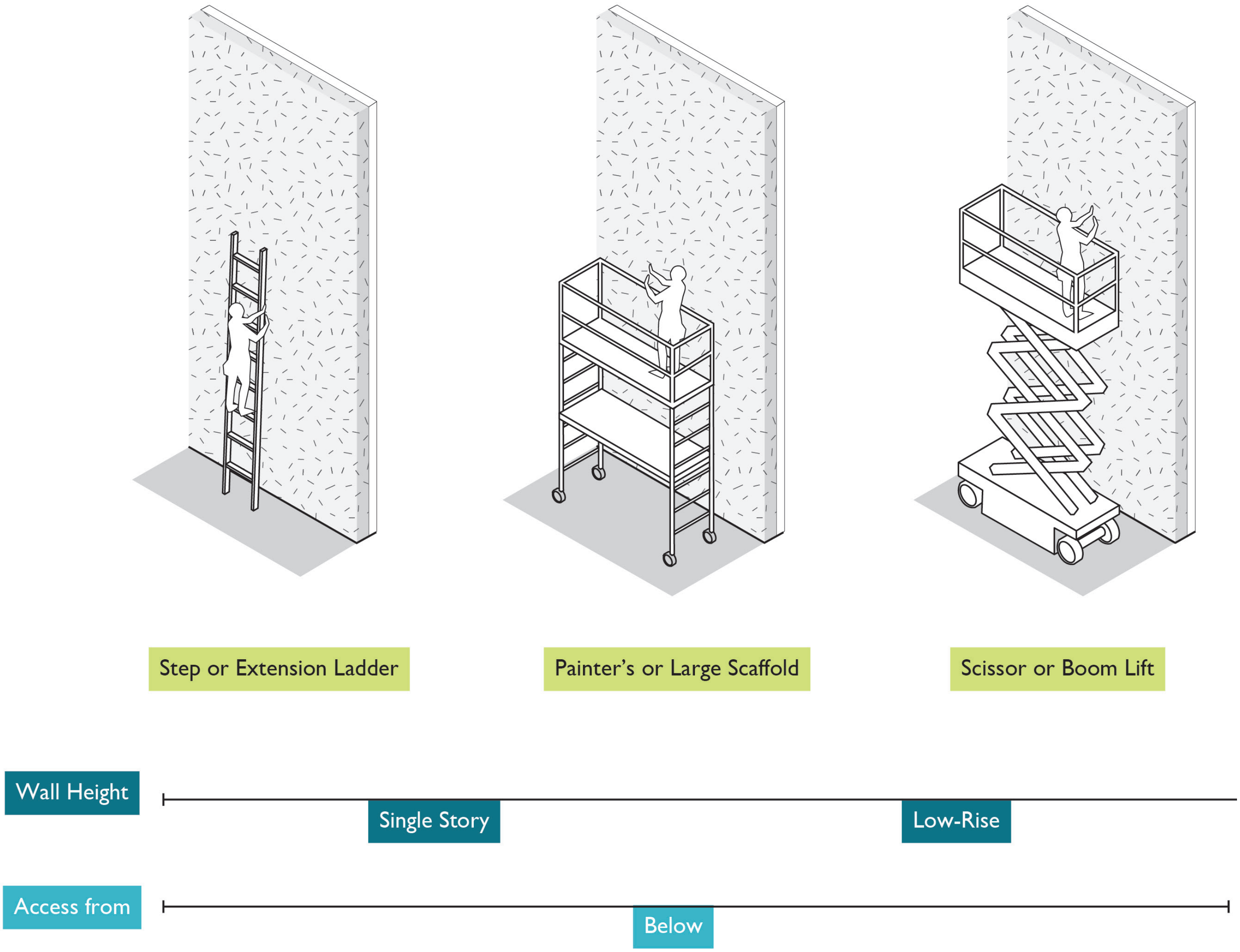
IRRIGATION

One of the main reasons for system failure is inconsistent watering. Built-in automated irrigation systems reduce maintenance and provide consistent water supply, which minimizes plant loss.[15] Adequate water supply, proper drainage, and good site access is important for vegetation growth and maintenance.

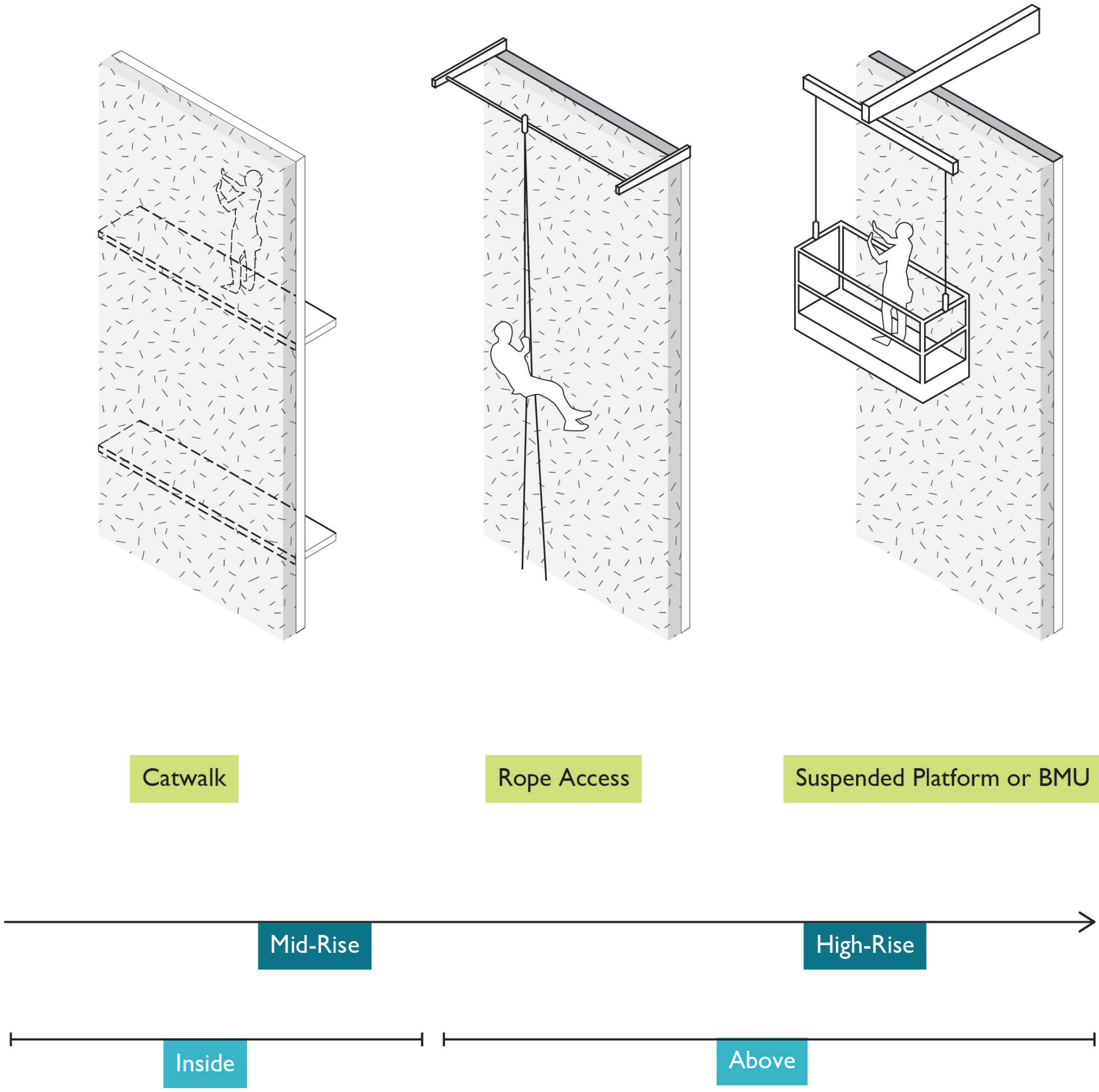
The irrigation of green façade vegetation can be done manually with a hose, or through automated irrigation systems, including surface or below surface dripper systems. Water sources from harvested rainwater or recycled building water is preferable over water taps to reduce water usage. There are many considerations for irrigation of VGS. Container plants require free-draining substrate and drainage holes to prevent oversaturation of soil or pooling of water.[16] Runoff water from containers can be collected with drip trays or simply run onto the ground beneath. Drip trays may not be necessary if runoff irrigation water will irrigate vegetation below.[17] However, ensure that the runoff does not provide excess water or nutrients to ground plants. Caution should also be taken so that it does not cause slip hazards or water damage to the building.[18] Ensure adequate water supply pressure from tanks when irrigating raised planters on multiple levels.[19]

Green walls typically have automated recirculating irrigation systems. Irrigation systems include vertical irrigation pipes around the green wall carry irrigation up, horizontal drip lines that release irrigation to vegetation from the top of the wall or top of planting modules, and drip trays at the base of the wall to capture excess irrigation from the growing media and plants. Green wall irrigation lines are usually 20 mm PVC tubing. Drip trays should be large enough to hold the water volume of a full irrigation cycle.[20] Water run-off can be captured from drains in the drip tray and stored in a reservoir tank and pumped back into the green wall provided it is treated to prevent a build-up of nutrients.[21] The reservoir tank is typically located

15 Tong and Yin, *Living Wall*, 18.
16 Ibid., 28
17 Ibid., 17.
18 Ibid., 28.
19 Ibid., 9.
20 Ibid., 17.
21 Ibid., 17.



2-5 Maintenance access methods for vertical greenery systems


Catwalk
Rope Access
Suspended Platform or BMU
Mid-Rise
High-Rise
Inside
Above

at the base of the wall, floor, or nearby storage closet. A typical irrigation cabinet will contain a pump, remote sensing controller, a fertilizer injection system for hydroponic systems, and connection to power and water supply (refer to Figure 2-4).

There are two main types of green walls: substrate-based and hydroponic systems. Substrate-based GWs utilize a water retentive growing medium and therefore, usually require less frequent watering than hydroponic systems. Systems in cooler climates may prosper on weekly watering cycles. Hydroponic GW systems on the other hand may require irrigation completed in multiple cycles throughout the day, with each cycle usually lasting a few minutes.[22] Smaller and more frequent irrigation cycles reduce water waste and runoff. Water use can also be reduced by selecting species with lower water needs. Position plants with greater water needs at the base of the green wall because the base will usually have more water available.[23]

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22 Tong and Yin, *Living Wall, 19*.

23 Ibid., 21.

MAINTENANCE

Maintenance is the work required to nuture plants in their healthcare environment. Happy and healthy plants create the most aestheticly pleasing and healing environments for everyone. One strategy to plant care is thinking from the plant's perspective. A plant-centred approach helps ensure that individual plants have all their needs met.

Vegetation maintenance may include plant health checks, foliage trimming, and individual or module plant replacement.[24] Typical AGS maintenance includes general gardening and cleaning, as well as inspections on structure, irrigation, and drainage systems. Technicians can provide remote irrigation monitoring, standard on-site water quality checks, nutrient balancing, salt accumulation, and pH management.[25] Maintenance requirements will depend on plant types and overall style of the garden, for example a natural versus manicured appearance.[26] Maintenance can be more frequent in the first few months after installation to ensure plant establishment on site.[27] Installing smaller plants on GWs sllows roots to establish themselves into the system, but will take longer for the GW to fill out than when using more larger plants from the start.[28] Modular systems usually incorporate pre-grown plantings to shorten growth timelines. GFs may require pruning and training. Pruning encourages the growth of lateral shoots, and may help to rejuvenate older climbers. Maintenance requires close consultation between botanists and maintenance technicians. This improves the sustainability of the system and reduces maintenance input.[29]

Providing ease of access to the system for installation and maintenance work can be a design challenge of its own, especially on tall buildings and dense sites. How a system is maintained depends on its height, and whether you access it from the ground, from within, or from above (Figure 2-5). Considerations should also be made for the storage of the maintenance equipment.

24 Tong and Yin, *Living Wall, 49*.

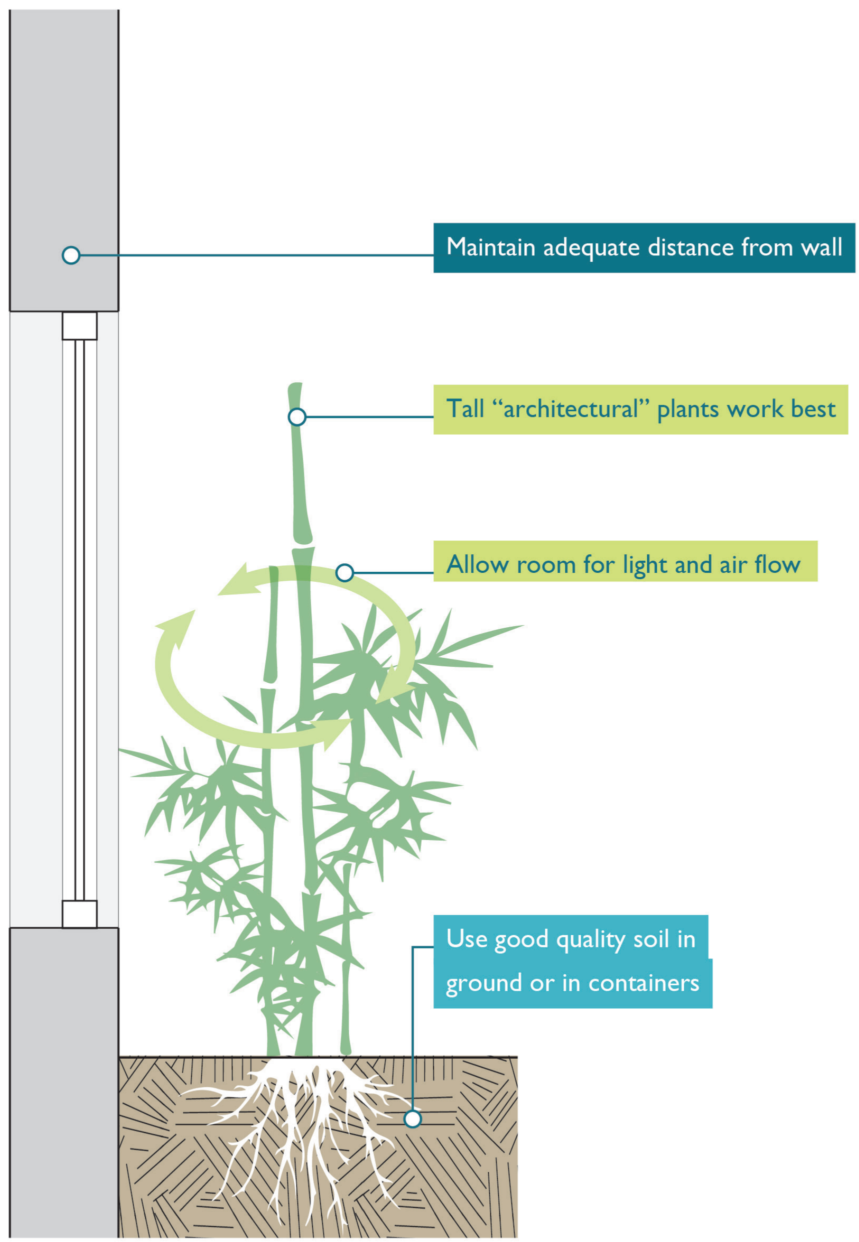
25 "GSky Products Catalog" (GSky Plant Systems, Inc., 2019), www.gsky.com, 49.

.26 Tong and Yin, *Living Wall*.

27 "GSky Products Catalog," 49.

28 Tong and Yin, *Living Wall*, 20.

29 "Ecologically Sustainable Vertical Gardens" (Fytogreen: Greening the Built Environment, 2019), https://fytogreen.com.au/wp-content/uploads/2019/12/Vertical-Gardens-2019.pdf.



2-6 Near-wall planting section

GREEN FAÇADES

Green façades (GF) provide greenery using plants that grow vertically from the ground or from planters at various heights on a building façade. Near-wall planting, seen in Figure 2-6, uses tall architectural plants like bamboo for ground level greenery. With this construction, coverage is limited by the height and form of the plant species. However, they can achieve architectural greenery over the entire height of a multi-story building with the help of climbing species and supporting structures. Systems generally use climbing or hanging plant species that are capable of extended growth on a vertical plane. Climbing plants are rigorous and hardy species that have evolved to be able to ascend great heights up natural habitat structures like trees, and rock cliffs to access daylight, pollinators, and open air.[30] Ideal plant characteristics for GFs to retain their lower foliage, are tolerance of severe pruning, have longevity, and a reliable growth rate.[31] Refer to Appendix B for a selection of climbing species, including those with flowers, fruit, and vegetables. Climbing species can be categorized in the following ways.

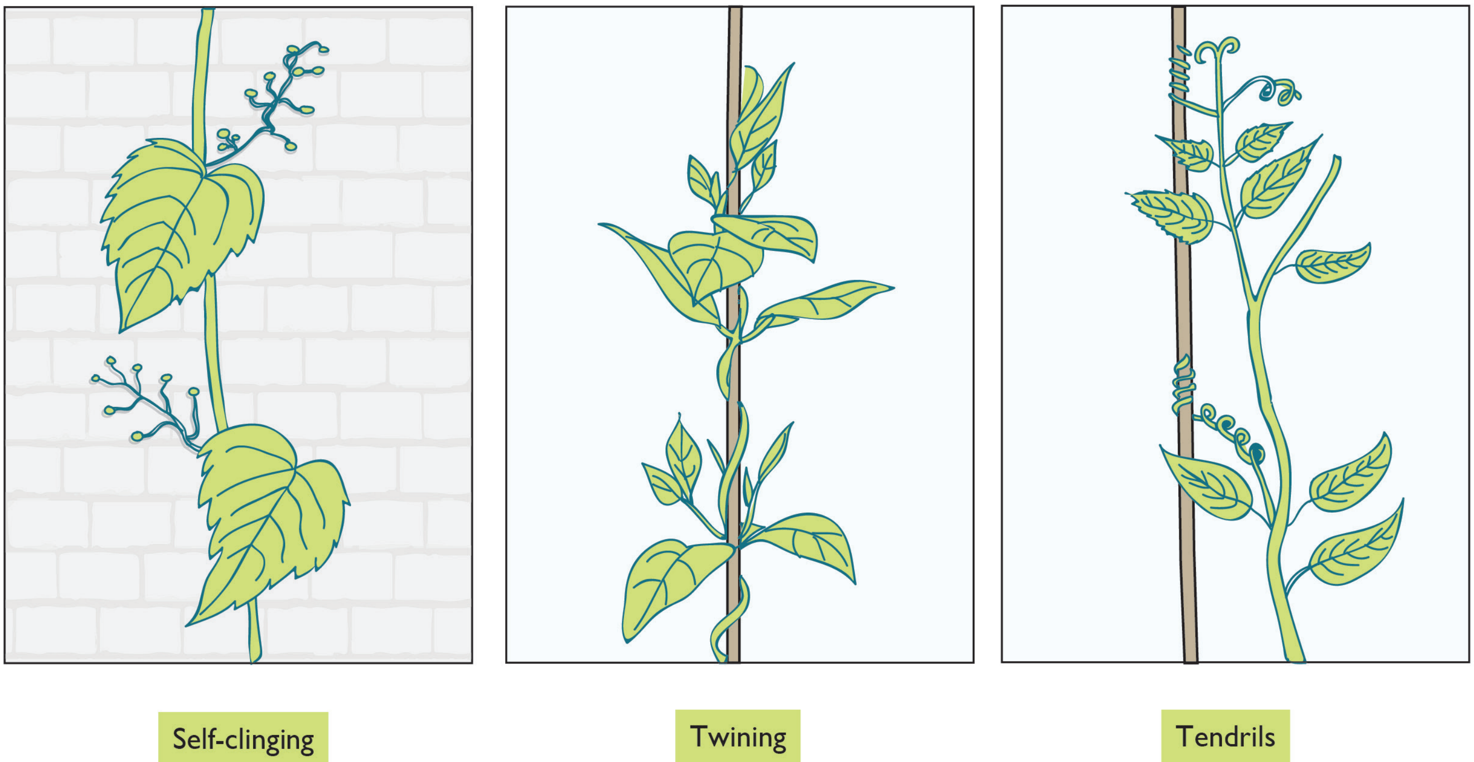
SELF-CLINGING CLIMBERS

Self-clinging climbing species attach themselves directly onto building surfaces with adhesive suckers, disks, or clinging stem roots (refer to Figure 2-7). They do not require a vertical support, but rather can be apply greenery through a direct green façade construction (refer to Figure 2-8). Self-clinging plant species, like the common ivy, are best suited to stone structures with minimal grouting, because they can damage building certain surfaces over time.[32]

30 van Zuilekom, "Guidelines for Going Green," 24.

31 Tong and Yin, *Living Wall, 28*.

32 Ibid., 12.



2-7 Climbing methods of green façade plants

TENDRIL AND TWINING CLIMBERS

Tendril climbers are plant species with wiry structures on the plant's stem, called tendrils, that reach and coil themselves around support structures to scale great heights (see Figure 2-7). Twining climbers, use their stems or leaves to reach and coil around a support structure. Both require a construction system like the indirect green façade construction (refer to Figure 2-9) with a vertical supporting structure that is separate from the building.

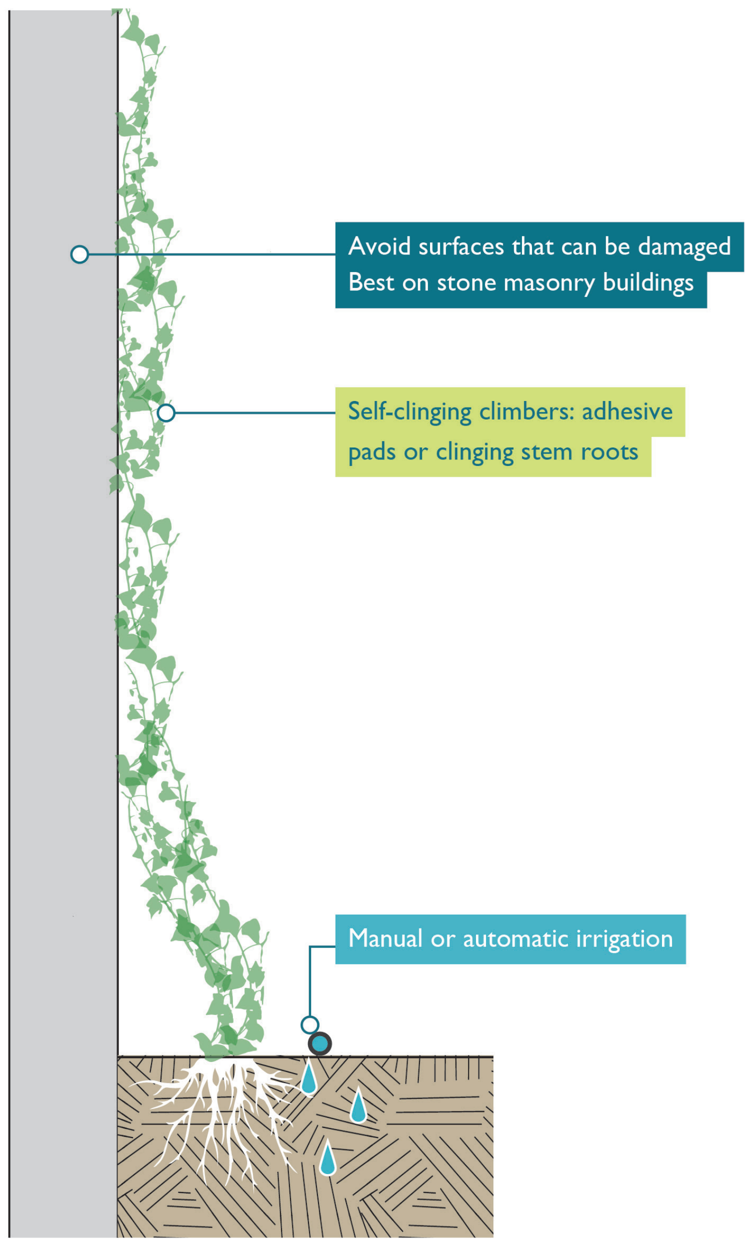
PLANT ATTACHMENT

Strong winds may cause problems with plant attachment on multi-storey façades, especially in the case of self-attaching climbing plants. Twining climbers perform best under wind conditions because they wind themselves around a support system.[33] Similarly, small-leafed species with strongly attached leaves are more suitable on windy sites because large leaves may be stripped or shredded under strong winds.[34] Careful assessment of plant growth behaviours and attachment systems are required to ensure adequate structural load support and to allow for maximum plant growth.[35]

GREEN FAÇADE GROWING MEDIA

Green façade plants are grown in a soil-like substrate. Substrate types vary in the amount of water they can hold, which effects how much water is available for plants to grow. GFs use a similar growing media and technology as green roofs with a lightweight substrate containing a mix of organic and inorganic materials that provide plants with long-lasting access to water, air, and nutrients.[36] Containers are designed to hold the least possible substrate weight that would support the maximum required plant growth across the building façade.[37] Substrate depth is limited by the weight loading capacity of the system and by the project budget. The volume of

33 Tong and Yin, *Living Wall*, 9.
34 Ibid., 27.
35 van Zuilekom, "Guidelines for Going Green," 24.
36 Ibid., 24.
37 Ibid., 24.



2-8 Direct green façade section

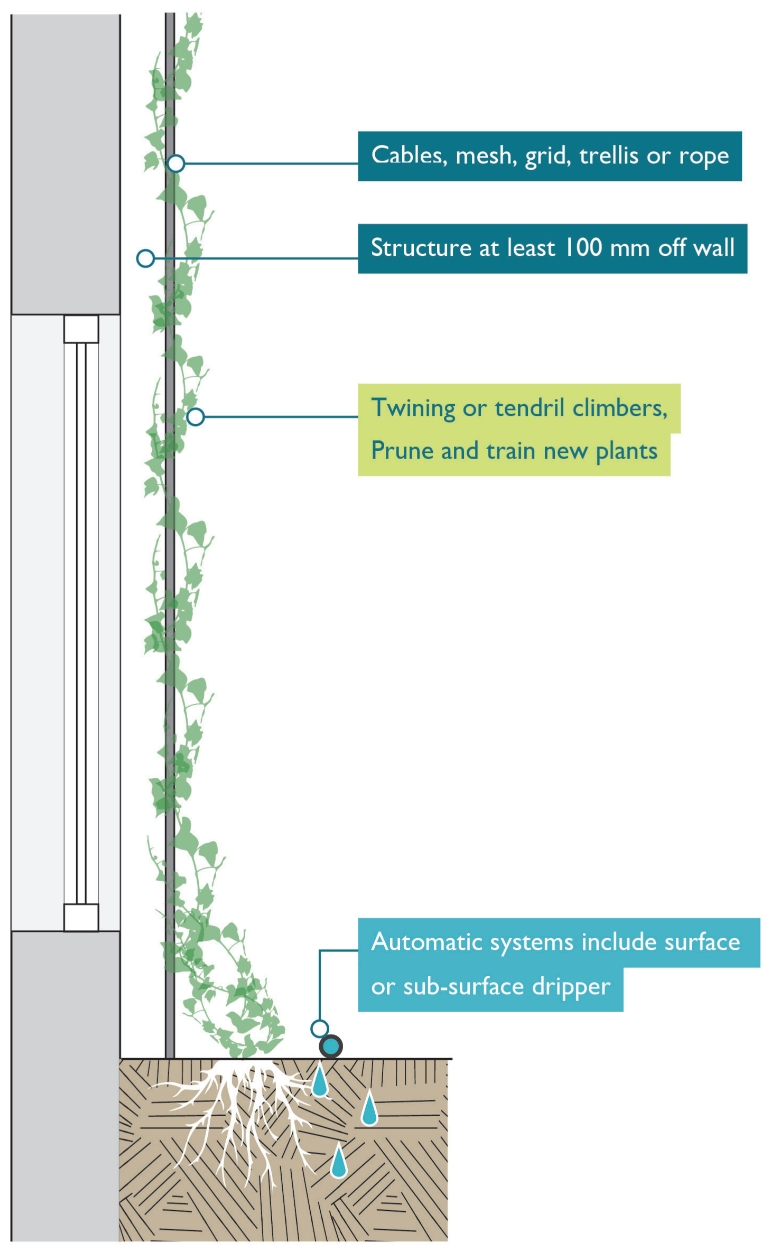
substrate in planters will also limit the size of the plant. Therefore in-ground plants generally outperform container plants in the long term.[38] Growing substrate in container-grown plants should also incorporate controlled-release fertiliser at the time of planting.[39] If a goal of a GS is to produce food, the substrate will require greater depth and organic content.[40] A horticultural consultant can provide advice on plant species requirements and the volume of the growing medium required to support the desired building coverage and design goals.

SUPPORT STRUCTURE

Support structures for tendril and twining climbers include stainless steel cables, cable nets, wire mesh, grid, or lattice support system. Support structures can be made of many materials such as steel, plastic, wood, or aluminum. However, wood is prone to weather and plant damage, and plastics can become brittle over time with continuous UV exposure and temperature changes. Therefore, steel structures are the most durable, low maintenance, and offer much design flexibility. Where wind is a concern, consider a secondary structure like a wind protection trellis to protect plants against stem damage and detachment.[41]

Support systems provide a structured way to arrange plants and keep them at a certain distance from windows and building finishes no matter the building geometry. The support system themselves can provide additional aesthetic appeal to the building façade, and are especially visible when the plants have not yet grown to full size or if deciduous plants are used.[42] Design of the support structure should consider project lifespan, plant growth habit, structural loads, and necessary spacing and offset from the wall.[43] Support systems have a suggested minimum distance of 300 mm from the building wall.[44] Thus, waterproofing of the wall is not required for green façades. Moreover, leaving an air gap between the building wall and plants maximizes the cooling microclimate effects.

38 Tong and Yin, *Living Wall*, 25.
39 Ibid., 26.
40 Ibid., 12.
41 Ibid., 12.
42 Ibid., 25.
43 Ibid., 24.
44 Ibid., 27.



2-9 Indirect green façade section

STACKED PLANTERS

Raised / stacked planters (Figure 2-10) can be mounted at various heights on the building façade to allow plant coverage over taller buildings where ground level planting cannot reach. In the raised planter system, choice of plant species as well as container size and spacing are critical for establishing effective vegetation heights and spread.[45]

DOUBLE-SKIN GREEN FAÇADE

A double-skin green façade (Figure 2-11) is created with space between the greenery system and the building envelope. This can provide additional thermal and shading benefits. A balcony or exterior walkway can be incorporated between the two façade structures.

ALGAE PHOTOBIOREACTOR FAÇADE

A photobioreactor (PBR) façade is an unusual greenery system that offers many additional benefits (refer to Figure 2-12). The system grows microalgae, a cyanobacteria in the protist kingdom rather than a species of the plant kingdom. However, algae are plant-like because it is green in colour and performs photosynthesis to grow. A PBR façade uses species of microalgae grown in water with the help of sunlight or grow lights and are fed carbon dioxide and other nutrients through pipes. The algae biomass can be harvested and used for pharmaceutical and biofuel production. In addition to sequestering carbon dioxide, the system collects and stores heat from excess sunlight that can be used to heat building water and spaces.[46] The system can also provide shading throughout the year. The more sunlight the algae receives, the more densely it grows in the façade and the more shade is provided in the building.

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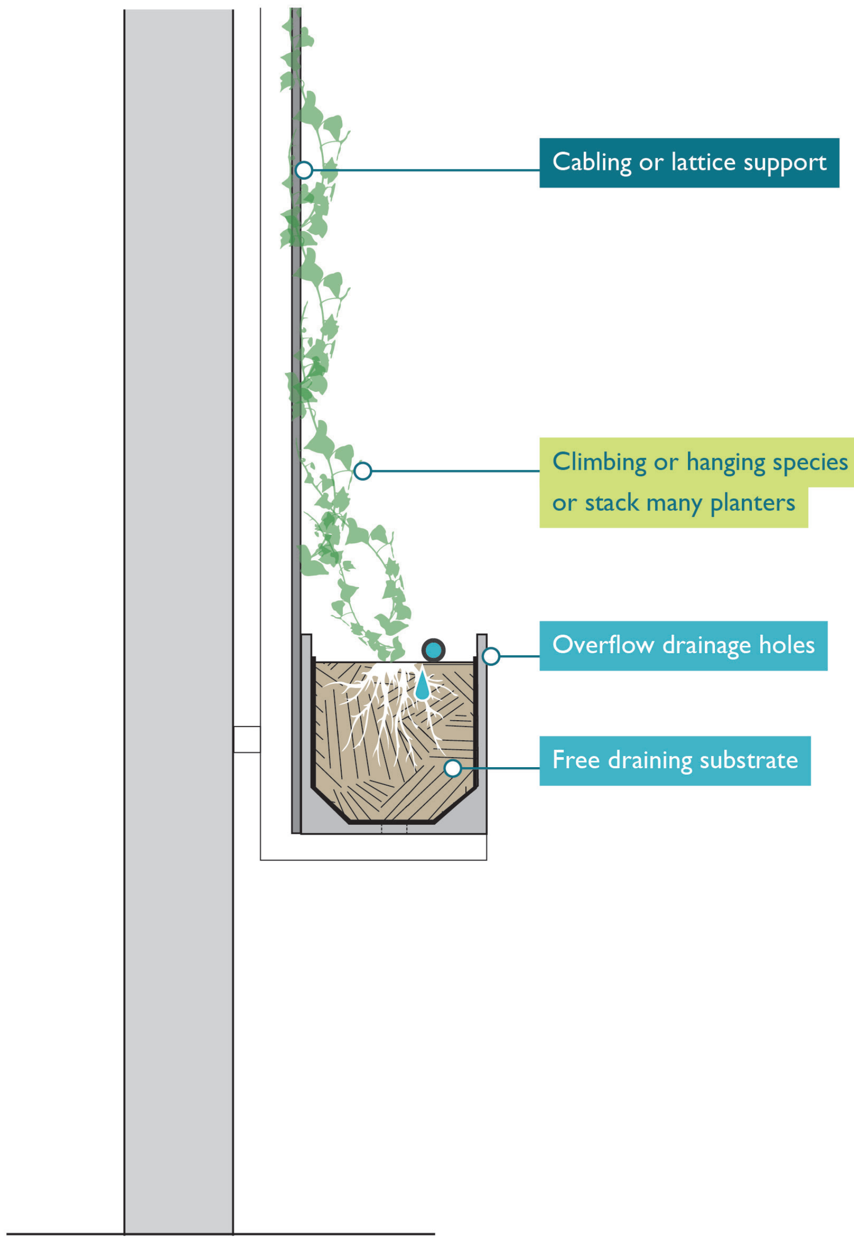
45 Tong and Yin, *Living Wall*, 24.

46 Nicky Rackard, "World's First Algae Bioreactor Facade Nears Completion," ArchDaily, March 4, 2013, https://www.archdaily.com/339451/worlds-first-algae-bioreactor-facade-nears-completion.



2-10 Raised / stacked planter green façade section

GREEN FAÇADE COMPARISON – BENEFITS

The green façade comparison diagram (Figure 2-13) illustrate estimated benefit and cost levels of construction types in relation to one another. This analysis includes the main construction types discussed in this thesis. The spider charts in Figure 2-13 compare building and healthcare benefits that are created by specific GF construction types. The comparison criteria and system benefits are described as follows.

SOCIAL AND VISUAL BENEFITS

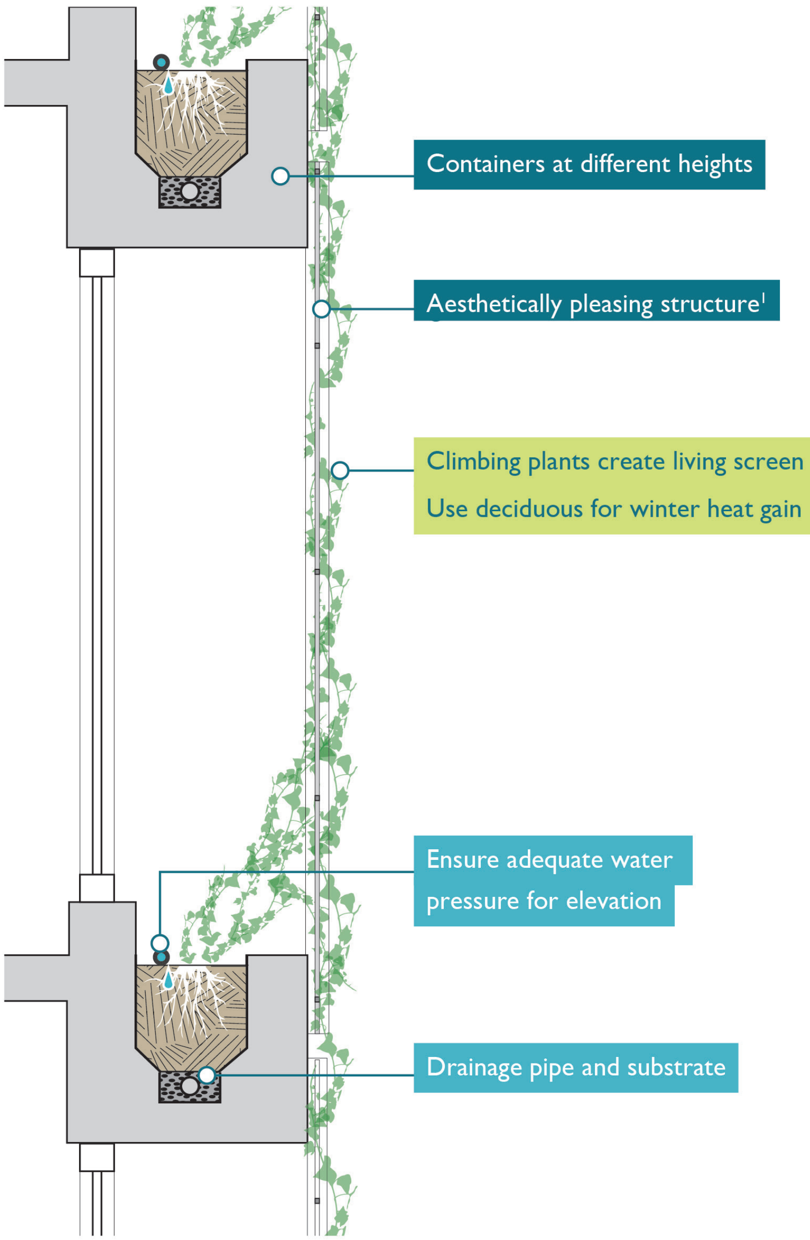
VGS provide aesthetic benefits in healthcare facilities through visually appealing plant colors, textures, and forms, and patterns. Since indirect green facades, stacked planters, and double skin facades have higher porosity and are offer greenery on both sides, they can be designed as an attractive screen to provide more greenery to the site, shield against unsightly views, and give occupant privacy. However, the visual and social effects of GF construction types have been valued slightly lower than green walls because they are generally less densely planted and usually have less variety of plant species, resulting in generally lower visual variety, design complexity, and aesthetic appeal compared to GWs.

LIFESPAN AND DURABILITY

Green façade systems have lifespans that are only limited by plant failures. They can provide great foliage cover but climbing plants can take several years to achieve full coverage. Some GF providers may have pre-grown GF units that offer good foliage cover at installation.[47] Regular inspection and maintenance ensure that vegetation is healthy and looking great. Plants that are no long thriving can be replaced and soil can be renewed at low cost so that the GF lasts for the duration of the building.[48] Algae PBRs are made with durable materials that will last as long as other mechanical systems, with regular inspections and maintenance.

47 "Ecologically Sustainable Vertical Gardens," 9.

48 Katia Perini and Paolo Rosasco, "Cost-Benefit Analysis for Green Façades and Living Wall Systems," *Building and Environment* 70 (December 2013): 110–21.



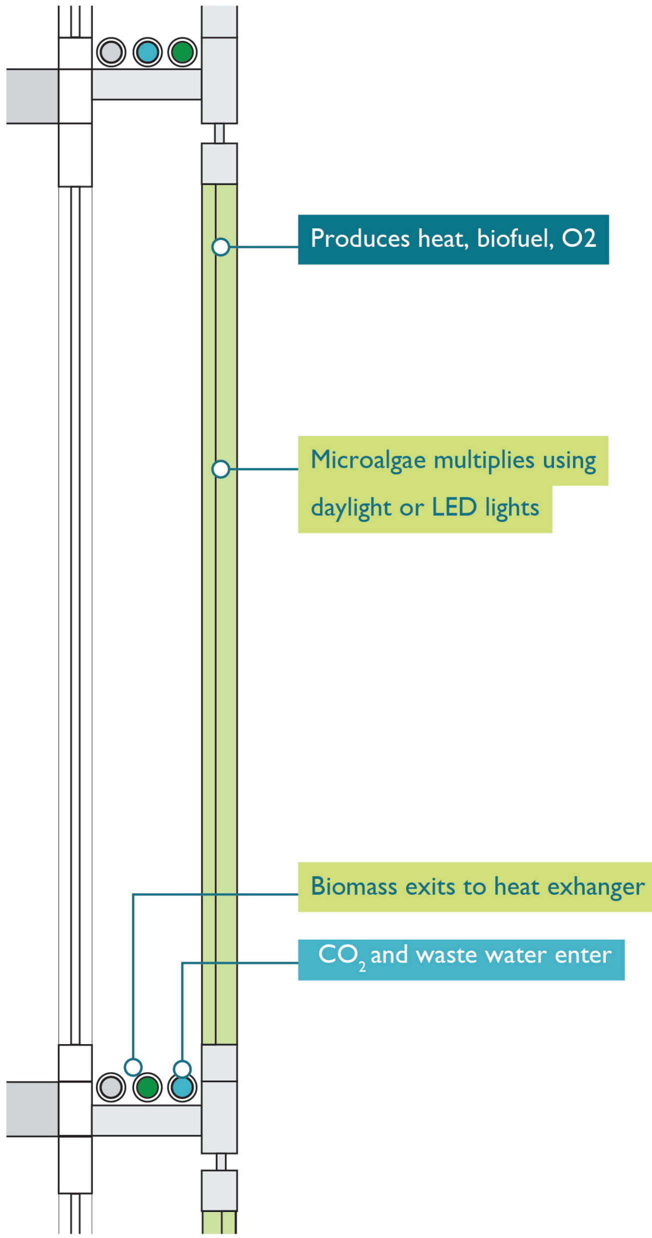
2-11 Double-skin green façade section

HYDROLOGY BENEFITS

Green façades can be integrated with rainwater collection and management systems. Like green walls, GFs can be irrigated with stormwater collected from building roofs or recycled grey water, rather than with potable water. All GF construction types have the potential to aid in building and site water management. Ground and raised container green façades have a slightly lower hydrology rating than living green walls because the amount of planting and growing media per vertical surface area is less than that in living walls.

BIODIVERSITY BENEFITS

Plant diversity is typically less than that on green walls. The more a system relies on specific growth habits for building coverage, the more limited the number of species there are to choose from. Often just one or two climbing species are used. The benefits of being very selective include reductions in cost and maintenance as well as increased system predictability. Alternatively, the advantages of more plant diversity include potentially greater ecological benefits, and more aesthetic interest. Direct, indirect, and double-skin GFs that all rely on climbing species have lower biodiversity. Near-wall planting and stacked container plantings can accommodate more plant diversity. Photobioreactor (PBR) GFs are limited to microalgae species.



2-12 Algae photobioreactor façade section

NOISE REDUCTION

Greenery systems can reduce noise reflections from hard building surfaces due to the sound scattering abilities of vegetation. GF systems generally have less sound absorption abilities than green walls because of their higher porosity and lower levels of substrate. Double-skin GFs systems have been shown to reduce noise by 5-10 decibels (dB) for low to middle range frequencies.[49] Another study showed that double-skin GFs increase sound insulation by 1 dB for traffic noise and 3 dB for pink noise.[50] Algae PBR façades are reported to be effective sound insulators due to the water contained in the system.[51]

IMPROVED AIR QUALITY

All green façade construction types improve air quality by taking in CO_2 and releasing much needed O_2. They also reduce concentrations of toxins and pollutants in the air. Algae PBR can purify air if gases are fed and collected from the closed loop system. With careful species selection and higher density of plant foliage, GFs can also be effective air filters.[52] Studies suggest that smaller-leaved plants are more effective than wider leaved plants at collecting particulate matter (PM).[53] One study showed the effectiveness of ivy to collect fine dust particles, and like many other plants, efficiently use rain-induced leaf cleaning to wash off PM.[54]

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49 Nyuk Hien Wong, Alex Yong Kwang Tan, and Puay Yok Tan, "Acoustics Evaluation of Vertical Greenery Systems for Building Walls," *Building and Environment* 45, no. 2 (February 2010): 411–20.

50 Gabriel Pérez, Julià Coma, and Camila Barreneche, "Acoustic Insulation Capacity of Vertical Greenery Systems for Buildings," *Applied Acoustics* 10 (September 2006): 218–26.

51 "SolarLeaf, Hamburg: Worldwide First Façade System to Cultivate Micro-Algae to Generate Heat and Biomass as Renewable Energy Sources," Arup, n.d., https://www.arup.com/projects/solar-leaf.

52 Radić, Dodig, and Auer, "Green Facades and Living Walls."

53 Udeshika Weerakkodyy, John A Dover, and Paul Mitchell, "Particulate Matter Pollution Capture by Leaves of Seventeen Living Wall Species with Special Reference to Rail-Traffic at a Metropolitan Station," *Urban Forestry & Urban Greening* 27 (October 2017): 173–86.

54 G. Reznik and E. Schmidt, "Reduction of Immission by Vegetation - Dry Collection and Wet Resuspension of Fine Dust Particles on Ivy," *Gefahrstoffe Reinhaltung Der Luft* 69, no. 10 (October 2009): 434–38.

IMPROVED THERMAL PERFORMANCE

Depending on location and density, GFs can help cool a building through shading. If solar heat gain is desired in the winter, deciduous species are beneficial because they shed their leaves in the fall. For the best shade during summer months, choose a very leafy plant that covers the entire wall. On the other hand, evergreen species offer year-round therapeutic greenery and screening of unsightly views. GFs can also create cooler and humid microclimates through evapotranspiration.[55] Experiments on the thermal effects of climbing plants show slight reductions in ambient air temperatures of about one degree Celsius during the hottest months, especially in warm and dry climates.[56] PBR façades achieve the highest thermal performance because they can provide dynamic shading through greater algae growth in areas where it receives more sunlight. Also, excess solar heat from PBR façades can be stored in geothermal systems for building heating.[57]

PLANT DENSITY

Since its vertical supports are open structures and plantings are more spaced apart than in green walls, GF systems have lower plant density. GF porosity allows for daylight, air, and views to filter through window openings, walkways, or balconies. In all construction types, plant density can be controlled through support structure design, species selection, spacing of plants, and growth management through pruning. Plant density in PBR façade systems is typically higher, but porosity depends on the formal design of the bioreactor container, and the stage of algae growth at any given time.

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55 Gabriel Pérez et al., "Green Vertical Systems for Buildings as Passive Systems for Energy Savings," *Applied Energy* 88, no. 12 (December 2011): 4852–59.

56 Radić, Brković Dodig, and Auer, "Green Facades and Living Walls," 8.

57 "SolarLeaf, Hamburg."

GREEN FAÇADE COMPARISONS – COSTS

The bar charts on Figure 2-13 compare some of the resources required for the green façade construction types discussed including estimated ongoing maintenance costs, initial installation costs, non-organic material usage, and irrigation system requirements. This analysis provides a general indication of relative system resource use levels based on industry research. Generally, the greater the system size and intensity, the more resources required because the green system becomes integrated with other building components like structure, shading, and mechanical systems.

MAINTENANCE COSTS

Green façades generally require less maintenance than green walls. In a direct GF, maintenance costs could be higher if there is need to control vigorous growth or repair damage to building façade materials.[58] Indirect GF and raised container systems with climbing species may require more maintenance and specialized knowledge because plants require training on support structures, pruning, and inspections to ensure the system functions as intended. Near-wall planting is the simplest system to implement because it has the least building integration. Algae PBR façades requires the most specialized knowledge for both design and construction. Due to the necessary precision of nutrients, liquids, and gases transferred in and out of the system, Algae PBR facades require constant monitoring and more system maintenance. Other systems may require consultation from a horticulturalist for species selection, growth requirements, plant training and inspection.

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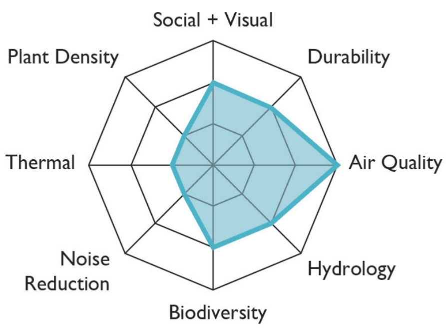
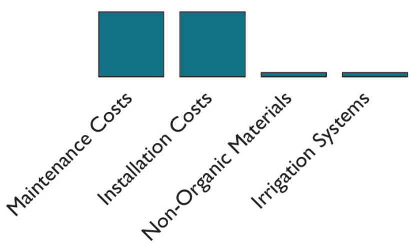
58 Pérez et al., "Green Vertical Systems for Buildings as Passive Systems for Energy Savings."

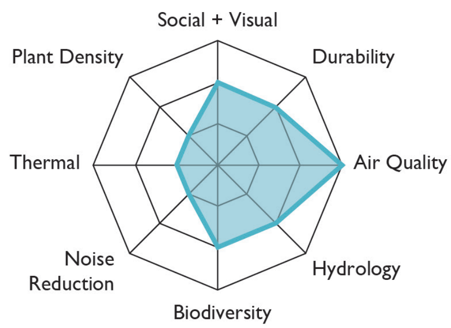
GREEN FAÇADE CONSTRUCTION TYPES

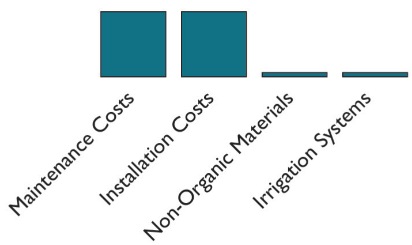
Near-Wall Planting



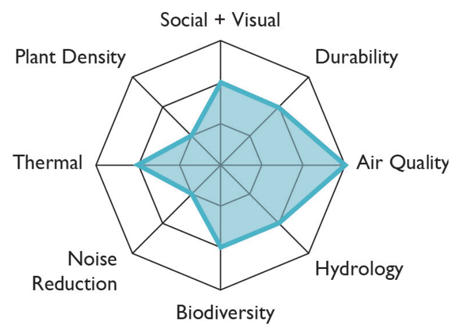


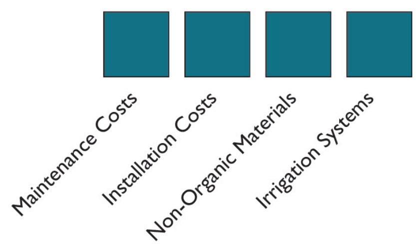
Direct Green Façade

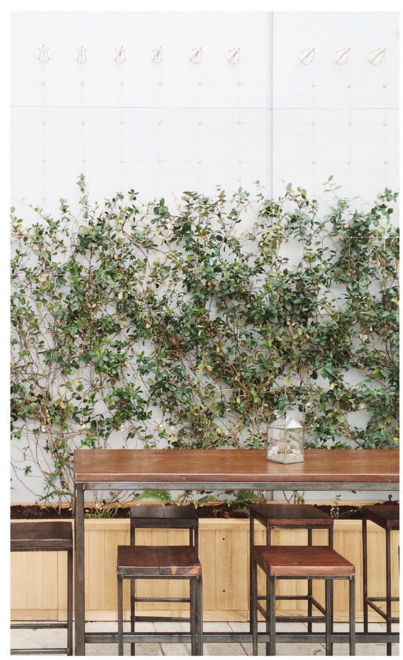




Indirect Green Façade

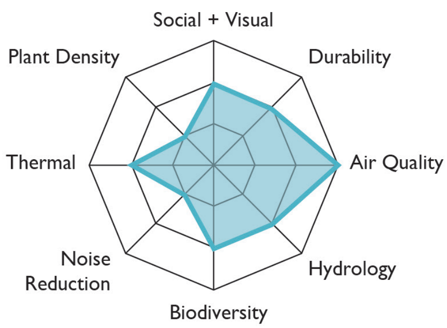


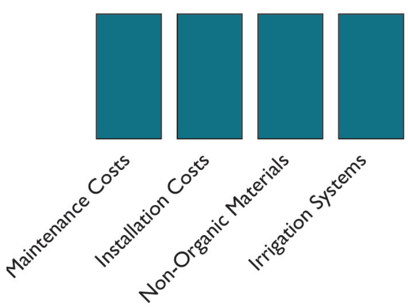


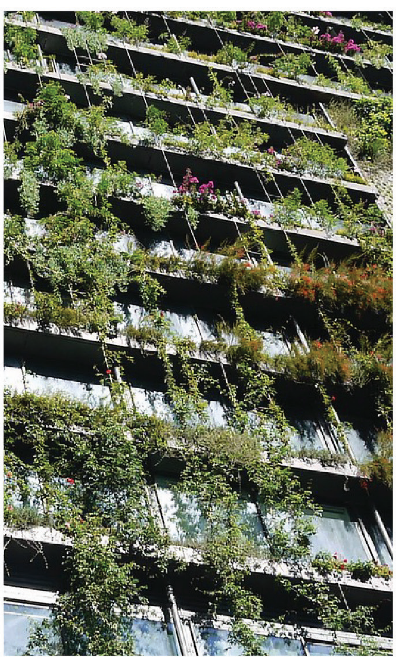


2-13 Comparison of green façade construction types

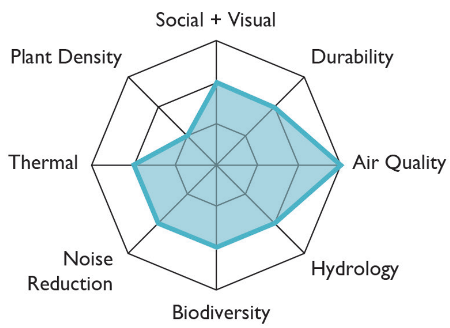
Stacked Planters

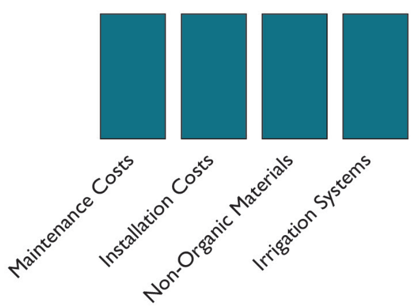




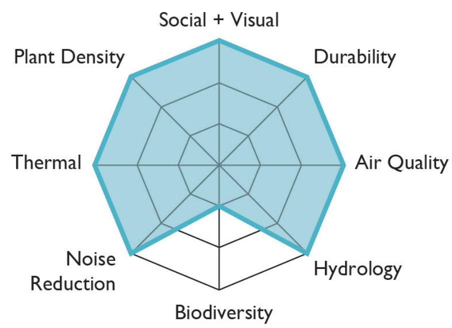


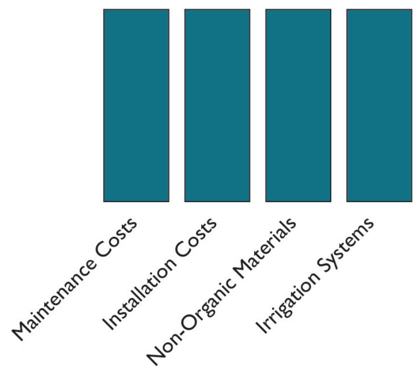
Double-Skin Green Façade





Algae Photobioreactor





INSTALLATION COSTS

Near wall planting and direct GF systems are the simplest to install and usually do not require specialized knowledge from a horticulturalist. Indirect GFs, raised container system, and double-skin GFs have higher initial costs because of their required structural support systems and more elaborate irrigation systems. Algae PBR façades have the highest initial costs and specialized knowledge requirements due to the higher intensity and level of integration with mechanical systems.

NON-ORGANIC MATERIAL USE

Near wall planting and direct GF have low material usage because they do not require any support structure. For direct, stacked, and double-skin GF construction systems, initial material costs depend on the size and intensity of the structural support and planter systems. Algae PBR facades require the most elaborate structural and mechanical systems.

IRRIGATION SYSTEM REQUIREMENTS

The irrigation of ground level plantings in near-wall system, direct or indirect GFs can be done manually with a hose, or through simple automated irrigation systems like sprinklers or drip irrigation lines. Systems like the raised-planter GF, or the double-skin GF with plantings on multiple building stories usually have more complex, automated irrigation system with surface or subsurface irrigation lines. Adequate water pressure is required to ensure the irrigation can reach higher building levels. PBR façades have the largest and most complex irrigation system because the entire façade system is filled with water. The system requires larger pipes and pumps, in addition to more irrigation control and monitoring.

GREEN WALLS

Green walls (GW), also known as vertical gardens, living walls or bio-walls, are VGS in which plants usually grow out horizontally and up from growth media on a vertical support structure. A GW system incorporates living plants, growing medium, irrigation, and drainage.

STRUCTURAL COMPONENTS

The growing media is contained within fabric sheets, felt pockets, modular panels, or containers of various sizes. The GW can be attached to a load-bearing wall, column, beam, or a freestanding structural framework.[59] To protect the building structure, sheathing or vertical supports or brackets will be used to create an air gap between the structure and the back of the GW system. A waterproofing treatment, such as roller-applied liquid waterproofing, may be required if there is not a sufficient air gap between the back of the planting system and the wall to prevent water, moisture, or dissolved salts that can damage the building wall.[60] Even if a wall structure is fully waterproof rated, wall penetration points and areas around drip trays may need waterproofing.[61]

SUBSTRATE-BASED GREEN WALLS

Differentiated by growing media, GWs can be divided into hydroponic and substrate-based systems. Smaller scale installations tend to be substrate systems, while larger and long-lasting installations tend to be hydroponic systems because of the weight limitations and nutrient limits in substrate systems.[62]

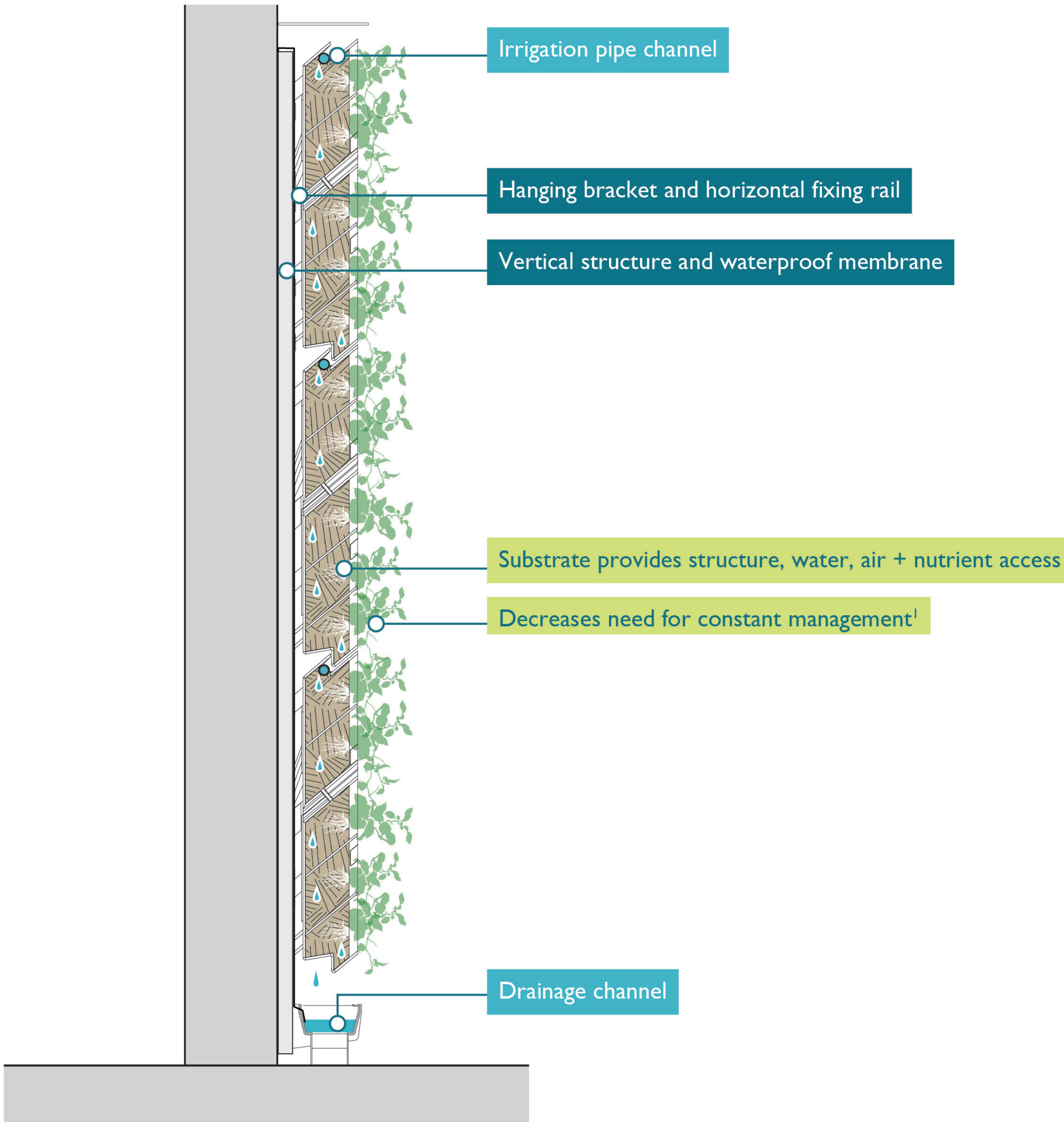
Substrate based systems use substrate holding plastic or metal containers. Growing containers are hung or anchored to metal grid fixed to a wall or free-standing metal framework. Substrate green walls use a soil-like

59 Tong and Yin, *Living Wall, 8*.

60 Ibid., 18.

61 Ibid., 18.

62 van Zuilekom, "Guidelines for Going Green," 25.



2-14 Modular substrate green wall section growing media. Substrate growing media is a mix of organics like peat moss, bark, coconut coir, and rice hulls. Inorganic components include mineral aggregates like perlite, pumice, vermiculite, and sand. Traditional potting mix is not suitable.[63] The substrate growing medium structurally supports plant roots and provides them with water, air, and nutrients.[64] A system provider will advise on the most appropriate growing medium for specific designs and plant types. Like hydroponic systems, most are also designed for automatic irrigation. These systems require less control and nutrient management than hydroponic systems but overtime the nutrient levels will be depleted from the substrate and salt buildup can form.

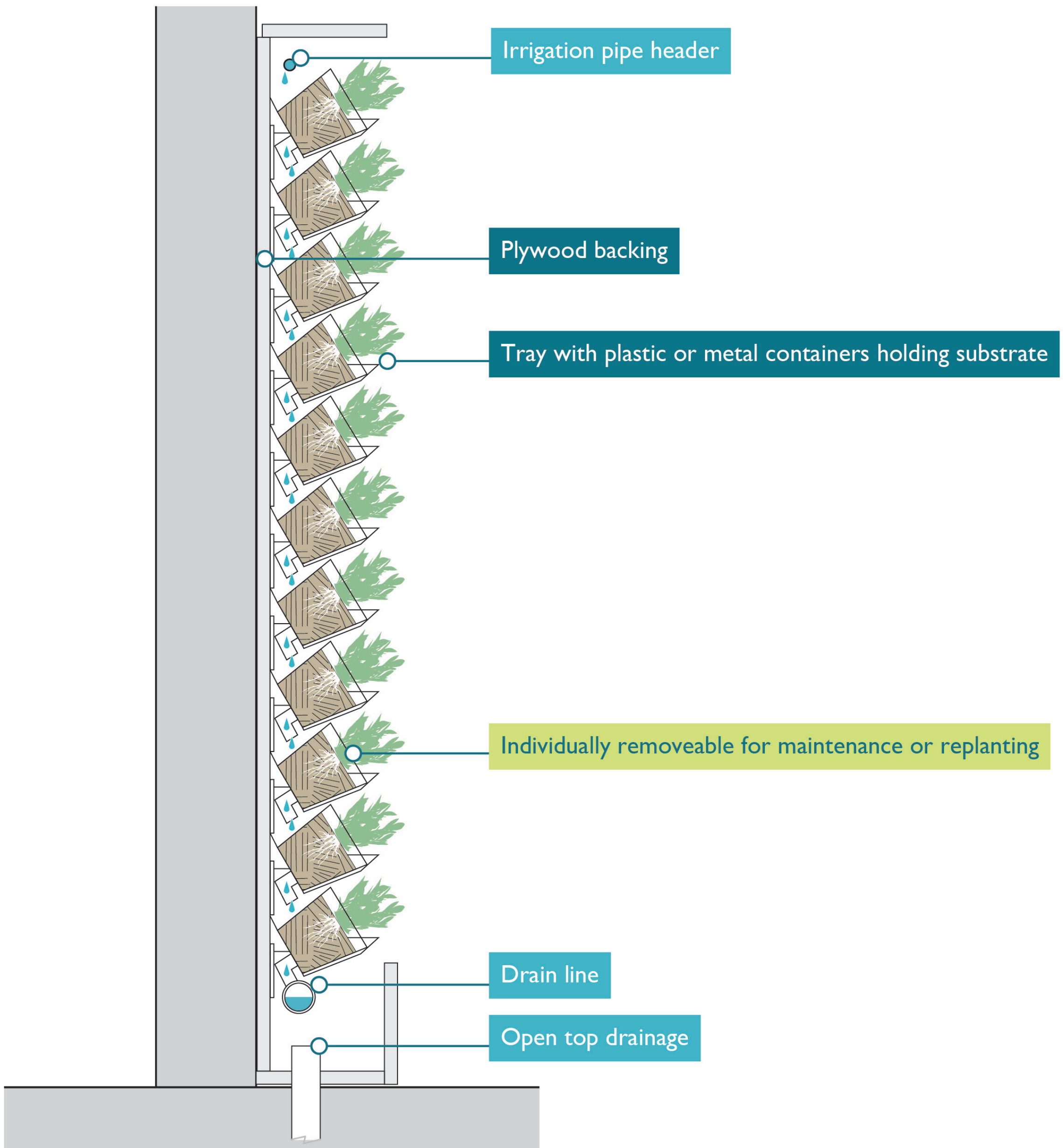
Substrate systems are all modular and vary in the size and form of plant modules. One category of a substrate-based construction is a modular substrate GW system that holds multiple plants in each panel (refer to Figure 2-14 for an example section). The modular panel system is made up of substrate panels or boxes housing multiple pre-grown plants, that when installed act as a non-modular whole. Figure 2-15 illustrates an example assembly of a tray and cellular GW system where plants are in individual growing containers that can be removed for maintenance or replacement.

HYDROPONIC GREEN WALLS

Hydroponic GW construction can be either continuous or modular. Hydroponic systems come in non-modular fabric sheet or mats made of felt or another fibrous material. Refer to Figure 2-16 for an example construction of this system. Other hydroponic systems are constructed with modular panels containing growing media, where plants are pre-grown in panel boxes or large tiles (see Figure 2-17 for one such assembly).

Hydroponic systems use inert growing media such as a mineral fiber, felt mat, or foam for plant roots to anchor onto.[65] Growing media is usually a mat material made of spun polyester fibres held together with epoxy resins. Organic fibres like coconut coir can be used and are biodegradable,

63 Tong and Yin, *Living Wall*.
64 Ibid.
65 Ibid., 16.



2-15 Tray substrate cell green wall section but do not have same life expectancy as inorganic growth media.[66] Inorganic inert materials include rockwool, polyester mat or felt, and horticultural foam.[67] Hydroponic systems are usually lighter in weight compared to soil-based substrate systems but require precise control and management of nutrient level.[68] One of the main advantages of hydroponic systems made of inorganic materials is that there is no structural decay of the growing media and no salt build-up from fertilisers.[69]

This growing media does not contain the nutrients. Rather the irrigation system supplies plant nutrients through fertilizer injection. The growing media acts like a sponge to soak up and retain water. Irrigation with the addition of fertiliser, called "fertigation", is typically used in hydroponic systems, whereby nutrients are delivered to the system in a controlled amount and rate. In hydroponic systems, water quality parameters like pH, water hardness and total dissolved solids (TDS) should be continually monitored and adjusted as needed.[70] The amount of irrigation solution required per day ranges from 0.5-20 L per square meter per day, with interior green walls requiring less than external green walls.[71]

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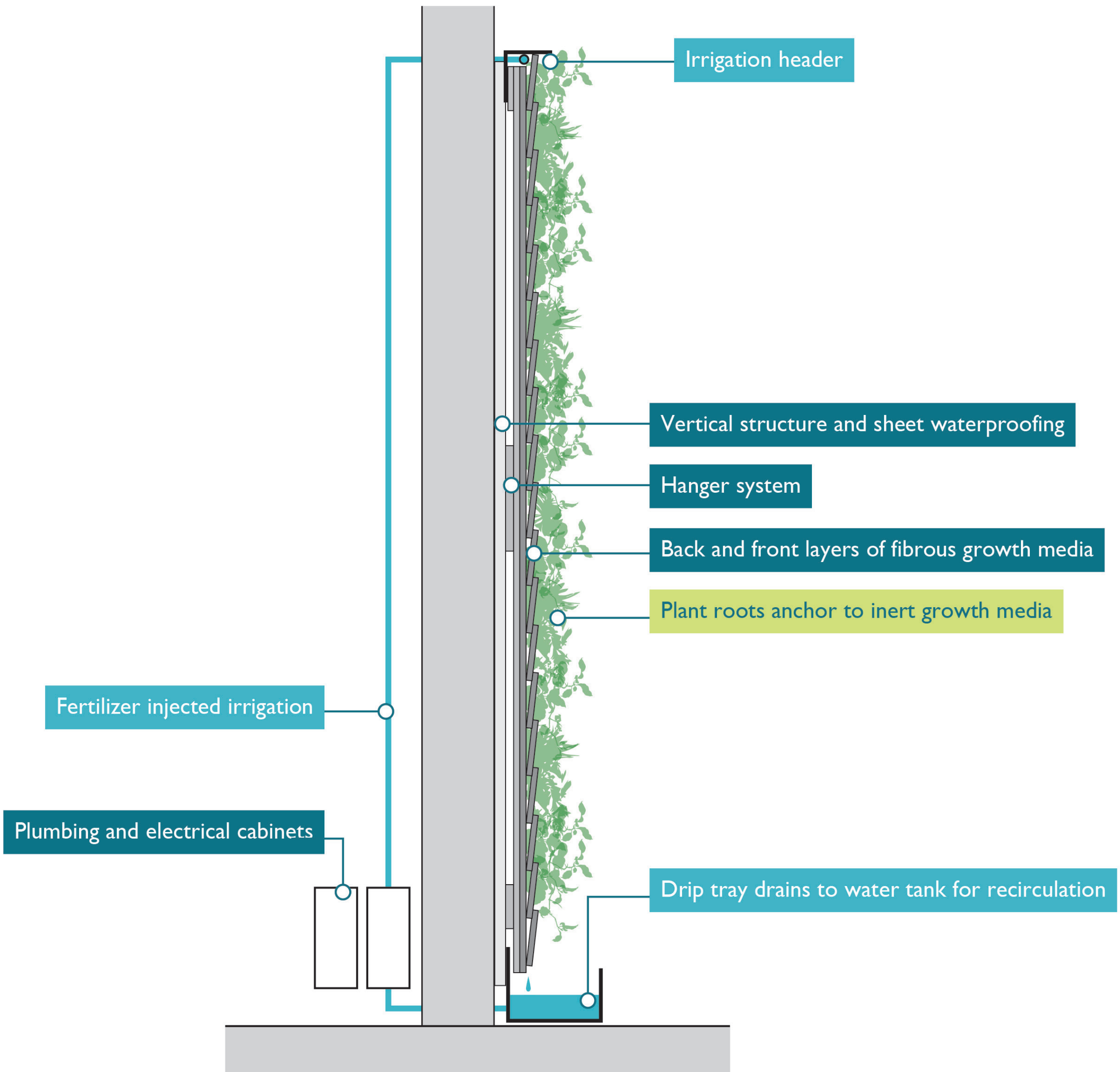
66 Peter J. Arsenault and Alan Darlington, "Hydroponic Living Plant Walls: Creating Reliable Living Indoor Environments," *Continuing Education Center, Architecture + Construction,* July 2014, https://continuingeducation.bnpmedia.com/article_print.php?C=1100&L=326.
67 Ibid.
68 van Zuilekom, "Guidelines for Going Green," 25.
69 Tong and Yin, *Living Wall*, 16.
70 Ibid,. 19.
71 Ibid., 19.



2-16 Continuous fabric / fibre green wall section

PRESERVED FOLIAGE GREEN WALL

Moss and preserved foliage come in many colours and can be used to create both natural looking and vibrant arrangements (see Figure 2-18). While other kinds of preserved foliage appear dry and lose color, preserved moss looks and feels just like living moss.[72] Preserved foliage GWs require virtually no maintenance.[73] These systems are usually flame retardant and help to absorb sound.[74] However, they lack many of the therapeutic qualities and environmental benefits of a living wall. They may be an ideal option for indoor locations where there is no desire, space, or budget for an irrigation system.

ARTIFICIAL GREEN WALL

Another alternative to a living wall is an artificial green wall (refer to Figure 2-19). Usually made from synthetic plastics, artificial green walls may not be as eco-friendly and sustainable as living or preserved GWs. Possible drawbacks are that artificial plants may appear fake and lack the building benefits of living systems. However, artificial plants may be a good alternative in healthcare applications where irrigation systems or negative interactions with some patient groups are an issue. The Lunder building at Massachusetts General Hospital incorporates artificial bamboo plants and suspended artificial vines in an 80-foot tall skylit atrium ceiling. Although live plants could have improved the air quality of the space, the artificial greenery still provides aesthetic interest and helps to create a more calming space due to their realistic appearance.

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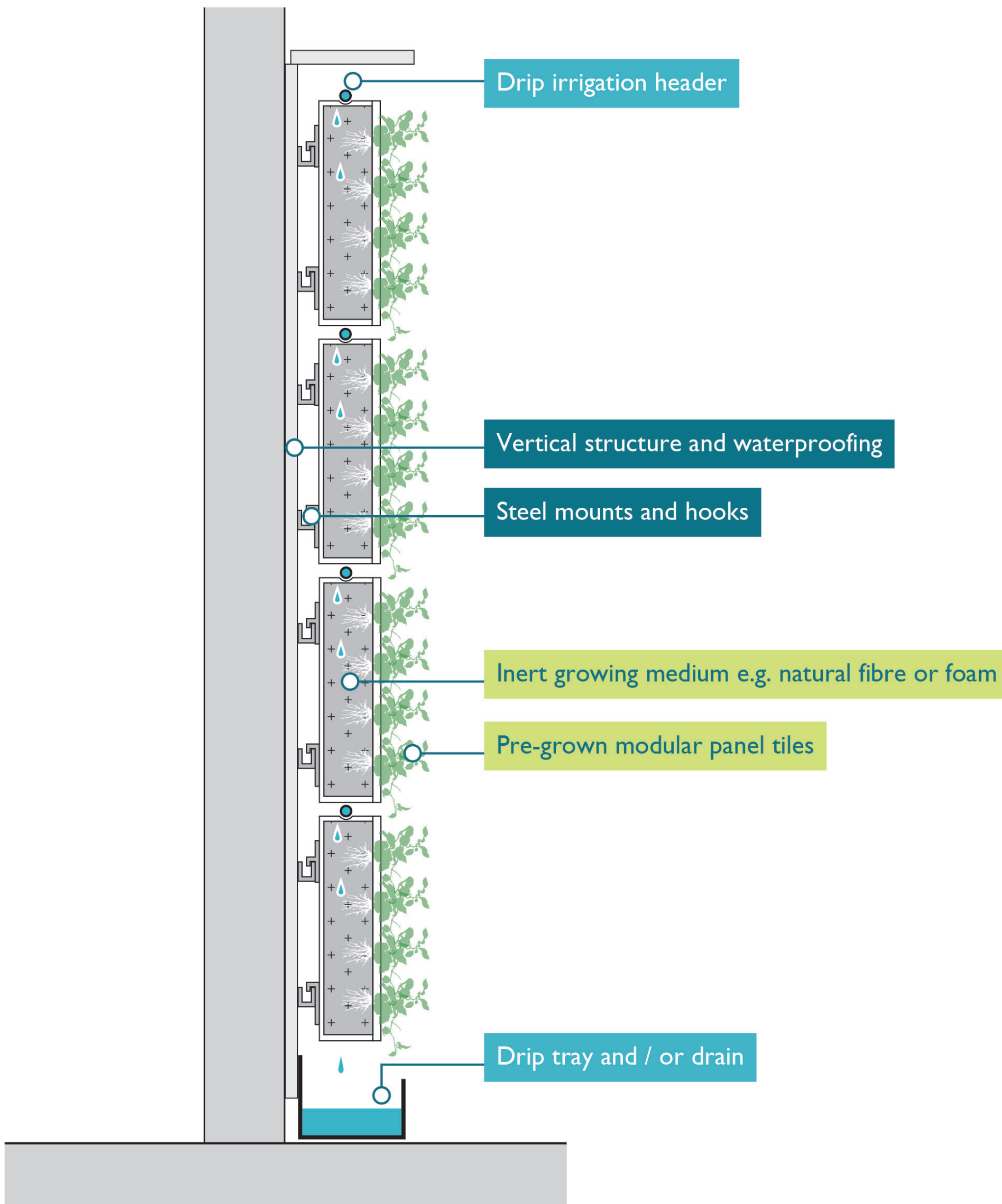
72 "Living Walls vs. Preserved Moss Walls," Artisan Moss, February 8, 2019, https://www.artisanmoss.com/living-walls/.

73 "Ecologically Sustainable Vertical Gardens," 9.

74 Ibid., 9.



2-17 Modular hydroponic panel green wall section

GREEN WALL COMPARISON – BENEFITS

The green wall comparison diagram (Figure 2-20) illustrate estimated benefit and cost levels of construction types in relation to one another. This analysis includes the main construction types discussed in this thesis. The spider charts in Figure 2-20 compare many of the benefits of GW construction types in a qualitative fashion. This expands upon some of the human sustainability and building performance benefits explained earlier in the introductory essay. Note that a designer can combine several construction types and greenery typologies to maximize benefits and reduce costs. The criteria and system benefits are explained as follows.

SOCIAL AND VISUAL BENEFITS

Green walls utilizing a variety of real, thriving plants offer the highest amount of social and aesthetic benefits that can enhance the therapeutic and healing qualities of the built environment. Individual or groupings of plants can be used like tiles on a mosaic to create planted patterns, images, and even text. Continuous sheet hydroponic construction types are not limited to planar wall structures. They can be utilized in any three-dimensional building structural forms including cylindrical columns and round walls etc. Parameters that affect the perceived beauty of a green wall system include plant density, diversity and number of species, colourfulness, complexity, naturalness, and plant size.[75] Moss and preserved walls can be dyed any number of colours; however, the plant diversity, size and complexity are limited. The social and visual benefits of artificial green walls depend on quality of artistic design, and how realistic the system appears. Increased interest and a more dynamic design statement for a building by including plant species with different flowering times, and by extending the planting beyond the boundaries of a GW.[76]

75 Radić, Dodig, and Auer, "Green Facades and Living Walls," 13.

76 Tong and Yin, *Living Wall*.

PRESERVED FOLIAGE / MOSS WALL

No irrigation required
Ideal in locations where irrigation may be an issue
Avoid direct sunlight to prevent fading

System:	Preserved green wall
Project:	The Green Cathedral
Design:	Monamour Natural Design
Landscape:	Claudia Bonollo
Location:	Madrid, Spain, 2012
	Indoor double-sided screen
Vegetation:	Moss, ferns, eucalyptus, amaranthus, ivy

2-18 Moss wall in the Green Cathedral

ARTIFICIAL PLANTS

System:	Artificial UV Green Wall
Design:	Make Be-Leaves
Location:	Princess Margaret Hospital Toronto, ON, Canada, 2020 Exterior main entrance
Vegetation:	Plants can be made from plastics, fabrics, and wire
Lighting:	UV resistant coating to prevent fading and brittleness

2-19 Artificial green wall at Princess Margaret Hospital

LIFESPAN AND DURABILITY

Hydroponic systems tend to last longer without the need to replace growth media and system modules because the growth media is typically made of inert inorganic materials with no structural decay. Individually potted plants tend to last several years before they stop thriving. Individual plants can be replaced on felt pocket and mat systems, or entire plant modules can be replaced with new pre-grown modules.

Substrate green walls may not be as long lasting as hydroponic systems because the nutrient levels in the substrate will be depleted, and salt buildup can form. Plants in the planting modules, whether it be large panels or individual pots, can be replaced as needed. Individually potted plants in the cellular substrate system can become root bound in small containers, and therefore may require more frequent replacement or have restricted growth. Moss walls last about 10 years or more if kept free of dust, in regular humidity, and away from direct UV exposure.[77] Similarly, artificial walls are long lasting if well kept. They need to be kept away from direct sunlight unless UW protected, and away from harsh outdoor climates to prevent weather damage.[78]

HYDROLOGY BENEFITS

Green walls with irrigation systems can positively impact a building's water management system using rainwater, grey-water, or recycled irrigation, rather than potable water. Outdoor GWs can also reduce large amounts of stormwater run-off from building roofs and pavement by slowly trickling water through living walls, rather than going straight into the building's drainage system or city's storm sewers.[79] Moreover, the water pump can be powered by renewable energy sources. Preserved foliage walls and artificial GWs do not require irrigation systems and therefore offer no potential benefits to urban hydrology.

77 "Living Walls vs. Preserved Moss Walls."
78 "What Is UV Resistance & Why Does It Matter," Blooming Artificial, n.d., https://www.bloomingartificial.co.uk/help-centre/topics/about-artificial-plants/what-is-uv-resistance-and-why-it-matters.
79 Radić, Brković Dodig, and Auer, "Green Facades and Living Walls," 12.

BIODIVERSITY BENEFITS

All green walls can accommodate a wide variety of plant species. Plant diversity can ensure greater success of the system as a whole and provide greater ecological benefits. Exterior systems containing a diversity of plant species support wildlife by offering a variety of food, nesting material, and protection for birds and insects throughout the year.Arranging many different plant species together in a single design can assist in the development of individual plants through the sharing of water and nutrient resources and by offering shading and wind protection within plant communities. Hydroponic systems, or substrate systems with larger modules provide greater biodiversity and ecosystem benefits than cellular substrate system because greater sharing of resources and larger plant growth can occur. GWs with individually potted plants can lead to restricted growth, reduced plant lifespans, and decreased multi-species interaction.

NOISE REDUCTION

The degree to which construction types insulate against sound depends on the system materials, structural composition, and thickness and composition of its growing media. In this way, a GW can be designed for higher sound insulation and vibration absorption. According to research by Wong et al., substrate-based systems are effective at absorbing low to middle frequencies of sound, while greenery is effective at scattering a small amount of higher sound frequencies.[80] Empirical studies suggest that GWs provide significant sound insulation for buildings and are most effective when applied to acoustically hard façade materials in narrow canon spaces.[81] A weighted sound reduction index of 15 dB were found by modular based GWs.[82]

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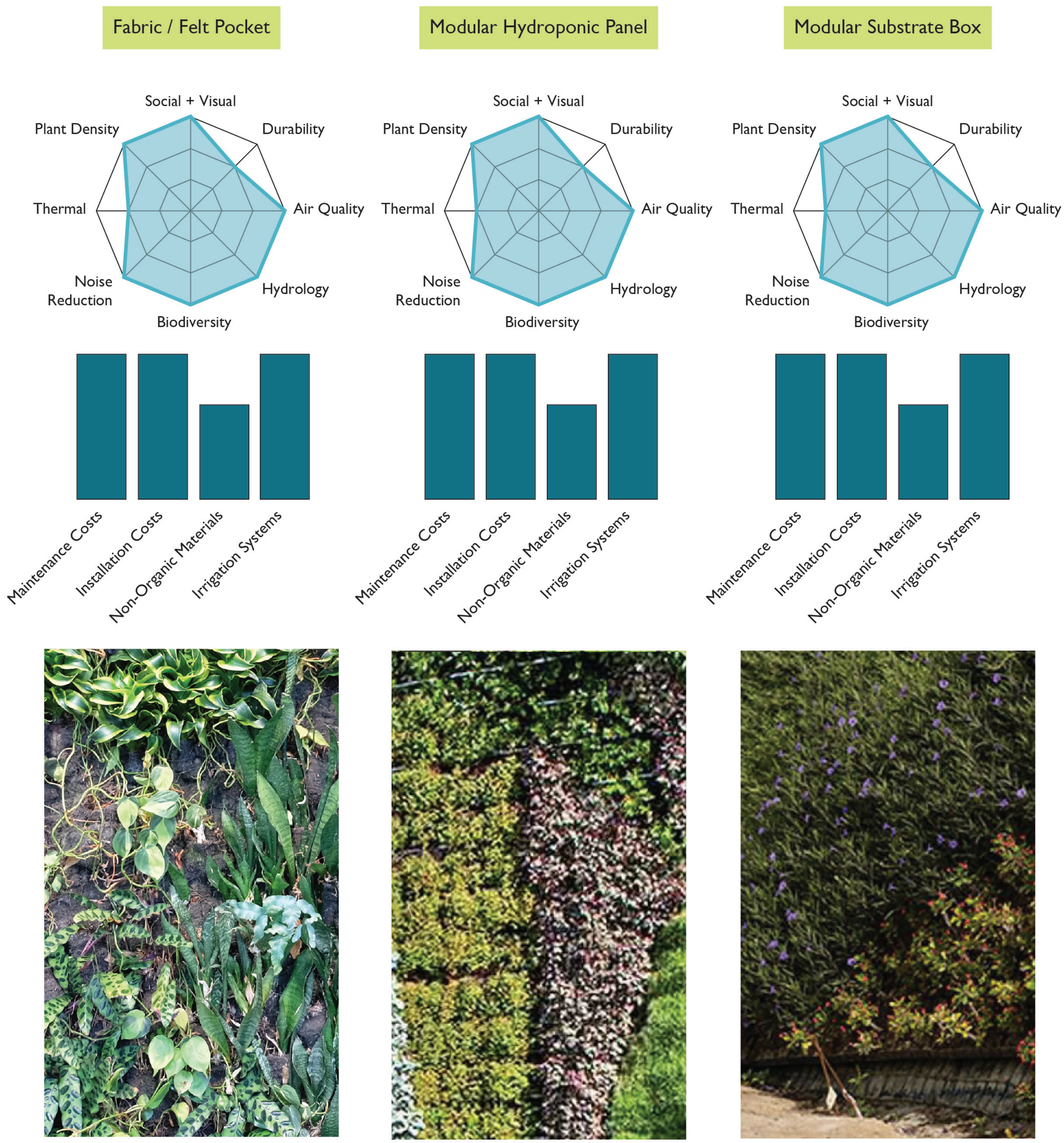
80 Wong, Tan, and Tan, "Acoustics Evaluation of Vertical Greenery Systems for Building Walls."

81 Radić, Brković Dodig, and Auer, "Green Facades and Living Walls," 10.

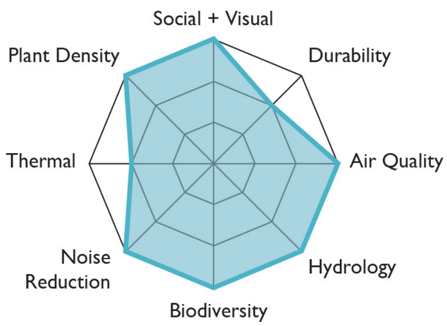
82 Z. Azkorra, G. Pérez, and J. Coma, "Evaluation of Green Walls as a Passive Acoustic Insulation System for Buildings," *Applied Acoustics* 89 (March 2015): 45–56.

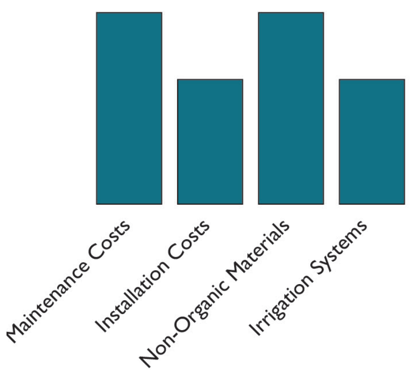
GREEN WALL CONSTRUCTION TYPES



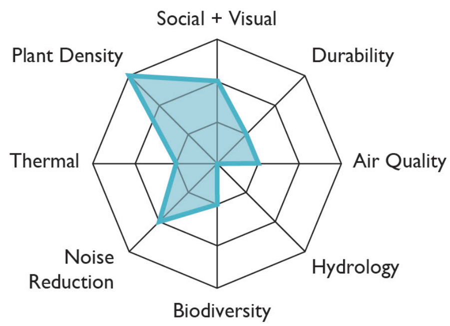
2-20 Comparison of green wall construction types

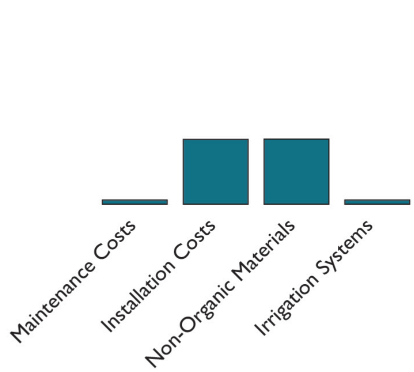
Modular Substrate Plug / Cell



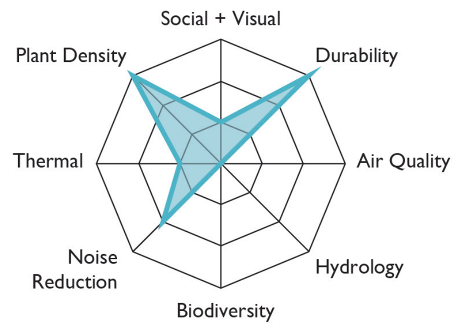


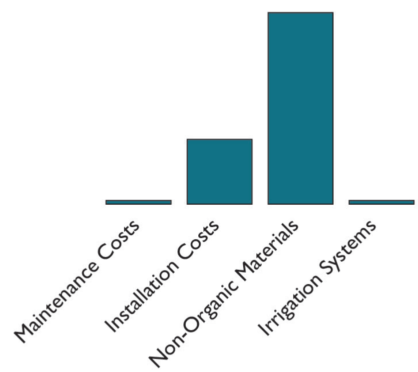
Moss / Preserved Foliage

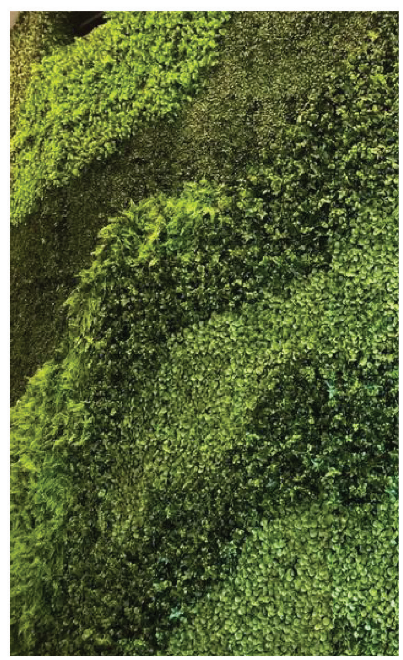




Artificial Green Wall







IMPROVED AIR QUALITY

VGS improve air quality in urban environments inside and outside hospitals because plants are natural air filters, absorbing carbon dioxide, nitrogen dioxide, and volatile organic compounds (VOCs), and releasing oxygen. Plant leaves collect dust and other particulate matter (PM), especially ultra-fine particles that are most hazardous to human health.[83] The system's performance as an air purifier largely depends on the types of plants used.[84] Therefore, all construction types score high on improving air quality and can be optimized with careful species selection and with higher density of plant foliage. Studies suggest that smaller-leaves, hairy leaf surfaces, and leaves with epicuticular wax enhance a certain plants' abilities to capture PM.[85]

IMPROVED THERMAL PERFORMANCE

Green walls create cooler and more humid microclimates. They can also help insulate buildings, which can reduce energy costs associated with cooling healthcare buildings. VGS achieve the best thermal and energy reduction benefits in warm-dry climates.[86] Thermal performance depends on many factors including climate, exterior building material, and the density of plant coverage. [87] Studies show that the total potential energy savings were found to be close to 9% in Vancouver.[88] The most important parameter was found to be the characteristics of walls covered by greenery. For example, vertical vegetation covering south facing walls in the northern hemisphere will result in the highest energy savings.[89]

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83 Jovana Alkalaj and Throstur Thorsteinsson, "Effect of Vegetation Barriers on Traffic-Related Particulate Matter" (Environment and Natural Resources, University of Iceland, 2014), www-3.vegagerdin.is.

84 Radić, Brković Dodig, and Auer, "Green Facades and Living Walls," 9.

85 Weerakkodyy, Dover, and Mitchell, "Particulate Matter Pollution Capture."

86 Radić, Brković Dodig, and Auer, "Green Facades and Living Walls," 8.

87 Ibid., 8.

88 Ibid., 8.

89 Ibid., 8.

PLANT DENSITY

All green wall systems have high planting density. Foliage density depends on the success of the system and time of year. Generally, foliage density increases as plants grow and establish themselves on the wall. Continuous sheet and pocket GWs are usually planted on site after structural installation and plants may take about four months to grow to near full foliage cover.[90] Pre-grown modules come fully vegetated immediately upon installation of the system on site.

90 "Ecologically Sustainable Vertical Gardens," 11.

GREEN WALL COMPARISON – COSTS

The bar charts in Figure 2-20 compare the resource use required for various GW construction types including ongoing maintenance costs, initial installation costs, non-organic material usage, and irrigation system requirements. This analysis provides a general indication of relative system resource use levels based on manufacturer provided information on products, and from industry research.

MAINTENANCE COSTS

Living walls require a maintenance schedule which typically consists of bi-weekly or monthly visits. Exterior system maintenance levels vary by season. Maintenance levels are also dependent on the planting design and location of the system. GWs in prominent indoor locations will likely have a more frequent maintenance schedule than those in outdoor or less prominent areas. Using hardy, low maintenance plant species that are apt for a site's lighting and climatic conditions will reduce maintenance needs as well. Use systems that can be easily maintained through easy access and ones that can be easily replanted. Preserved and artificial plants do not require maintenance beyond occasional cleaning, such as dusting.

INSTALLATION COSTS

Large and modular pre-planted constructions are more expensive than continuous GW systems that are planted on site. Preserved moss and artificial systems are lower in cost. Initial and ongoing costs can be minimized by reducing the size of GW systems. Self-contained GW units that recirculate water are also more economical.

NON-ORGANIC MATERIAL USE

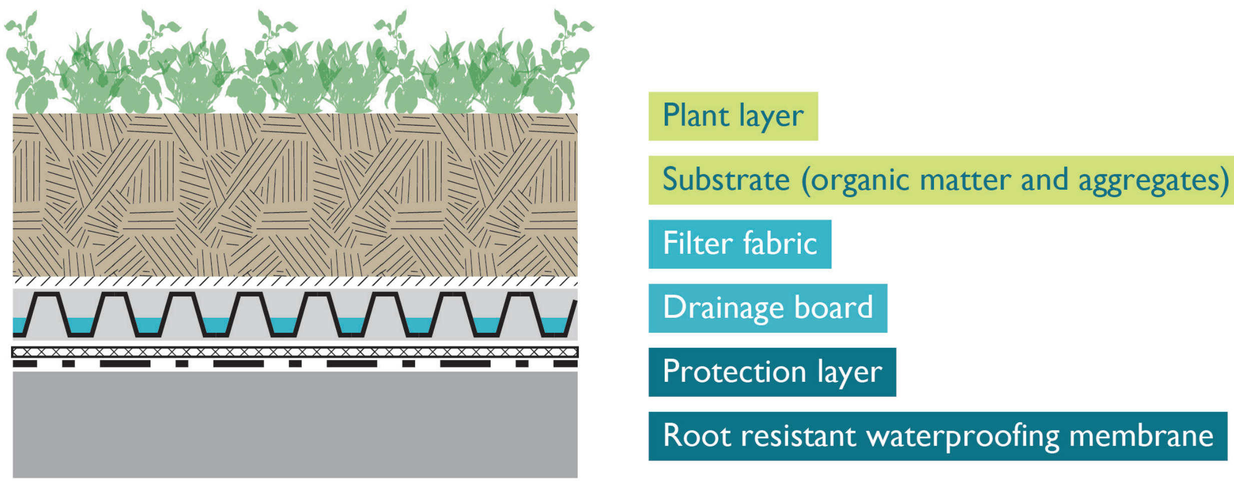
Non-biodegradable materials are used in hydroponic and substrate growing media, framing support structures, and irrigations systems. Some modular systems, like the tray and cell substrate construction types use plastic containers to hold the substrate. Many non-organic growing media and containers are made from recycled materials. Artificial and preserved foliage systems use less construction materials in general. They are thinner and lighter because they do not require an irrigation system. However, artificial green walls are typically made of non-biodegradable polymers.

IRRIGATION SYSTEM REQUIREMENTS

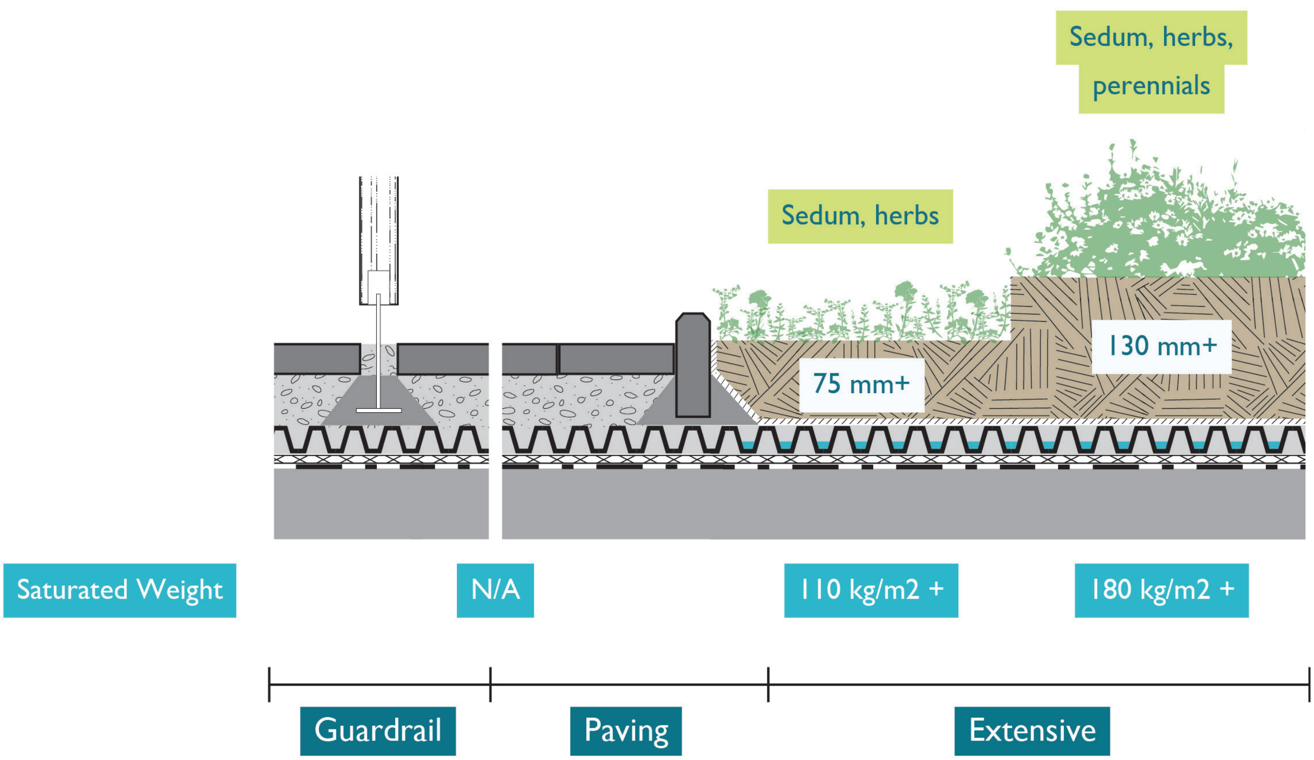
Preserved and artificial GWs do not require irrigation systems. The irrigation systems for all living wall construction types are similar. Hydroponic systems would also require a fertilizer tank and injection system, and an advanced remote monitoring system. Modular green wall systems will generally require more horizontal irrigation lines, typically running at the top of each module. Larger and taller greenery systems will generally have more intense irrigation systems with multiple watering zones for different microclimates, and larger pumps to ensure adequate water pressure allows water to reach the top of the system.[91]

91 Tong and Yin, *Living Wall*.

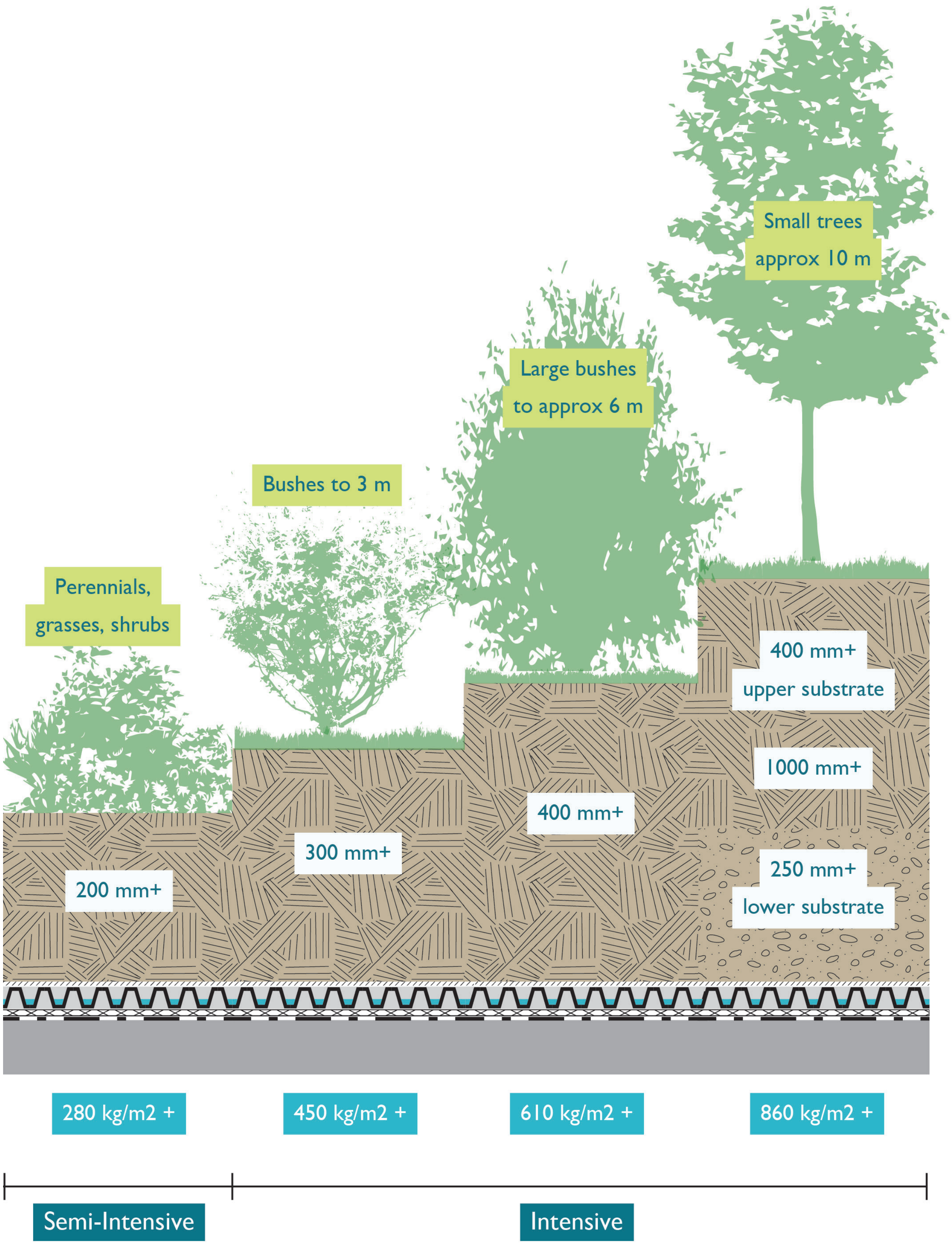
Drainage Plate Green Roof Built-up



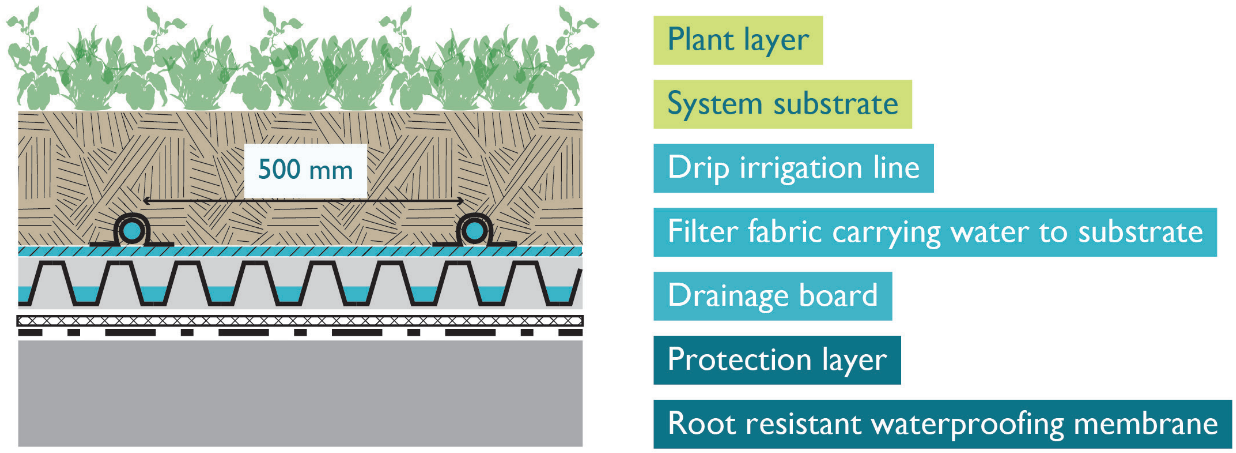
2-21 Built-up drainage board green roof system

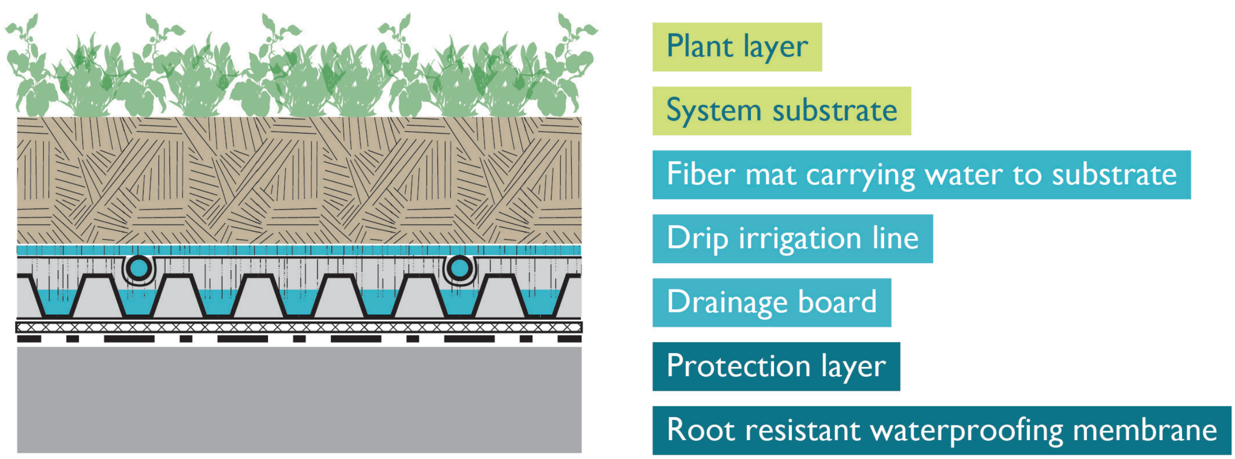


2-22 Green roof built-up drainage board system


Small trees
approx 10 m
Large bushes
to approx 6 m
Bushes to 3 m
Perennials,
grasses, shrubs
400 mm+
upper substrate
1000 mm+
400 mm+
300 mm+
250 mm+
lower substrate
200 mm+
280 kg/m2 +
450 kg/m2 +
610 kg/m2 +
860 kg/m2 +
Semi-Intensive
Intensive

Subsurface Irrigation





2-23 Subsurface irrigation of extensive green roofs

GREEN ROOFS

Roof gardens have a long architectural history and used centuries ago when buildings were lower to the ground or partially buried in the ground.[92] Historically, green roof (GR) construction were like traditional gardens on land because the roof gardens were soil-based.[93] No longer restricted to the weight of soils on roofs, advancements in GR material and design have led to extremely durable and lightweight assemblies that allow for larger scaled and more varied types of projects.[94] New GR materials offer greater resistance to weathering and more flexibility for a wide range of design applications.[95] Heavy aggregate GR systems are no longer used in large commercial application due to their weight.

The built-up drainage board system is the typical assembly for flat GRs (refer to Figure 2-21). This system consists of a plant layer, growing substrate, a filter fabric, a drainage board, a protection layer, and a root resistant waterproofing membrane.[96] The drainage elements can continue under supporting structures like paving stones and guardrails.[97] GRs can accommodate the growth of everything from sedum, perennials, large bushes, and small trees. The assembly weight, substrate depth and mixture will vary by the type of planting (refer to Figure 2-22). GR substrates are a mix of organic and inorganic material with a high mineral content.[98] Substrate thicknesses are set at a minimum to reduce structural load while still sustaining plant growth and organism development. GR suppliers develop substrate compositions with an ideal mix of organic and inorganic materials apt for specific plant types and climates. These formulas improve the permeability, nutrient access, and stability properties.

Building site topsoil can be preserved and reused as part of the substrate for growing vegetation on green roofs and substrate GWs, resulting in site sustainability benefits. This economy of materials helps to restore natural

92 van Zuilekom, "Guidelines for Going Green," 23.

93 Ibid., 23.

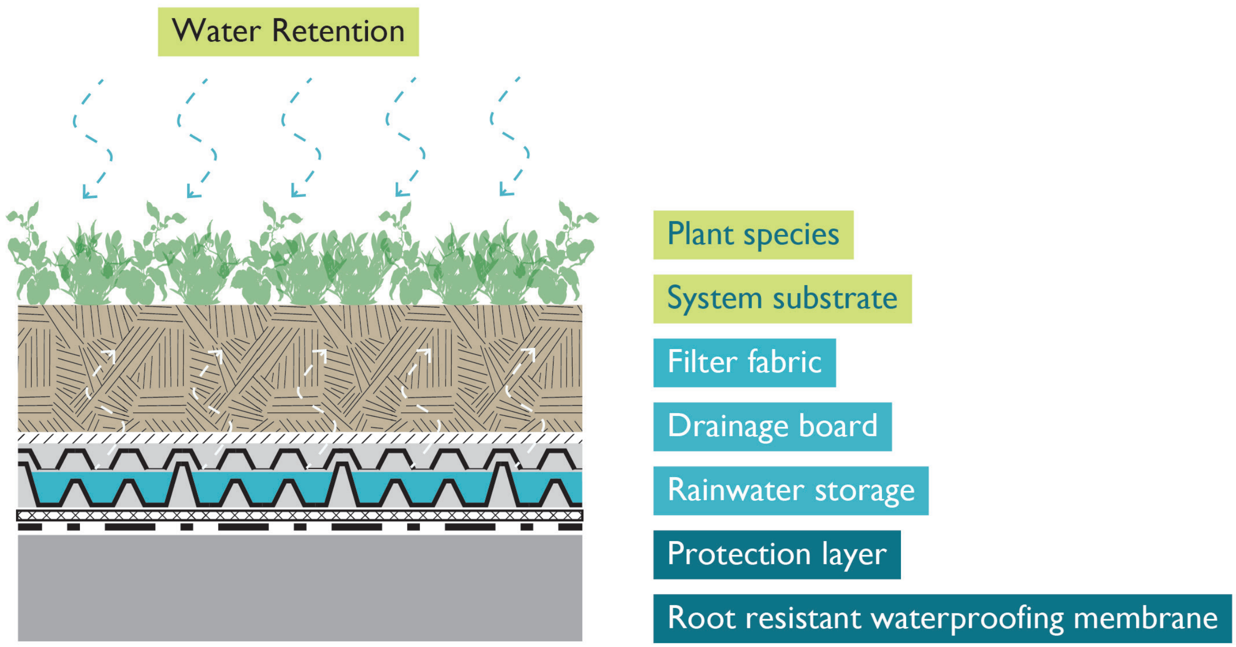
94 Ibid., 23.

95 Ibid., 23.

96 "Planning Guide: System Solutions for Intensive Green Roofs" (ZinCo, 2020), www.zinco-greenroof.com.

97 Ibid.

98 van Zuilekom, "Guidelines for Going Green.," 29.



2-24 Stormwater retention / passively irrigated green roof system site soil conditions and support the livelihood of native plant species inhabiting the area.[99] Turf rolls can be used initially on GRs to help preserve seeds in the substrate to help prevent problems with soil erosion and allow plants to adapt to the new substrate. [100]

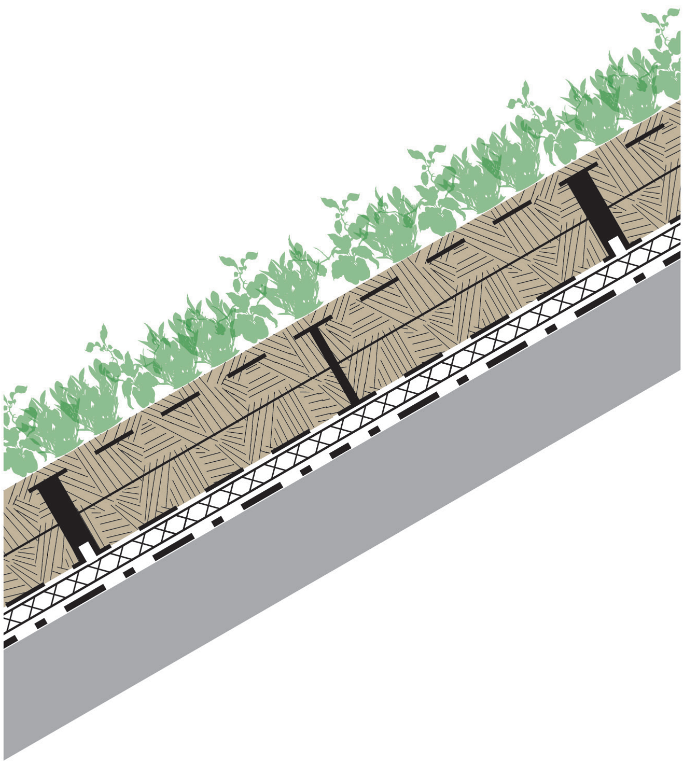
GREEN ROOF IRRIGATION AND DRAINAGE

Roof drainage is designed to suit different climates, from arid to tropical.[101] To encourage early rooftop vegetation growth, sprinklers can be distributed for the first few years after construction unit the GR vegetation is ready to sustain itself through rainwater only.[102] Dry and hot climates that experience long periods without rainfall may require built-in irrigation system. For flat GRs, this would consist of a subsurface irrigation line and a filter fabric or mat that carries water to the substrate (see Figure 2-23). Water logging inhibits plant growth; therefore, it is important to use a system that maximizes permeability yet retains enough water to support plant growth.[103]

Alternatively, an assembly like Figure 2-24 can utilize passive irrigation system as a good stormwater management strategy. Excess rainwater is retained under the drainage board and is absorbed by the substrate during drier times. Rainwater collected from a GR can also be collected and stored in reservoir tanks or ponds. Rainwater can be channeled through a drain at the bottom of the rooftop substrate into ponds located on site. Retained water from the roofs deviate and control water run-off into city's storm sewers.[104] Retention ponds temporarily store rainwater to support the presence of local flora and fauna.[105]

99 Ashizawa, "Guidelines for Green Façades and Roof Gardens," 20.
100 Ibid., 18.
101 van Zuilekom, "Guidelines for Going Green," 23.
102 Ashizawa, "Guidelines for Green Façades and Roof Gardens," 18.
103 Ibid., 18.
104 Radić, Dodig, and Auer, "Green Facades and Living Walls."
105 Ashizawa, "Guidelines for Green Façades and Roof Gardens," 20.

Steep Slope Assembly



2-25 Steep slope green roof assembly

SLOPED GREEN ROOFS

A GR above a 10-degree pitch is considered sloped. Sloped GRs are very attractive building features and highly visible from the ground. Sloped roofs will use techniques for erosion control and stabilization.[106] They do not require drainage boards but rather support structures, such as a web net mesh, that helps to prevent movement and erosion of substrate. A steep sloped roof, one over a 20-degree slope, can have interlocking cellular grid elements to contain substrate and additional shear barriers like stable eave upstands and edging (see Figure 2-25).[107]

GREEN ROOF BENEFITS

Green roofs provide many benefits for the HCF. These include additional useable healthcare space, aesthetic improvements, thermal benefits, habitat restoration and other environmental benefits.[108] GRs work as a heat insulator, building membrane protector and rainwater collector.[109] The additional layers protect the roof structures from harsh environmental exposures such as solar UV rays, wind, erosion, and temperature fluctuations.[110] Moreover, the vegetation reduces heat island effects and stormwater runoff.[111] Resulting green spaces can provide wildlife habitat, a landscape view, or useable therapeutic green spaces.

Issues with GRs include urban conditions that interfere with the therapeutic qualities of the green spaces. Possible negative qualities in hospital gardens reported by occupants include cigarette smoke, urban and machine sounds, a predominance of hardscape, and overcrowding.[112] In addition, wet and cold weather can be a barrier to GR activities and reduce time spent in exterior gardens.[113]

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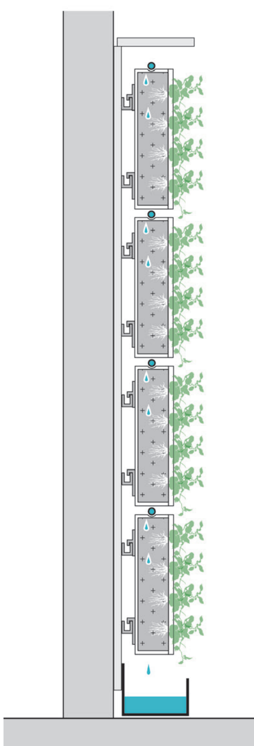
106 Ashizawa, "Guidelines for Green Façades and Roof Gardens," 19.
107 Ibid., 19.
108 Muhannad Shafique, Reeho Kim, and Muhammad Rafiq, "Green Roof Benefits, Opportunities and Challenges - A Review," *Renewable and Sustainable Energy Reviews* 90 (July 2018): 757–73.
109 Ashizawa, "Guidelines for Green Façades and Roof Gardens," 16.
110 van Zuilekom, "Guidelines for Going Green," 23.
111 Shafique, Kim, and Rafiq, "Green Roof Benefits, Opportunities and Challenges."
112 Ulrich, "Health Benefits of Gardens in Hospitals," 8.
113 Ibid., 8.

PRECEDENT PROJECTS

Precedent case studies of green walls in both healthcare and non-healthcare projects are included. Precedent projects in healthcare facility demonstrate how VGS work within specific healthcare environments and functional programmes. Since Part 3 of my thesis is a design application of a health care facility in British Columbia (BC), I have researched precedent living walls inside hospitals as well as exterior GWs in locations with a similar climate as BC. Non-healthcare project case studies provide ideas and inspiration for new designs.

Lancaster General Ann B. Barshinger Cancer Institute
Hydroponic Modular Panel Construction

System:	GSky Pro Wall® panel
Design:	Ambius
Location:	Lancaster, USA, Installed 2013
Site:	Indoor hospital lobby, Integrated bench
Size:	37 sq m (33' x 12' tall)
Lighting:	Clerestory windows, grow lights at the top of wall



CYRTOMIUM FALCATUM
"Holly Fern"

ASPLENIUM NIDUS
"Bird's Nest Fern"

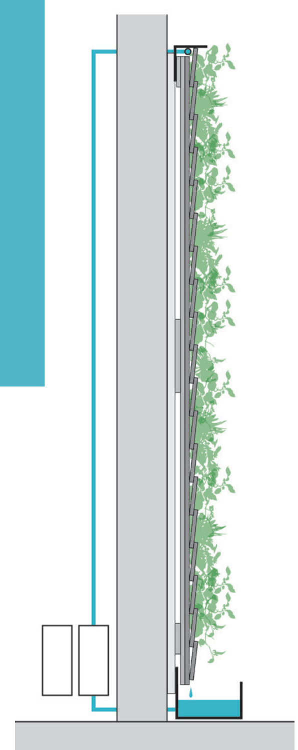
SCINDAPSUS PICTUS
"Silver Satin Pathos"

2-26 Green wall in hospital lobby area

Santa Fe de Bogotá Foundation Hospital
Hydroponic Felt / Fibre Mat Construction

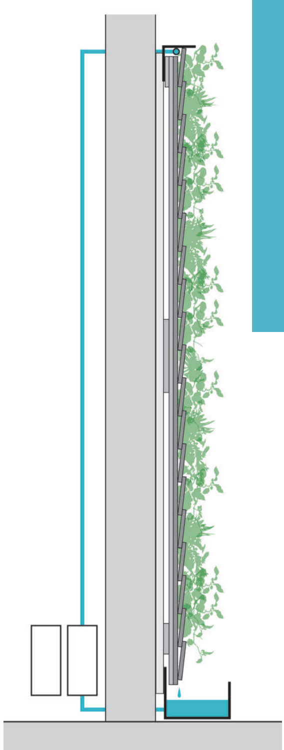
System:	Fabric / fiber hydroponic Living columns
Architect:	El Equipo de Mazzanti
Landscape:	Groncol
Location:	Bogotá, Colombia, 2016 Exterior solarium garden
Biome:	Tropical and subtropical forest
Building:	Brick facade supported by steel and cable structure

2-27 Green columns in hospital exterior garden



Changi General Hospital Visitor Centre
Hydroponic Felt / Fibre Mat Construction

System:	Panels with nano-fibre and sterile geo-fabric
Design:	Greenology Pte Ltd.
Location:	Simei, Singapore
	Indoors along major walkway
Structure:	Double-sided screen
Vegetation:	15 different species
Lighting:	120 watt LED grow lights



PTERIS ALBO LINEATA
"Silver Ribbon Fern"

ANTHURIUM CULTIVAR
"Flamingo Lily"

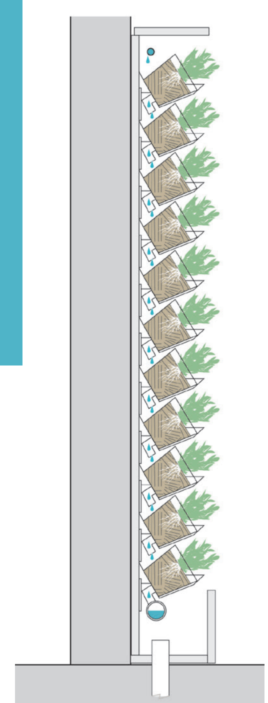
PHILODENDRON LIME GREEN

2-28 Green wall in hospital walkway

Good Samaritan North Health Center
Substrate Tray / Cellular Construction

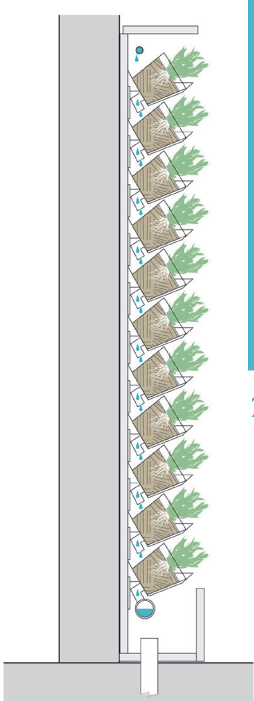
System:	GSky Versa Wall®
Architect:	Andrews Architects
Plant Desiger:	GSky Plant Systems, Inc.
Location:	Dayton, Ohio, USA, 2015
	Miami Valley Hospital North
	Indoor reception area
Vegetation:	Compact low light species
Size:	60 sq ft / 5.6 sq m
Lighting:	Recessed lights min. 5' away

2-29 Green wall in hospital reception area



Hudson Spine & Pain Medicine
Substrate Tray / Cellular Construction

System:	GSky Versa Wall®
Architect:	Lothrop
Plant Designer:	Debbie Kotalic
Location:	New York, NY, USA, 2016
	Rehabilitation, pain management, sports medicine, orthopedics, Indoor fitness area
Size:	596 sq ft / 55 sq m
Lighting:	Suspended lights min. 5' away

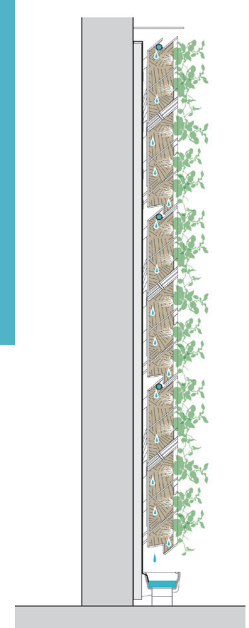


2-30 Green walls in health care exercise area

Jersey Shore University Medical Center HOPE Tower
Planter Box / Trough Substrate Construction

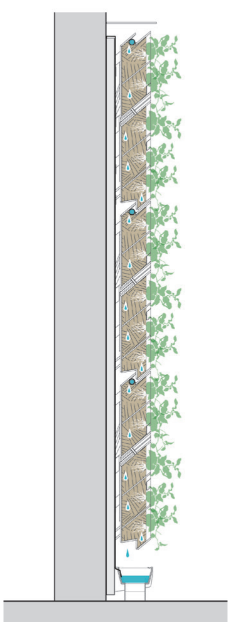
System:	LiveWall® Outdoor Living Wall
Architect:	EYP Architecture & Engineering
Location:	Neptune, NJ, USA, 2018 Outdoor garden courtyard
Biome:	Temperate deciduous forest
Vegetation:	Perennials, edible plants
Size:	2 walls total 514 sq ft / 48 sq m
Feature:	Cover exterior walls and extends landscape vertically

2-31 Green walls in outdoor hospital garden



National Grid Car Park
Modular Substrate Construction

System:	ANS Living Wall by ANS Global
Architect:	One-World Design Architects
Location:	Warwick, UK, 2014
Biome:	Temperate deciduous forest
Structure:	Pre-fab steel and concrete
Vegetation:	97,000 plants, 20 species
Size:	1,027 sq m (largest in Europe)
Time:	4 weeks
Features:	Houses bird and insect boxes



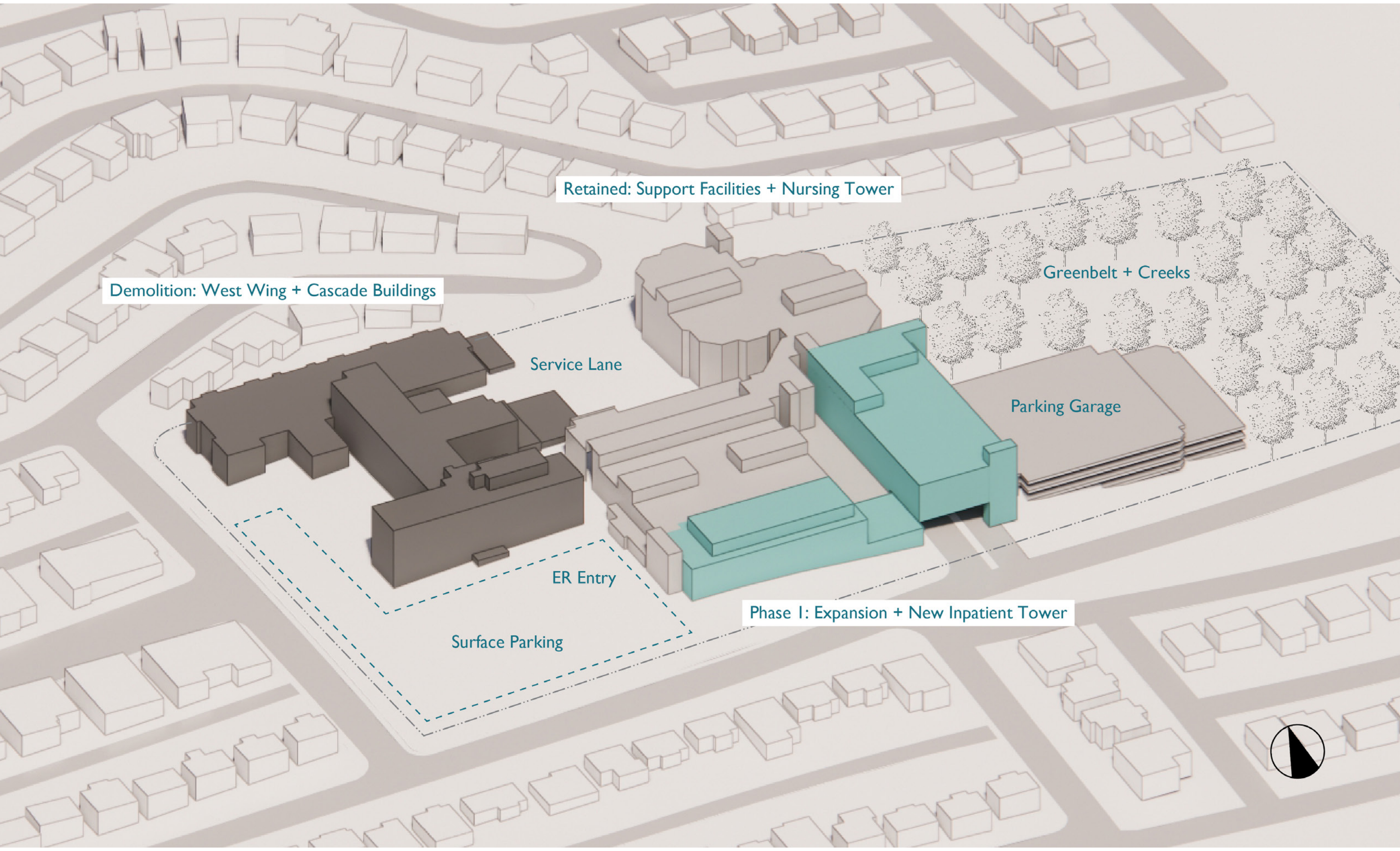
MENTHA
"Mint"

VINCA MINOR
"Lesser Periwinkle"

BUXUS SEMPERVIRENS
"Common Boxwood"

2-32 Green walls on parkade

Part 3 : Nature Assisted Healthcare Architecture



3-1 Existing Burnaby Hospital redevelopment site

DESIGN SITE

Part 3 is a design application of the principles discussed in the previous sections. The design demonstrates nature assisted healthcare architecture and its benefit to occupants in various medical units. Hortitecture helps to create healing and therapeutic spaces in specialized long-term care units like rehabilitation, palliative care, and mental health units. A typical hospital nursing tower functional program and stacking organization is used to illustrate the design of a series of interior and exterior green spaces within a complete inpatient tower form.

BURNABY HOSPITAL DESIGN SITE

The location of this envisioned nursing tower is at Burnaby Hospital in British Columbia, Canada. The hospital is currently undergoing redevelopment with Phase 1 recently proposed.[1] Phase 1 redevelopment plans include a new inpatient tower, expansion of the Support Facilities building, and demolition of the West Wing and Cascade buildings on the northwest side of the hospital site (refer to Figure 3-1).[2]

The West Wing and Cascade buildings will be demolished, and where they currently stand the City of Burnaby proposes a Phase 2 development consisting of an eight storey, 160 bed inpatient tower.[3] This soon to be vacant site and the proposed Phase 2 inpatient tower, is the location and narrative basis of my proposed inpatient tower form and nature-assisted healthcare green spaces (see Figure 3-2). During the completion of this thesis, no further details of the Burnaby Hospital Phase 2 redevelopment had been provided. The proposed patient tower will connect to the existing support facilities building and connect to a possible future expansion on the northwest portion of the site.

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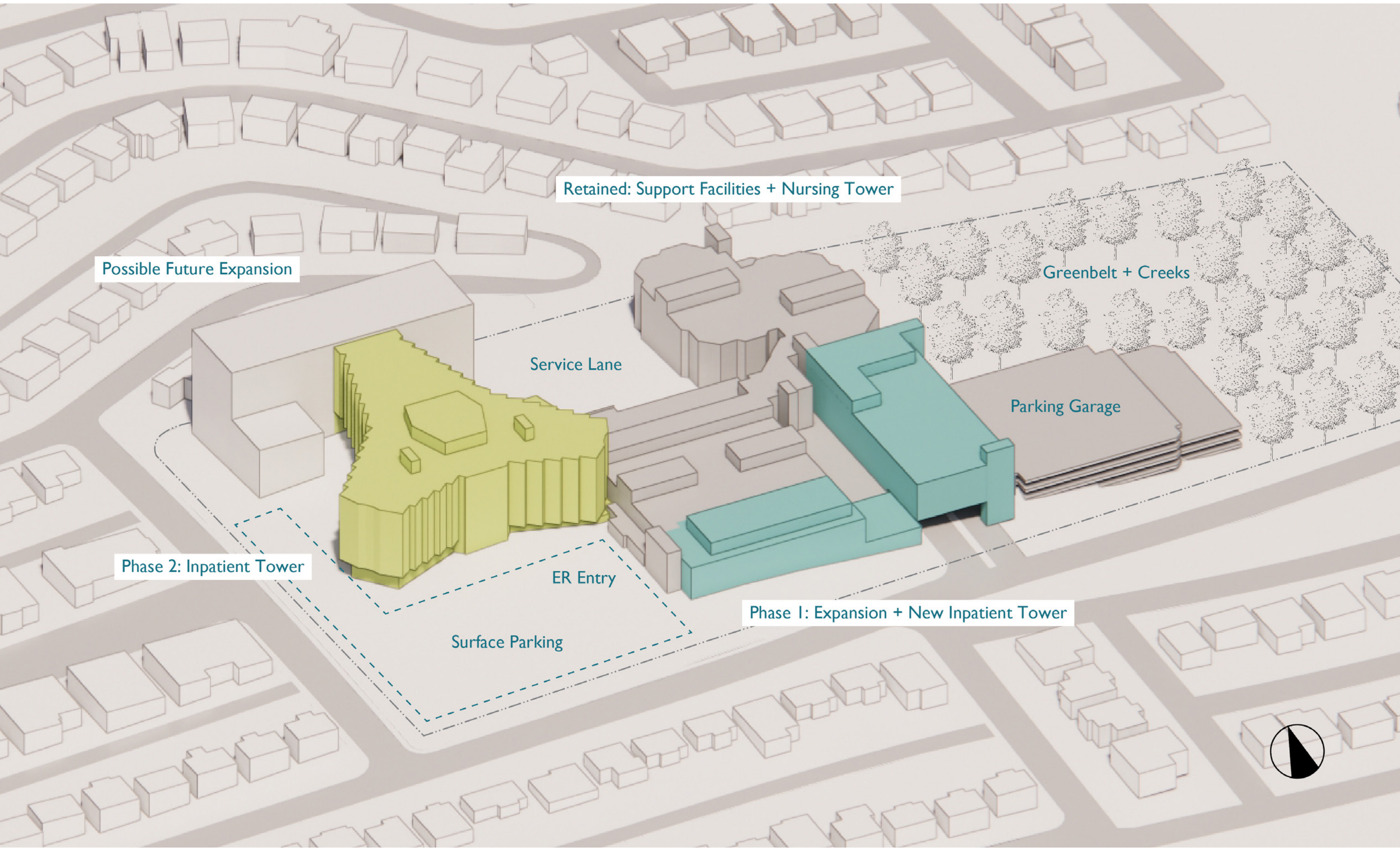
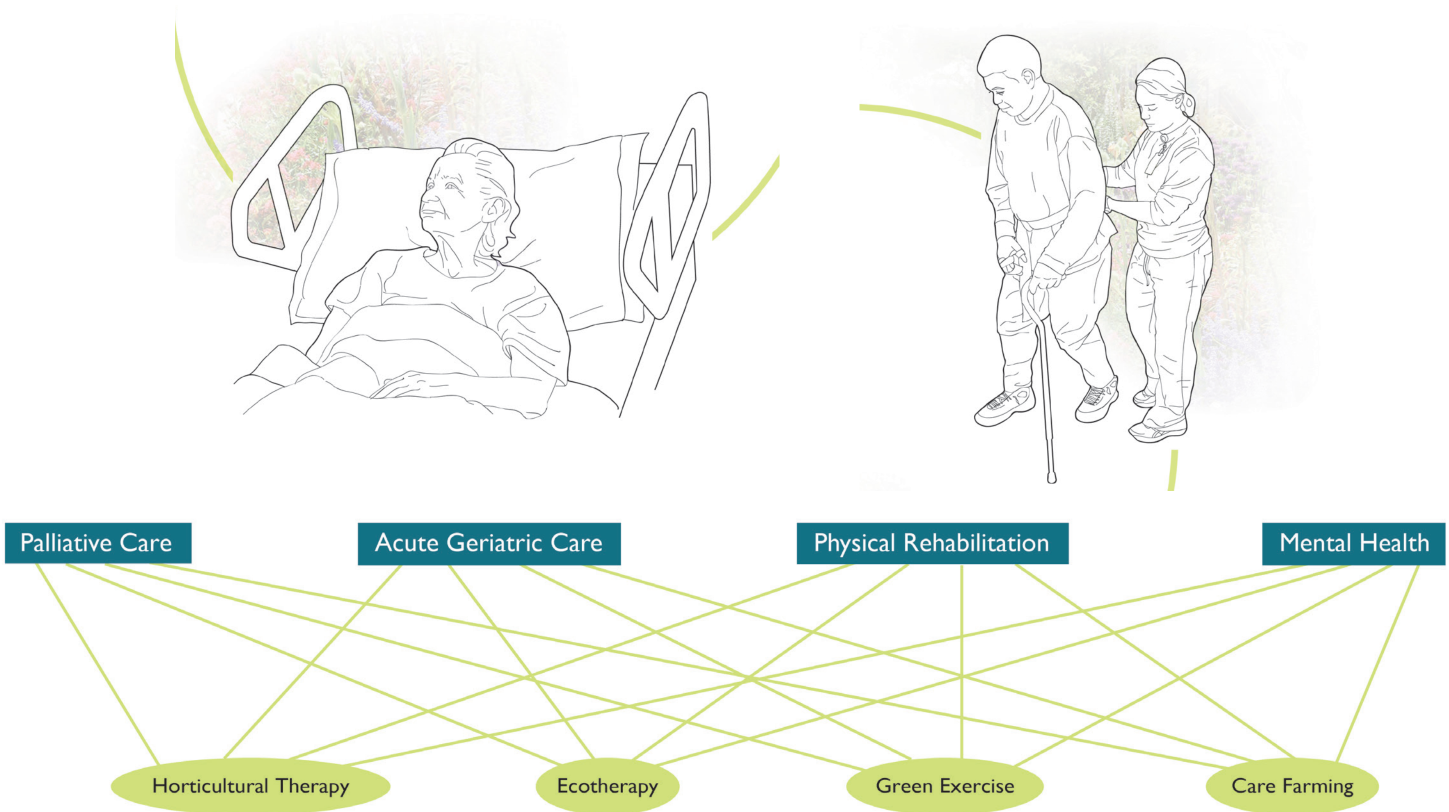
1 "Burnaby Hospital Redevelopment Will Deliver Better Health Care in a Growing Region," BC Government News, September 3, 2019, https://news.gov.bc.ca/releases/2019HLTH0121-001694.

2 Ibid.

3 Ibid.



3-2 Burnaby Hospital site with Phase 2 tower design



3-3 Medical program and nature assisted interventions

NATURE ASSISTED INTERVENTIONS

The proposed nursing tower will be comprised of various medical units, including palliative care, acute geriatric care, physical rehabilitation, and mental health. Patients with various conditions and illnesses can benefit from nature assisted interventions (NAIs), which are activities that directly use natural elements for health and well-being.[4] NAI is different from nature-based interventions (NBI), which can take place in any natural outdoor environment. With NAI, "the activity is always directed related to the use of nature elements".[5]

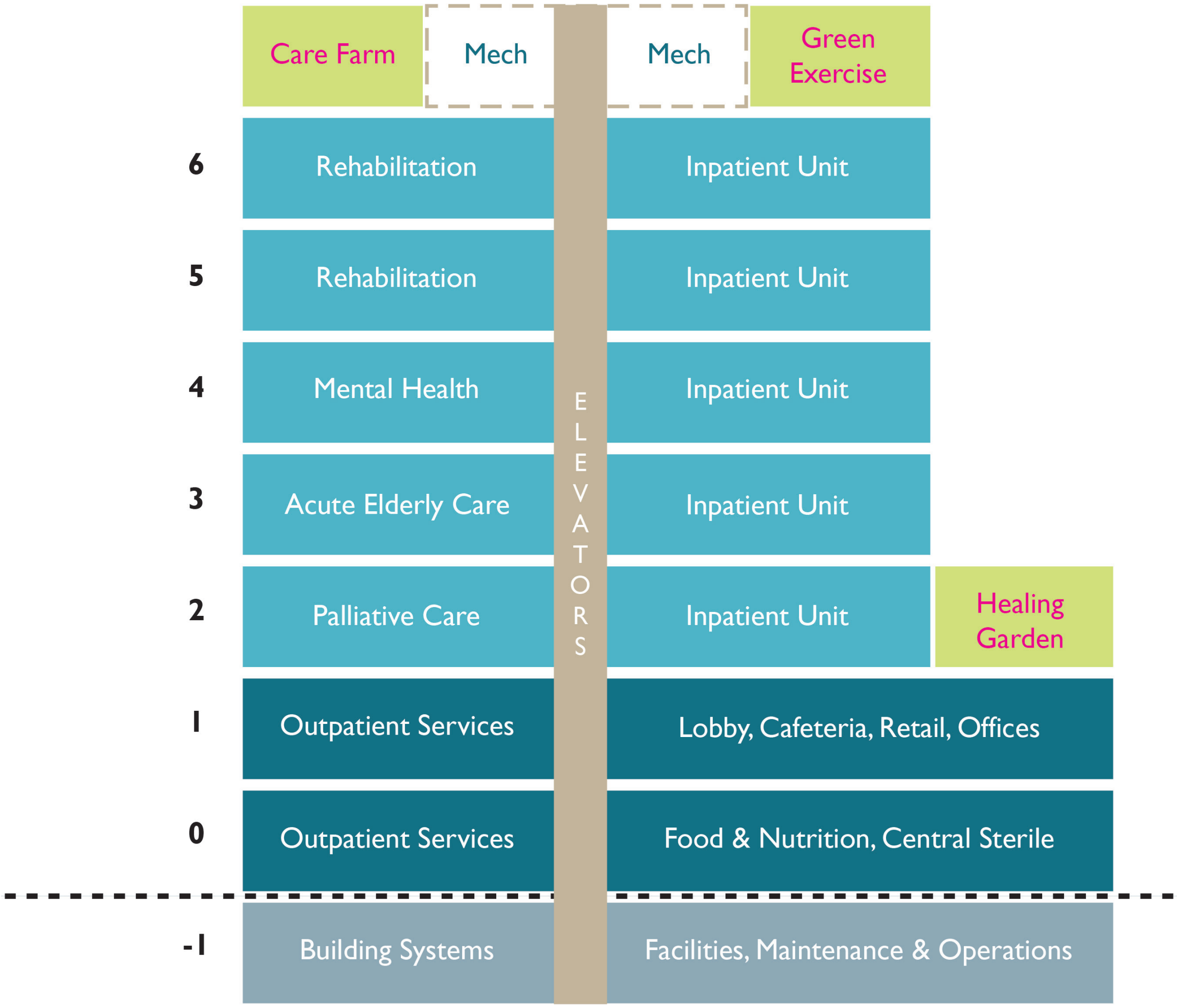
4 Pálsdóttir, Sempik, and Bird, "Using Nature as a Treatment Option," 125-31.
5 Ibid., 125.

The NAI activities shown in Figure 3-3 are horticultural therapy, which includes sensory gardens; ecotherapy which are therapies in multifunctional green spaces that are equilibrium between human health and ecosystems; green exercise which is physical activity combined with nature; and care farming, which is working with plant crops.[6] Designs for NAI spaces within the interior and exterior envelope of the hypothetical patient tower are demonstrated herein. Hospital areas outside of this inpatient tower, such as the surface parking area for the emergency entrance, are not within the scope of this design thesis.

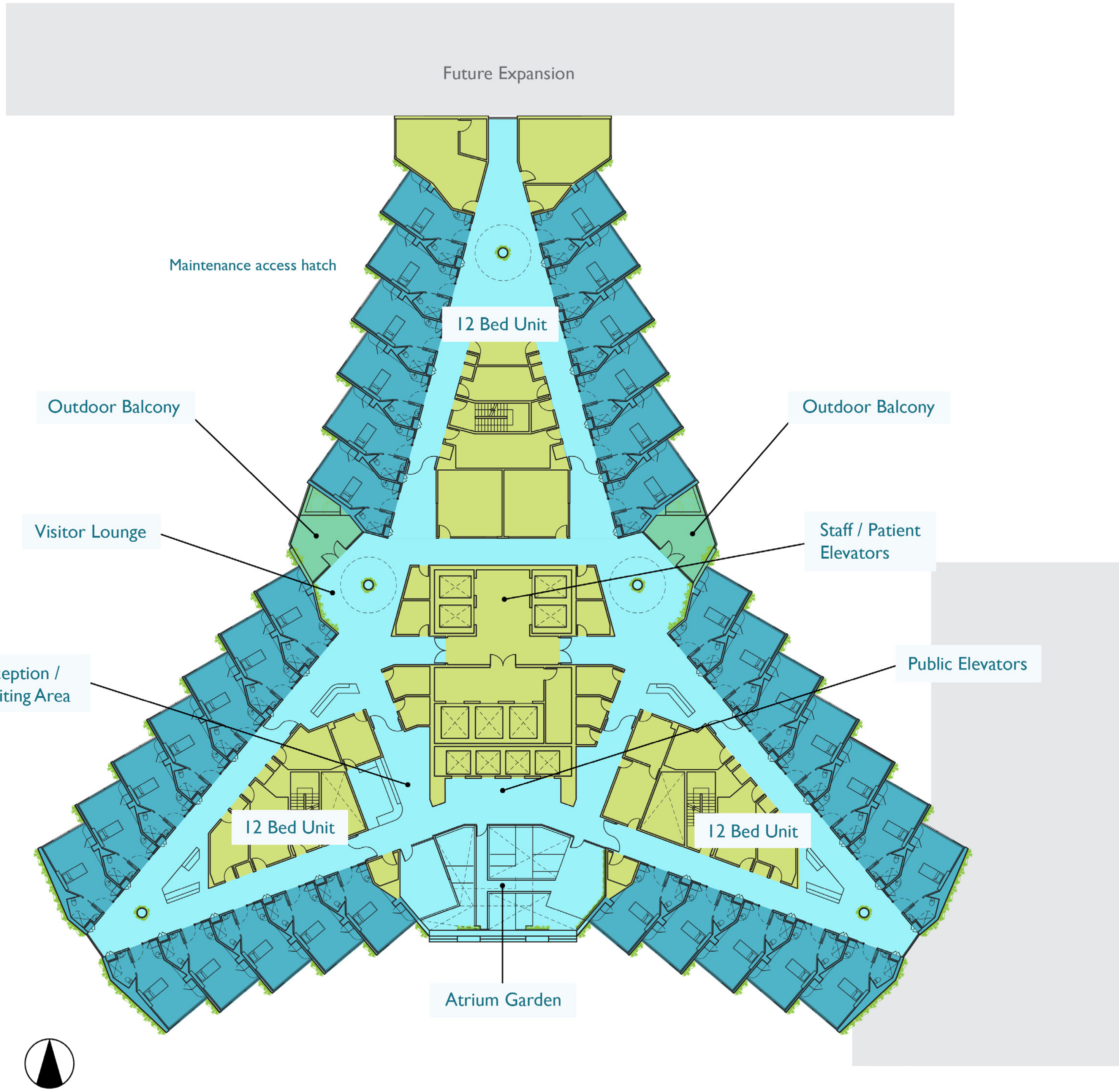
STACKING DIAGRAM

Figure 3-4 is a programmatic stacking diagram of the proposed eight-level nursing tower. The proposed tower will consist of medical units from the buildings to be demolished, and other areas of the hospital site. The organization of program follows common nursing tower program stacking with inpatient units on the upper levels, followed by outpatient services, offices and administration on the podium, and facilities and operations at the lower level. The thesis design intervention will include interior and exterior green spaces. The diagram shows the location of designed exterior green roofs including a horticultural care farm, and green exercise area, and a healing garden.

6 Pálsdóttir, Sempik, and Bird, "Using Nature as a Treatment Option."



3-4 Programmatic stacking diagram of proposed tower



3-5 Typical inpatient floor plan

TYPICAL INPATIENT FLOOR PLAN

Figure 3-5 depicts the tower's typical inpatient level floor plan. Inpatient floors are comprised of three triangular, 12-bed nursing units. Compact triangular nursing units increases efficiency and reduces travel times. Bedrooms are laid out in a serrated pattern to provide direct views to the exterior living walls, well illuminated by their orientation. The building is oriented so that green walls are facing either southeast or southwest to maximized daylight exposure on the living gardens. This provides adequate lighting for many plant species and illuminates the green walls in the daytime for better patient views from the interior, and at a distance from the outside. Each floor will have visitor lounges with balconies and access to the atrium garden on the south side of the site. Separate patient, visitor, and service elevators are housed in a central elevator core, accessible from multiple sides of the building floor. Redundant circulation paths within offer multiple route options for occupants to choose from, which increases efficiency and reduces walking times among staff.

3-6 Exterior envelope greenery systems

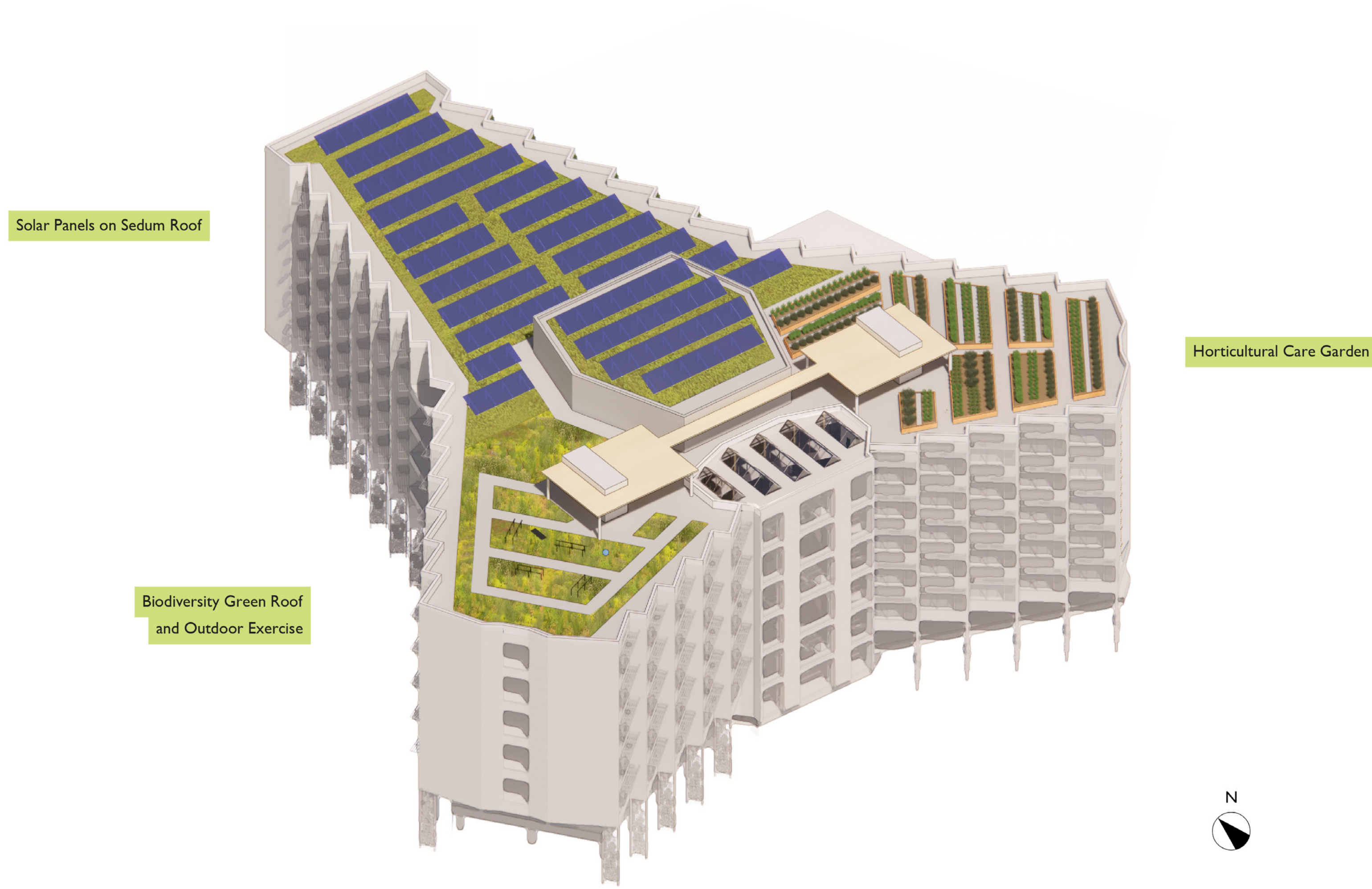
EXTERIOR GREENERY SYSTEMS

The exterior will feature a series of hydroponic green walls adjacent to patient rooms (see Figure 3-6). Continuous fabric hydroponic green walls are lightweight, long lasting, less expensive and require less irrigation lines than modular green wall systems. Hydroponic green walls are suitable for exterior use in temperate and warm climates like southern British Columbia. However, colder areas of Canada may benefit from using a substrate-based modular box/panel system, which can be designed to be much more like natural soil conditions. During cold periods, the irrigation system can be shut down to prevent freezing. Substrate-based growing media retains water, air, and nutrients so that plants can survive without irrigation for much longer periods than with hydroponic systems.

A VISIBLE ECOSYSTEM

The exterior green walls are visible from the building entrances, surface parking areas, and exterior gardens. The south sides will feature large hydroponic green walls. The planting design will be in graphic pattern visible from afar and upon entry to the hospital. Dozens of different species will be used to create an ecosystem of native plants. The community of plant species will support one another by sharing water and nutrient resources. Larger plant species will create niche microclimates and pockets of shade and wind protection for smaller and more sensitive species. A dense and mixed planting design of proven plant species types should ensure that plants on the vertical garden thrive for years and grow to their size potential.

Green walls can become habitats and nesting grounds for birds. Unfortunately, glass on building windows and balcony railings can reflect the surrounding landscape, causing birds to crash into them. Therefore, all glazing adjacent to greenery will be treated with frit, film, or acid etching to prevent bird collisions. In some areas they will include artistic wildlife graphics that reflect the theme of the building and personalize each patient room.



3-7 Green roof axonometric showing solar farm, biodiversity roof, and care garden

GREEN ROOF AXONOMETRIC

The nursing tower will have an occupiable green roof that actively assists with therapeutic patient activities (see Figure 3-7). The southwest wing of the roof will be a biodiversity roof with outdoor ecotherapy and green exercise spaces. The southeast side of the building will feature a working horticultural care garden. The north wing will generate renewable energy for the building through a solar green roof with photovoltaic panels installed over sedum plants. In addition to providing thermal insulation for the building, the sedum green roof helps keep the solar panels cool under extreme heat conditions. This is an innovative strategy to cool hospitals and generate clean electrical energy to power healthcare equipment, as well as greenery irrigation and lighting systems.

BIODIVERSITY ROOF

The biodiversity green roof consists of hilly areas planted with forage plants, shrubs, grasses, and perennials that attract pollinators. A variety of landscape features like large wood branches, rocks and open water will provide habitat resources for birds and insects. This becomes an eco-therapeutic setting of outdoor green exercise areas with accessible walking trails, and some natural looking physical therapy equipment like parallel bars, and exercise stairs. The wildlife garden provides soft fascination through nature immersion. The green roof is intended to provide a safe and remote space for outdoor activity and physical exercise. With only the view of sky, mountains and cityscape, there will be no reminders of the clinical therapies while on the green roof. A minimal of outdoor lights will be used to reduce night sky light pollution.[7]

7 Facility Guidelines Institute, ed., *Guidelines for Design and Construction of Health Care Facilities*, 2010 ed (Chicago, Ill: ASHE (American Society for Healthcare Engineering of the American Hospital Association), 2010).

3-8 Next page, Horticultural care garden perspective


It feels good to burn some energy and help grow all this food!
Picking your own veggies provides a varied daytime activity for residents.
Accessible raised planters with walks


So juicy and sweet! Now I know why the hospital's hot tomato soup tastes so fresh.
Year-round productive vegetable garden
This is a great way to engage with other people outside.
Covered horticultural education and activity area

HORTICULTURAL CARE GARDEN

The horticultural care garden provides spaces away from the medical environment for residents, volunteers, and staff to work with crops and grow food. Care farming is beneficial to many patient groups including those with mental disorders or cognitive disabilities.[8] It provides meaningful occupation and increases self-efficacy. The physical activity and social inclusion are also rewarding and provides individuals with a sense of identity and purpose.[9] Raised planters offer greater accessibility, and those with physical disabilities can use special tools. Plant-based food is nurturing and for many cultures a source of natural medicine. Hospital food made from freshly picked organic vegetables and herbs can provide nutritious and meaningful sustenance for patients to support their recovery.

8 Pálsdóttir, Sempik, and Bird, "Using Nature as a Treatment Option."

9 Ibid.

3-9 Healing garden plan

HEALING GARDEN

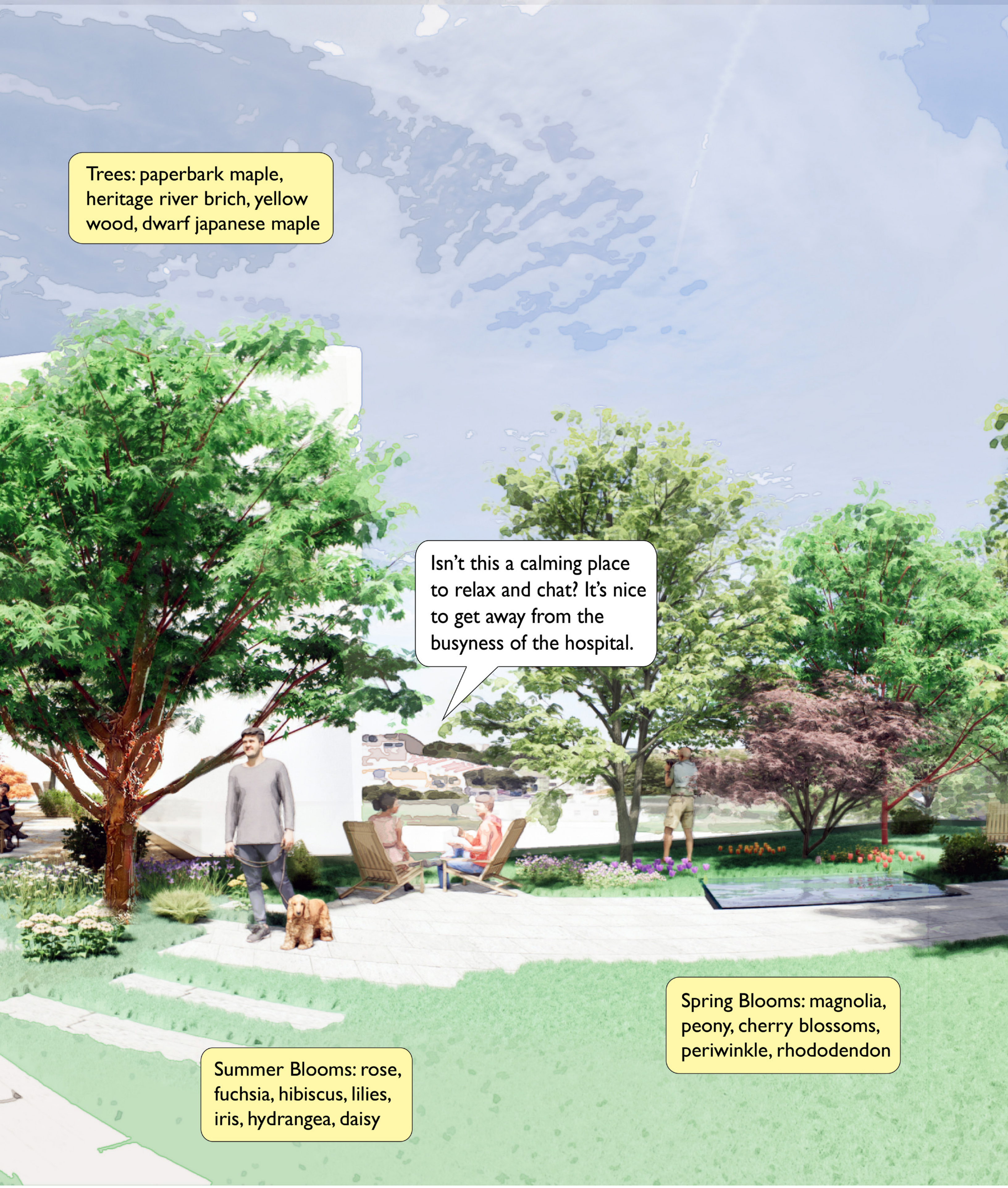
In the case of vertical gardens, extending planting beyond the horizontal plane allows occupants to inhabit the green space. The creation of occupiable green space makes for a more healing and therapeutic environment. The healing garden on the podium rooftop is an intensive green roof that provides spaces of respite for hospital occupants (refer to Figure 3-9). The healing garden contains both open spaces that encourage social interaction as well as quiet private spaces for contemplation and meditation. There is an open lawn area for social activities and quiet seating areas near fountains and garden sculptures. Fragrant and colourful plant species provide sensory experience. The sound of water and wind are soothing. The wide walkways through planted garden areas provide opportunities for prospect and refuge. Tall running bamboo planted in front of patient windows provide privacy and relaxing green views for residents.

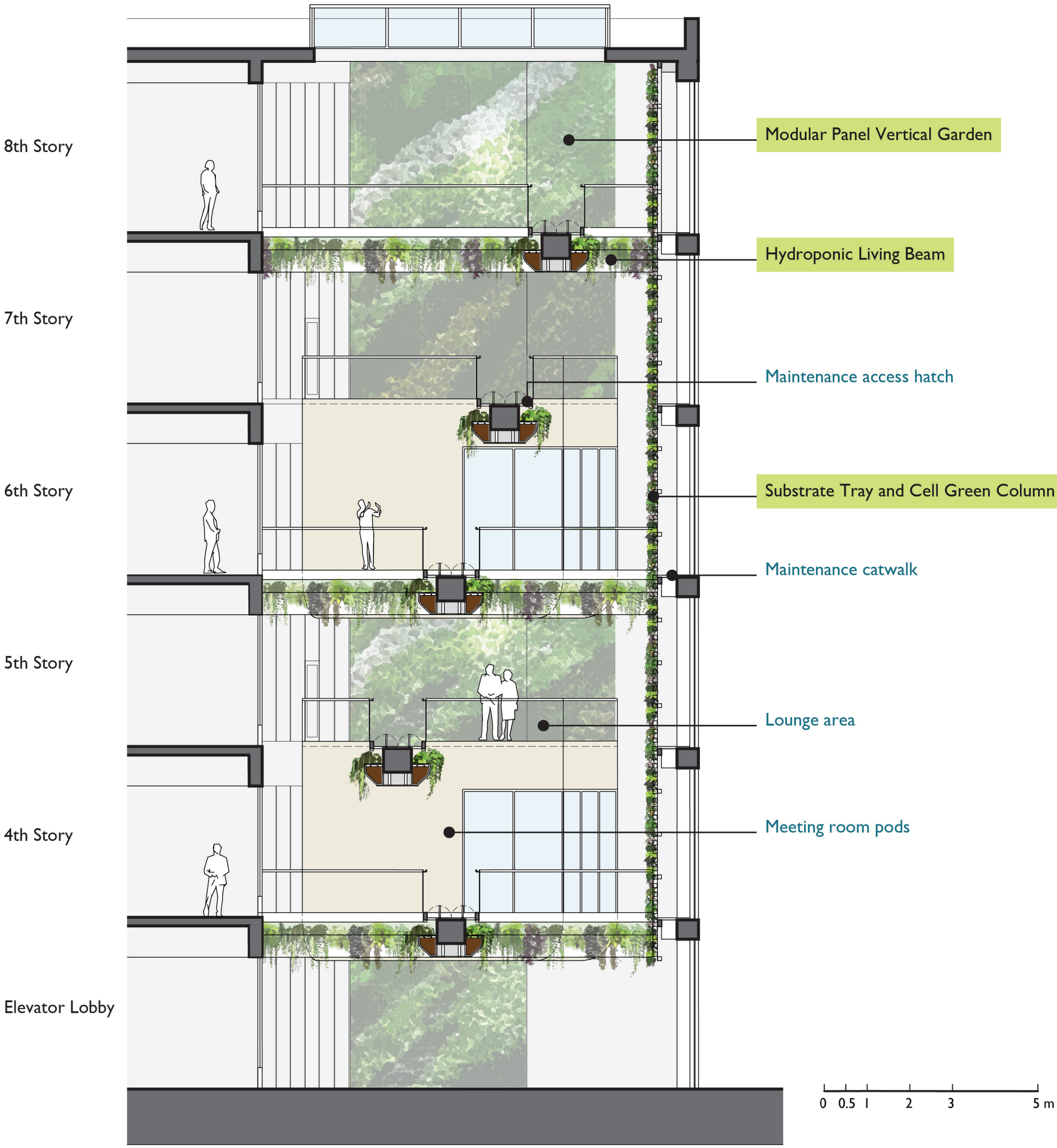
SEASONAL INTEREST

The panoramic perspective on Figure 3-10 shows the healing garden at different seasons. The healing garden green roof is planted with small ornamental trees like paperbark maple and heritage river birch that provide texture and colour with their changing foliage colours and textured peeling bark. The green roof is planted with species with different blooming times and species providing changing seasonal colours and interest. Visiting the healing garden in the winter, healthcare occupants will experience beautiful textures and silhouettes. As well, many plant species will provide winter flowers and colourful berries and stems. These include witch hazel, berry bush, dogwood, and winter jasmine. The exterior green walls on the patient rooms extend the vegetation upwards and helps to integrate the building with the garden landscape.

3-10 *Next page,* Healing garden perspective illustrating four seasons


This is a serene place to unwind. I like to be able to walk outside or sit alone, immersed in nature.
Winter Colour: witchhazel, beautyberry bush, dogwood, winter jasmine, winter aconite
Fall Colour: maples, aster heathers autumn crocus, fatsia, ornamental grasses

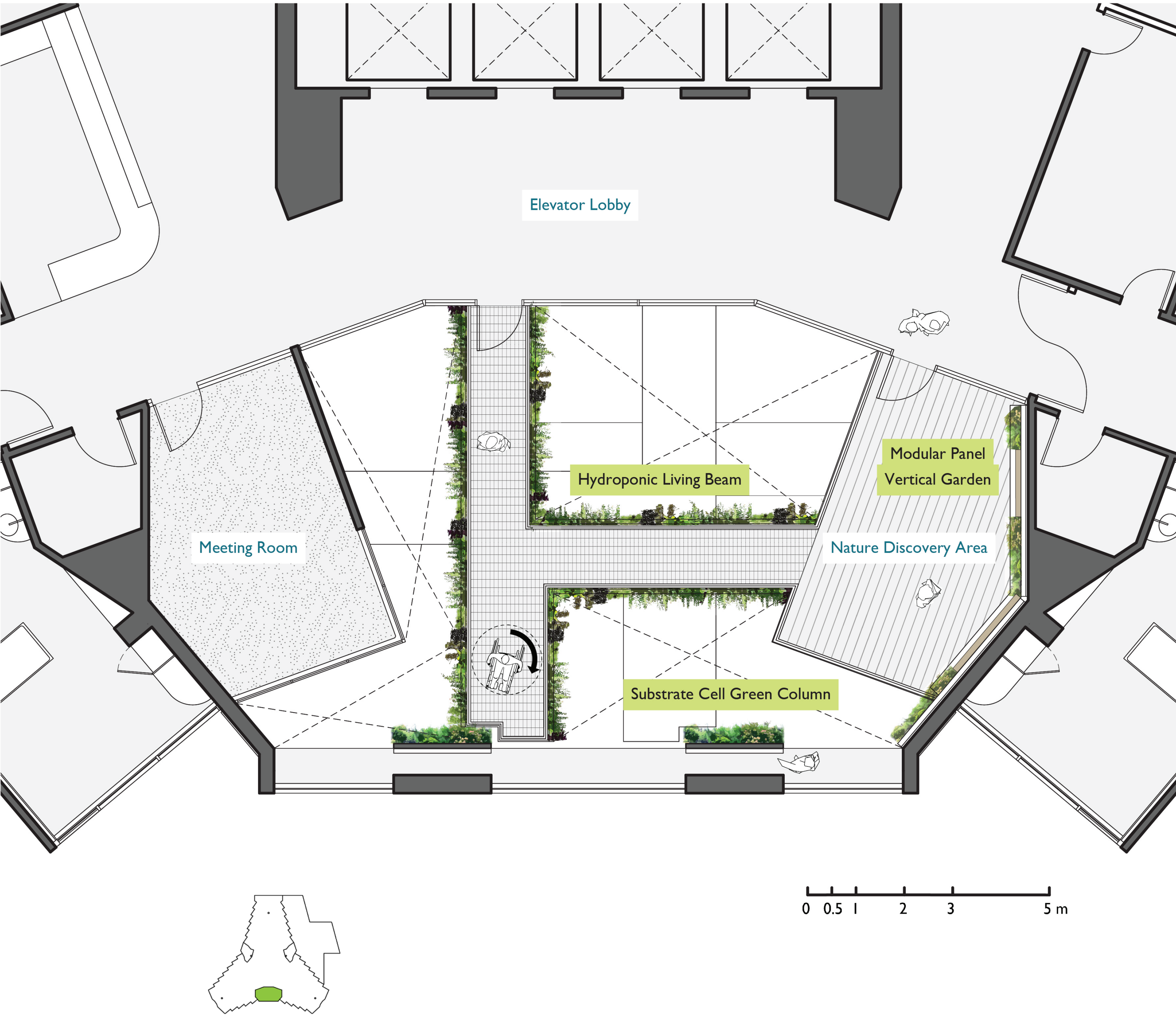

Trees: paperbark maple, heritage river brich, yellow wood, dwarf japanese maple
Isn’t this a calming place to relax and chat? It’s nice to get away from the busyness of the hospital.
Spring Blooms: magnolia, peony, cherry blossoms, periwinkle, rhododendon
Summer Blooms: rose, fuchsia, hibiscus, lilies, iris, hydrangea, daisy



3-11 Multi-storey atrium section

MULTI-STOREY LIVING ATRIUM

An interior NAI is created by a six-storey atrium garden at the south entrance of the building accessible from all inpatient floors (refer to Figures 3-11 to 3-14). Vegetated pedestrian bridges feature planters on each side containing hanging plants species that create a forest-like experience inside the tall space. The bridges extend out to two feature living columns. These utilize the substrate cell GW system because a clean and uniform appearance can be maintained with individually potted plantings. With individual pots, plants can be easily changed to create seasonal colour themes and different artistic compositions throughout the year. Ease of maintenance is provided on the bridges through access hatches on the sides of the floorplates. Furthermore, the living columns have catwalks behind them for maintenance access. Meeting rooms extend out to the atrium space and have open lounge areas on top. A typical plan shown in Figure 3-12 depicts pods on either side with views of the green columns. On top of the pods are visitor lounge spaces featuring hydroponic green wall panels and relaxing water features or interactive displays.



3-12 Multi-storey atrium plan

ATRIUM GARDEN NATURE ASSISTED INTERVENTIONS

Figure 3-13 is a perspective view from a third-floor pedestrian bridge approaching the green columns. Visitors can look up or down to view the hanging plant species on all the floors and see the whole extent of the six-storey living columns, which can give a feeling of suspension and grandeur. There will be supplementary lighting and irrigation lines for living walkways, and spotlights on the green walls that will offer different experiences of the space in the evenings. Figure 3-14 provides a perspective view from the top floor of the atrium garden. This perspective gives a sense of the amount of sunlight in the space from the skylights and south-facing windows, offering visitors a feeling of being outdoors. The humidity and warmth of the tropical greenery creates a feeling of being transported away from the medical environment. The open lounge areas can offer space for reading and discovery. The double-height space on the top floor and open areas in the middle provide opportunity for sculptural art installations with greenery. The addition of forest nature sounds is soothing and provides a nature immersive experience indoors. Natural and tactile materials, as well as focus soft and natural lighting are utilized.

3-13 *Next page,* Multi-storey atrium perspective


Hydroponic
living beams


So many different colours and textures. I see new plants every time I visit.
Substrate cell living column
I like looking above and below at the suspended pods and hanging plants.

3-14 Multi-storey atrium top floor perspective


Substrate cell living column with access catwalk behind
The forest and water sounds are calming.

VISITOR LOUNGE AREA

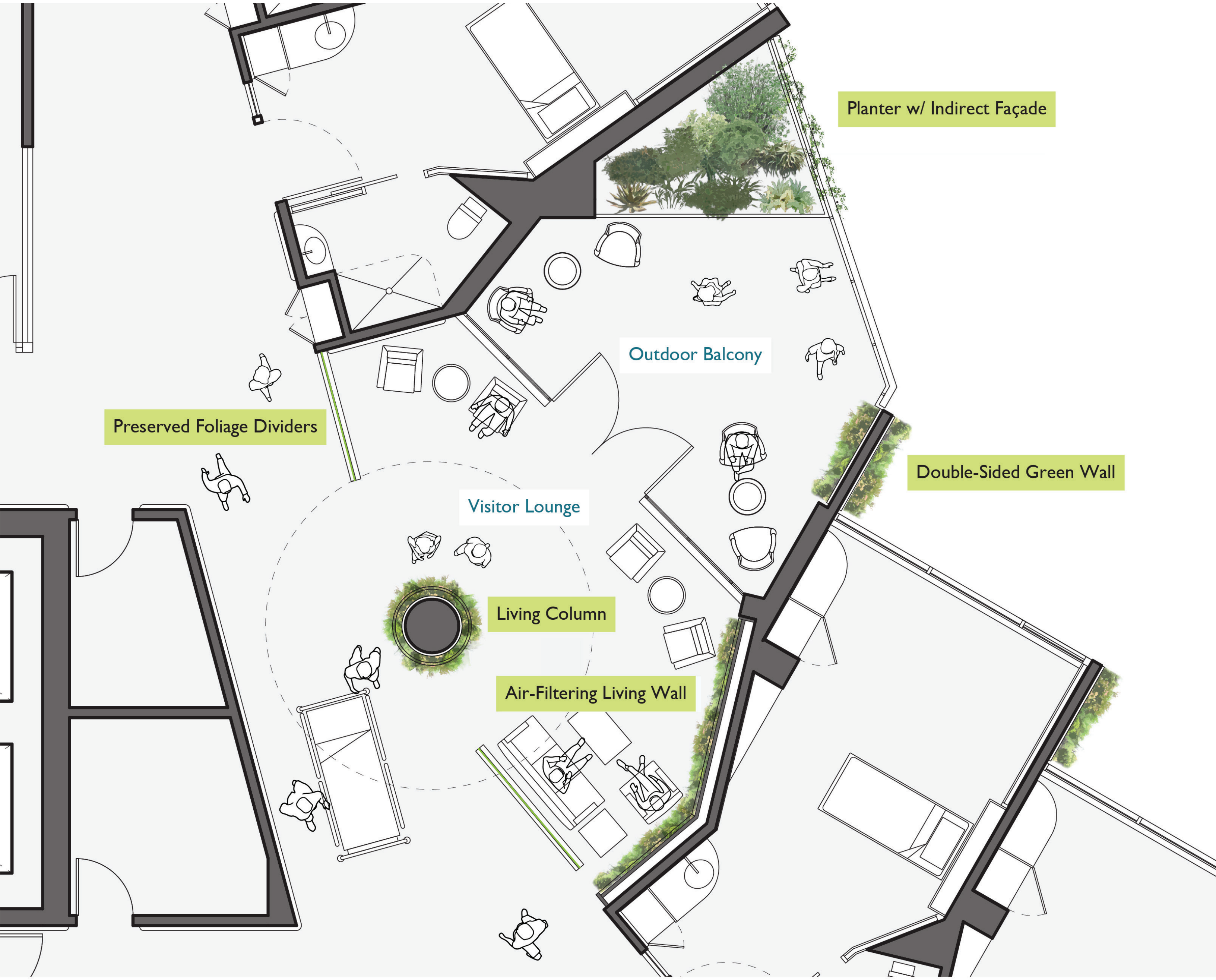
On every impatient floor there are two visitor lounges with access to an outdoor balcony (refer to Figure 3-15). These environments provide an extension of personal space for visitors and family to gather. A living column and an air filtering green wall in the lounge provide healing green views for patient, visitors, and staff as they walk by. The balcony features a large planter and indirect green façade connecting the balcony floors, as well as a double sided hydroponic green wall.

The inpatient floorplan features a living column in each visitor lounge, and at each of the three tips of the building. These five living columns disbursed throughout the plan provide greenery views along the main circulation corridor, without interfering with hospital traffic. Occupants do not have to travel far within the building to benefit from healing nature views. Figure 3-16 shows the tree-like living column at the centre of the space and visible from all directions. A hydroponic air filtering living wall is integrated into the building air conditioning systems. As leaves and root systems are great at absorbing suspended particles and VOCs, circulating room air through the system improves indoor air quality. The greenery system acts as a pre-filter, regulates humidity, and increases energy efficiency of the air conditioning system.[10]

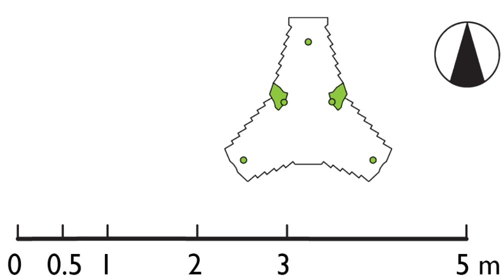
OUTDOOR BALCONY

The outdoor balcony as seen in Figure 3-17 is accessible from the visitor lounge. Architectural greenery systems include a large balcony planter with climbing plants scaling steel cable support structures extending up all inpatient floors. A double-sided green wall provides additional sensory interest. The outdoor balcony area allows family and visitors to enjoy fresh air, vegetation, and northern mountain views. This extension to the outdoors and being able to see the sky on every patient floor connects people with greater natural forces like the rising and setting of celestial bodies.

10 "SingularAir" (SingularGreen group, 2020), www.singulargreen.com.



3-15 Visitor lounge plan



3-16 Visitor lounge perspective


Air-filtering living wall integrated with ventilation system
I like waiting here by this green wall. The air feels naturally cleaner.
Dividers with pressed leaves between glass

3-17 Visitor lounge balcony perspective


Exterior double-sided hydroponic green wall
Look at the plants, sweetie. That one is a fern, and that one is lavender. Doesn't it smell nice!
Yes, it's my favourite because it's purple!

3-18 Universal single patient bed features

UNIVERSAL PRIVATE PATIENT ROOM

The patient room is the most significant space in the hospital as more time is spent here by the patient and family than any other. Each patient room has direct views to a hydroponic green wall shown in Figure **3-18**. The greenery is extended indoors with a preserved moss and foliage wall on the foot wall side. Floor patterns lead caretakers to the handwashing sink.

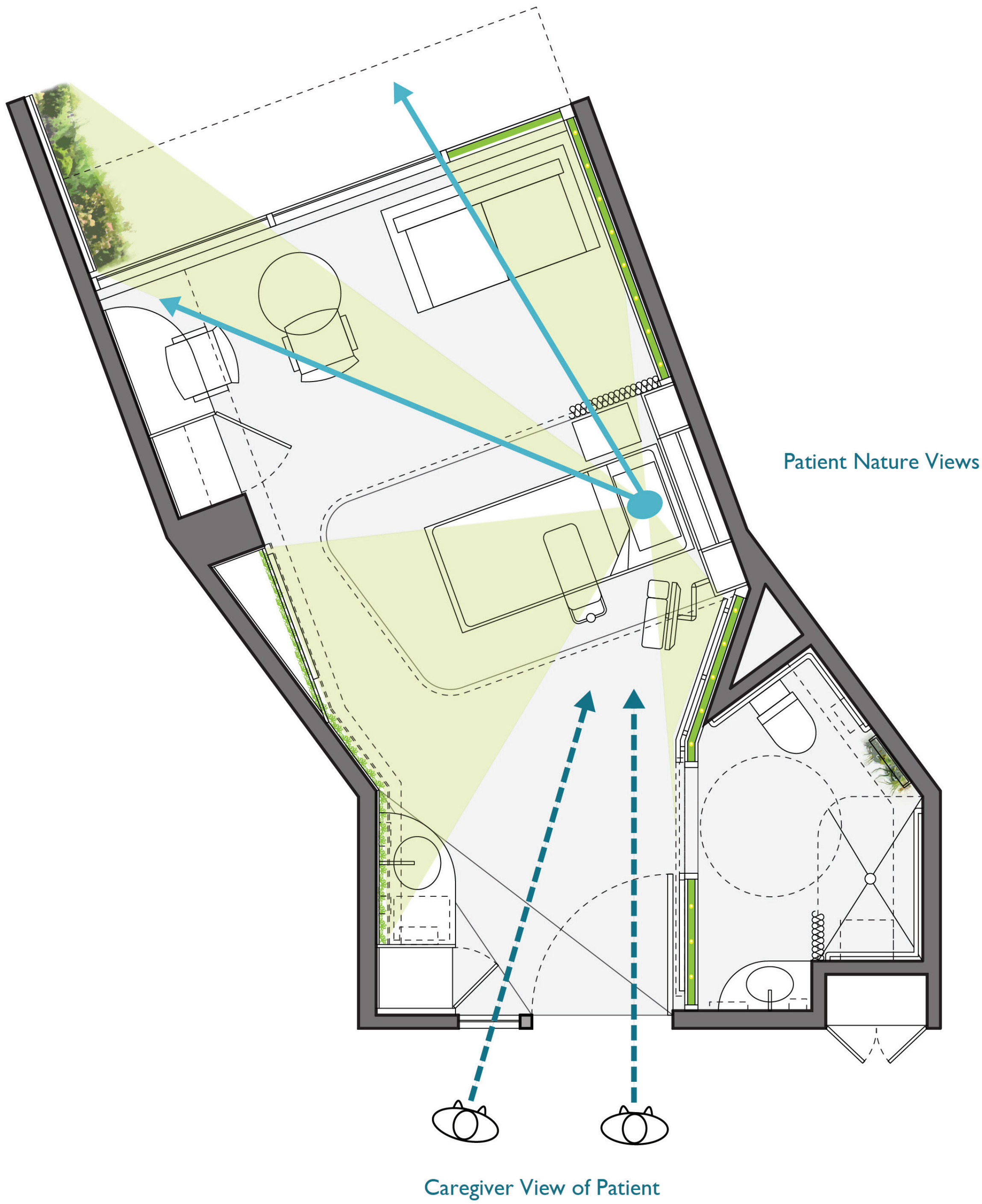
The head wall features a photobioreactor facade and walls extending across to the bathroom. The head wall also contains the medical equipment and computer station, conveniently out of patient sight and mind. Handrails to the bathroom assist with patient walking. Inside the bathroom is a display of air plants, which do not require soil or water, just an occasional mist, and light from the recessed ceiling lights.

As can be seen from Figure **3-19**, this universal layout provides good visibility of the patient by staff and offers many calming nature sightlines for the patient. The bathroom is position inboard to maximize nature views and daylight from full height windows. The head wall is angled slightly towards the entrance to provides more direct views of the patient, which allows nursing staff to monitor the patient more easily from outside the room.

PATIENT ROOM 360 DEGREE VIEW

As an acute care patient spends more time in their beds than any other place, it is important to design from their perspective in this space. Figure 3-20 is a panoramic view from the perspective of a patient lying on their hospital bed, showing the range of greenery systems visible to them, and providing a range of sensory experience.

To the left of the bed is the entrance and clinical side of the patient room. The green view to the left is the inboard bathroom wall containing a photobioreactor with microalgae and multi-colour LED grow lights. The patient will be able to watch the growth cycle of the algae and the walls increase in opacity and green colour as the algae grows through photosynthesis. The submerged bioreactor grow lights are colour changing



3-19 Sightlines in universal single patient bed and offer an interactive, sensory experience for the patient. All lights in the patient room, including plant grow lights, can be remote controlled from the bed with various mood and simulated daylight settings to suit patient preferences.

The foot wall features a preserved foliage and moss wall covered in antiglare glass, which can protect the wall from liquids and make the surface easy to clean. Warm natural wood tones and is uncluttered by the view of stress inducing medical equipment. Near the entrance is a handwash station, supply storage, and note board for the caregiver. The central foot wall area provides patient entertainment through a television, Wi-Fi internet access, and sound system for soothing music or relaxing nature sounds. Shelving and closet units offer storage and display areas for personal items.

The right side of the bed is family area with workstation and view of nature through the vertical garden. No matter the direction or height of the patient room, patients, staff, and family can benefit from relaxing nature views from the exterior green wall. The right window panel is a photobioreactor façade that assists in shading and retains solar heat energy for the building. It provides visual interest for the patient and family as carbon dioxide and other gas bubbles enter the system and provide nutrients for the microalgae.

Safety + Accessibility Features

- **No irrigation greenery systems inside**
- **Easy-to-clean and continuous surfaces**
- **Spacious inboard bathroom close to bed**
- **Handrails and wide entry doors**

3-20 Panoramic view from patient bed

Privacy + Control Features

Controllable lighting simulating daylight

Adjustable colours and dimable

Integral blinds and infection free curtains for privacy and sunlight control

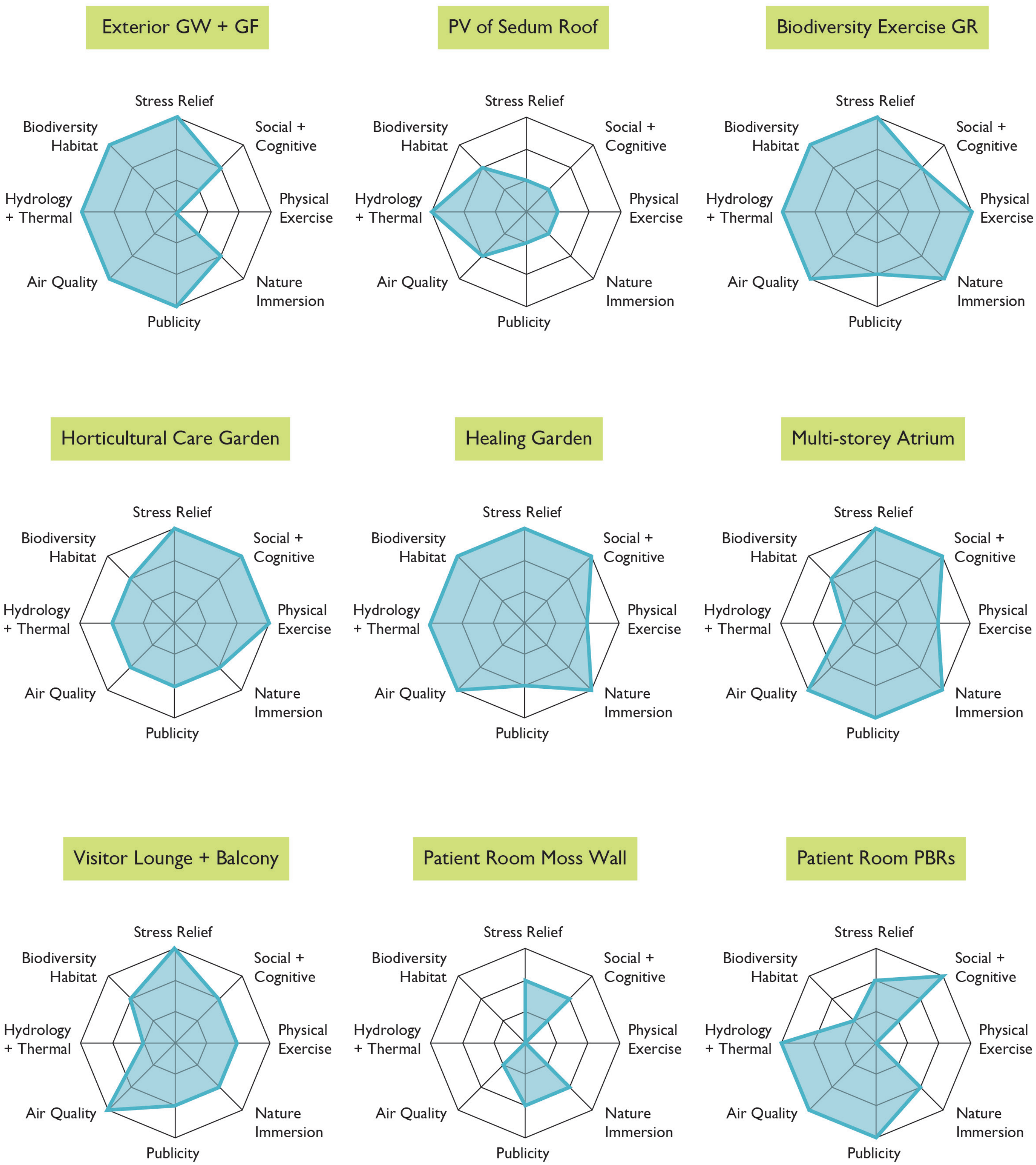
Healing Nature Features

Soothing music and nature sounds

Healing views of air plants + green wall

Sensory stimulating algae photobioreactor

walls with LED grow lights



3-21 Comparison of designed greenery systems

DESIGN OUTCOMES

The benefits and costs of the nature assisted green spaces designed in the patient tower design are compared in the diagrams in Figure 3-21. In many cases, a HCF development project will have a limited budget and would not implement all the greenery systems demonstrated in this design. Designers might illustrate the benefits and feasibility of these systems to ease client decision making. Real world application of architectural design would also benefit from user group meetings and surveys. Clients may choose among various garden spaces which system fits best for their priorities and needs. Together, these green spaces provide a range of supportive and therapeutic environments. The designed AGS provide a range of indoor and outdoor experiences and promote physical activity. Many of these benefits could lead to positive financial benefits for the institution.

CONCLUSION

Imagine if the hospital was a place that we looked forward to visiting; if there were spaces in a hospital that would be a treat to visit before or after medical appointments. Imagine if while staying in a hospital, we knew we would be supported by friends and family, because the building offers comfortable amenities for them too. What if the hospital environment could help us feel connected to nature, our own culture, other life forms, and higher powers? If this were the case, how could we not handle greater adversity and heal faster from illness?

A new approach calling for more views and access to natural elements is applied to the design of specific healthcare spaces. Orthographic drawings and renderings show the relationship between greenery systems in long-term care and rehabilitative healthcare spaces. These artifacts illustrate the possibilities of nature rich healthcare architecture and argue for a change in the way hospitals are conceived and positioned in our communities. The design demonstrates ways in which living plants can create synergies with healthcare building systems and services. In doing so, the thesis offers a new approach to sustainable healthcare architecture and illustrates what form a partnership between plant-based systems and hospital architecture can take. Through nature assisted architecture, designers can bring environments of care to reality.

Nature nurtures if we nurture nature.

3-22 *Next page*, Bird's eye view of nursing tower

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Appendix A: Indoor Tropical Plant Species

LOW LIGHT (150+ foot candles)

Asparagus setaceus
"Asparagus Fern"
PSH - SH
scrambling

Alocasia x amazonica
"Alocasia Polly"
PSH - SH
humid, toxic

Asplenium nidus
"Bird's Nest Fern"
PSH - SH
spores potential allergen

Caladiums bicolor
"Heart of Jesus"
PSH - SH
toxic

Chlorophytum comosum
"Spider Plant"
PSH - SH

Davallia fejeensis
"Rabbit's Foot Fern"
PS - PSH
furry aerial rhizome

Dracaena trifasciata
"Snake Plant"
PSH - SH
low watering

Dracaena fragrans
"Janet Craig"
PS - PSH

Ficus decora
"Rubber Plant"
PSH

Guzmania lingulata
"Scarlet Star"
PSH

Nephrolepis exaltata
"Boston Fern"
PSH - SH
spores

Maranta leuconeura
"Prayer Plant"
PSH - SH

Philodendron
hederaceum
"Lemon Lime"
PS - PSH
toxic

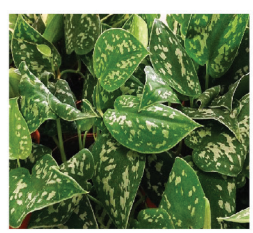
Philodendron selloum
"Tree Philodendron"
PSH - SH
large leaves

Philodendron tatei
"Philodendron Congo"
PS - PSH

Pilea SPP.
"Pilea"
PSH

Pteris cretica 'albo-lineia'
"Silver Ribbon Fern"
PSH - SH
moist soil, spores

Pteris cretica
"Cretan Brake Fern"
PSH - SH



Scindapsus pictus
"Silver Satin Pathos"
PSH
rich soil, toxic

Zamioculcas zamiiofolia
"ZZ Plant"
PSH - SH

4-1 Low light tropical indoor plant species

HIGH LIGHT (250+ foot candles)

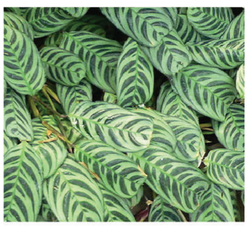
Aglaonema commutatum
“Chinese Evergreen”
PS - PSH

Anthurium andraenum
“Flamingo Lily”
PS
moist soil, toxic

Calathea lancifolia
“Rattlesnake Plant”
PS - PSH

Codiadeum variegatum
“Croton”
FS - PSH

Dracaena fragrans
“Corn Stalk Plant”
PS - PSH



Ctenanthe Burle Marx
“Fishbone Plant”
PS - PSH

Davallia fejeensis
“Rabbit’s Foot Fern”
PS - PSH
furry aerial rhizome

Dracaena deremensis
“Lemon Surprise”
PS - PSH

Epipremnum aureum
“Golden Pothos”
FS - PSH
trailing vine

Episcia cultivar
“Flame Violet”
PS - PSH
year-round red blooms

Ficus elastica ‘Sylvie’
“Indian Rubber Tree”
FS - PS

Monsteras deliciosa
“Tropical Split-leaf
Philodendron”
PS - PSH

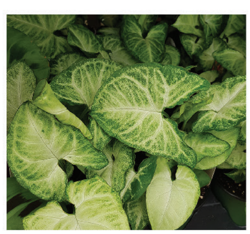
Monstera obliqua var.
“Swiss Cheese Plant”
PS - PSH

Dypsis lutescens
“Areca Palm”
FS - PSH

Philodendron
“Rojo Congo”
PS - PSH
moist soil

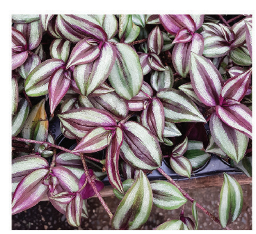
Platycerium alcicorne
“Staghorn Fern”
PS - PSH

Schefflera arboricola
“Dwarf Umbrella Tree”
PS - PSH
toxic



Syngonium
podophyllum
“Arrowhead Plant”
PS - PSH

Schlumbergera bridgessii
“Christmas cactus”
PS - PSH
winter flowering



Tradescantia zebrina
“Inch Plant”
FS - PS

4-2 High light tropical indoor plant species

Appendix B: Outdoor Plant Species

OUTDOOR GREEN WALL PLANTS

Andromeda polifolia
"Bog Rosemary"
FS - PSH | Z 2-8
dwarf evergreen shrub
blooms, native

Astilbe japonica
"False Buck's Beard"
PSH - SH | Z 4-9
herbaceous perennial
blooms, butterflies

Athyrium filix-femina
"Common Lady Fern"
PSH - SH | Z 3-8
spores, native

Buxus sempervirens
"Common Boxwood"
FS - PSH | Z 5-8
evergreen shrub
toxic

Carex oshimensis
"Evergold Sedge"
PSH - SH | Z 5-9
semi-evergreen perennial
native

Carex obnupta
"Slough Sedge"
FS - PSH | Z 6-9
evergreen perennial
birds, native

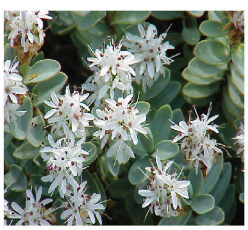
Chamaecyparis pisifera
"Sawara Cypress"
FS - PSH | Z 4-8
evergreen shrub

Cyrtomium falcatum
"Japanese Holly Fern"
PSH - SH | Z 6-10
spores

Dennstaedtia punctilobula
"Hay-scented Fern"
PSH - SH | Z 3-8
fragrant, native

Lavandula angustifolio
"English Lavender"
FS Z 5-8
perennial shrub
flowers, bee, butterflies

Gaultheria procumbens
"Eastern Teaberry"
PSH - SH | Z 3-9
evergreen shrub
flowers, birds, native



Hebe pinguifolia 'pagei'
"Pagei Hebe"
FS - PSH | Z 7-10
dwarf evergreen shrub
butterflies, bees

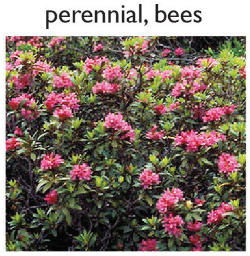
Heuchera 'Berry'
"Coral Bells"
FS - SH | Z 5-7
semi-evergreen
perennial, bees

Heuchera 'Obsidian'
"Coral Bells"
FS - SH | Z 5-7
semi-evergreen perennial
bees

Liriope varigated
"Lily Turf"
FS - PSH
herbaceous perennial
blooms

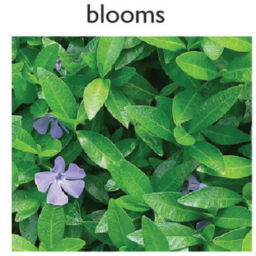
Mentha
"Mint"
PS - SH | Z 3-11
perennial herb
flowering, edible

Pieris Japonica
"Japanese Andromeda"
FS - PSH | Z 5-8
evergreen shrub
flowers, non-native



Rhododendron
ferrugineum
"Alpenrose"
PS - PSH | Z 4-8
evergreen shrub

Salvia
"Sage"
FS - PS | Z 5-10
semi-evergreen perennial
hummingbirds, bees



Vinca Minor
"Lesser Periwinkle"
FS - SH | Z 4-8
evergreen perennial
spring summer blooms

CLIMBING SPECIES (INDOOR OR OUDOOR)

Apios americana
“American Groundnut”
FS - PSH | Z 3-7
fragrant flowers, edible roots

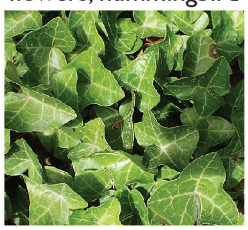
Bignonia capreolata
“Crossvine”
FS - PSH | Z 6-9
semi-evergreen tendril
flowers, hummingbird

Celastrus scandens
“American Bittersweet”
FS - PS | Z 3-8
twinning vine
fall/winter orange fruits

Clematis virginiana
“Old Man’s Beard”
PSH - SH | Z 8-10
twisting stem climber
butterflies, hummingbirds

Convolvulus arvensis
“Field Bindweed”
FS - PS | Z 3-10
perennial herb vine
twining, trailing

Ficus pumila
“Creeping Fig”
PSH | Z 9-11
self-clinging climbing or hanging, poisonous



Hedera helix
“Common Ivy”
PSH - SH | Z 6+
self-clinging climber

Hedera hibernica
“Atlantic Ivy”
FS - PSH | Z 5+
self-clinging
berries

Hydrangea petiolaris
“Climbing hydrangea”
woody climber
PSH - SH | Z 4-9
white flowers

Jasminum polyanthum
“Climbing Jasmine”
FS - PS | Z 7+
twining, trailing, fragrant
hummingbirds

Lonicera
“Honeysuckle”
FS - PSH | Z 4-9
shrub, twining vine
fragrant, hummingbird

Pandorea pandorana
“Wonga Vine”
FS - PSH | Z 8-11
twining vine

Parthenocissus tricuspidata
“Boston Ivy”
PS - PSH | Z 4-8
deciduous woody vine

Parthenocissus quinquefolia
“Virigina Creeper”
FS - PSH | Z 3-10
deciduous self-clinging
fall colours, berries birds

Wisteria sinensis
“Chinese Wisteria”
FS - PSH | Z 5-9
fragrant spring blooms

4-4 Climbing plant species for green façades