

## Designing with nature

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## CASE STUDY

# Designing with nature: Advancing three-dimensional green spaces in architecture through frameworks for biophilic design and sustainability



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Design with nature;  
Green space;  
Sustainability;  
Sustainable  
architecture

**Abstract** In the transition to a more sustainable built environment over the last two decades, the “greening” of architecture as a popular approach has received widespread attention. However, there are still many open questions and contradictions regarding how to design with “nature” and contribute to sustainability. In addition, explorations of built examples are rare, and three-dimensional (3D) green spaces in buildings are often overlooked. Therefore, we introduce “green pockets” (3D green spaces) as a typology distinct from two-dimensional green roofs and walls/facades. We draw on a mixed-method approach to study two cases (Erasmus MC and Hotel Jakarta), comprising 12 semi-structured interviews with different stakeholders, design document analysis, and site observation. We develop a critical reflection (a framework) on the impacts of “green architecture” on sustainability from unpacked benefits and adopt a biophilic design framework to analyse designing with “nature” in architectural practice. These findings demonstrate that green pockets contribute to integrating multiple experiences of “nature” into buildings and developing sustainable architecture. Designing green pockets with visibility, accessibility, and spatial characteristics (e.g., prospect and refuge, organised complexity, peril, and mystery) of “nature” improves building quality. Furthermore, we provide design recommendations to advance green pocket designs and make suggestions for future research.

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## 1. Introduction

Within the last two decades, the incorporation of vegetation into buildings has become a flourishing trend in contemporary urban architecture (Schröpfer and Menz, 2019; Strobl et al., 2021; VanderGoot, 2018). This is associated with sustainability goals that address environmental challenges and climate change. The built environment plays a key role in the pursuit of sustainability, notably in enhancing resource and energy efficiency, in conjunction with minimising negative impacts on the environment and on human health (Wilkinson et al., 2007). For instance, biodiversity decline is strongly linked to increasing urbanisation and the encroachment of human living areas on other species' habitats. Greenhouse gas emissions from building materials, construction and operations account for roughly 40% of total emissions (IEA, 2017). People spend approximately 90% of their time indoors, and poor indoor air quality can lead to sick building syndrome (Al Horr et al., 2016). Disconnecting with nature also causes difficulties in stress reduction and productivity, and the global COVID-19 pandemic shows how susceptible we are to all sorts of distractions and psychological stresses (Colding et al., 2020). Recent data shows that, on average, 42% of the urban area in European countries has green infrastructure, but only a low proportion of this is accessible public green space, at approximately 3% of the total urban area (EEA, 2022). The World Health Organization (2016) suggests living within a maximum distance of 300 m from green spaces, which can be achieved by barely half of the European urban dwellers. The integration of green spaces into buildings merits more intensive research in the realm of architecture.

The psychological need to connect with “nature” was interpreted by psychologists and biologists in the *biophilia* theory (Fromm, 1964; Kellert, 1993; Wilson, 1984). In the 21st century, pioneers of biophilic design translated the *biophilia* theory into the field of architecture (Heerwagen and Hase, 2001; Joye, 2007; Kellert et al., 2008), bridging it with many other theories in environmental psychology, such as those on the habitat settlement (Appleton, 1975; Hildebrand, 1999; Hidalgo and Hernández, 2001; Orians and Heerwagen, 1992) and psychological restoration (Kaplan, 1995; Ulrich, 1983). Many studies have explained the benefits of biophilic architecture in fulfilling the human-nature connectedness and fostering health, well-being, productivity, biodiversity, and resilience (Africa et al., 2019; Gillis and Gaterleben, 2015; Wijesooriya and Brambilla, 2021). The potential of biophilic architecture to reduce energy consumption and combat climate change has also been explored (Beatley and Newman, 2013; El-Baghdadi and Desha, 2017; Kellert, 2016; Lee and Kim, 2021; Littke, 2016; Reeve et al., 2015). This has increased recognition of its benefits in the pursuit of sustainability. At the 26th UN Climate Change Conference of the Parties (COP26, 2021) in Glasgow, Scotland, biophilic architecture was discussed as one of the agendas for its contribution toward limiting global warming from 2 °C to 1.5 °C.

Many theoretical methods and design strategies of biophilic design have been developed to conceptualise and explain the integration of “nature” into architecture.

Researchers have proposed biophilic design frameworks with diverse categories and elements. Stephen Kellert (2008) established the first structured framework for biophilic design, encompassing two dimensions, six elements, and over 70 attributes. This biophilic design framework was later refined to 25 attributes and grouped into three experiences: “direct experience of nature”, “indirect experience of nature”, and “experience of space and place” (Kellert, 2018; Kellert and Calabrese, 2015). Similarly, Browning et al.'s (2014) interpretation of biophilic design also comprises three categories: “nature in the space”, “nature analogues”, and “nature of the space”, covering 14 patterns that were further expanded to 15 in the updated version (Browning and Ryan, 2020). Zhong et al. (2022) proposed an optimised biophilic design framework by eliminating redundant, overlapping, and controversial elements in previous frameworks, as well as distilling those that are vital in contemporary architecture and may potentially contribute to the development of sustainable buildings. In this framework, “nature” in architecture contains 18 elements under three design approaches: “nature incorporation”, employing all sorts of natural elements and processes; “nature inspiration”, mimicking natural shapes, patterns and mechanisms and creating visual or tactile experiences of nature; “nature interaction”, arranging nature-like environments that have survival advantage characteristics (Fig. 1). Compared with the text-only versions, Zhong et al.'s biophilic design framework is more digestible as it provides infographics of each design element. This is particularly important for understanding the connections established with nature through intangible methods, such as sensory experiences, psychological associations, and emotional responses.

The interrelation between “green architecture” and sustainability is still under-researched, and in-depth explorations of built examples are rare. As “nature” is an unfixed and contested concept, intense debate exists on how to conceptualise and integrate nature into architecture. Hence, this article provides a critical and proactive approach to sustainability by developing a framework to evaluate and advance “green architecture” and unpacking how design projects define targets for sustainability challenges to be addressed. Additionally, the biophilic design framework developed by Zhong et al. (2022) is adopted to analyse designing with “nature” in architectural practices, as it is a well-tailored framework that categorises design approaches and comprises various crucial design elements with “nature” in contemporary urban architecture (Fig. 1).

### 1.1. Three-dimensional green spaces in architectural practices

In recent architectural practice, there has been a growing interest in volumetric three-dimensional (3D) green space (Fig. 2). Compared with the more common typology of 2D green surfaces, 3D green spaces differ in many features (Fig. 3). 3D green spaces can be conceived with rich spatial variations and accessibility, which also allows larger plants and diversified species to inhabit them.

Various 3D green spaces have been created on buildings, ranging from small-scale residences to larger public

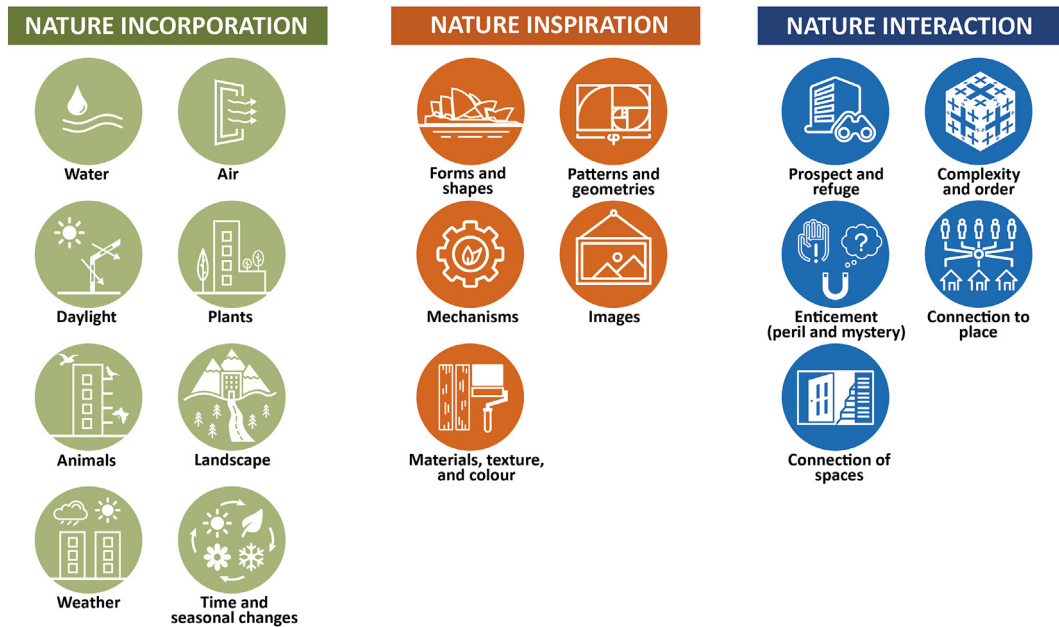


Fig. 1 A biophilic design framework with design approaches and elements used in this article (Zhong et al., 2022).

buildings and mega mixed-use complexes in diverse regions. Terms such as “garden terrace”, “sky/hanging garden”, “vertical forest”, and “living tower” are used by designers in practice, but there is no specific term in the academic field to describe these 3D green spaces. We thereby introduce the notion of the “green pocket” to characterise a broad variety of 3D green spaces in buildings as a distinct architectural typology.

## 1.2. Definition of “green pockets”

Green pockets are 3D green spaces in buildings that can appear in rich varieties of spatial forms and layouts. The term “green pocket” is coined for three main reasons.

- (1) Green pockets are in 3D volumes, emphasising the capacity to accommodate intensive vegetation. Height and width are designed in conjunction with the depth required for plant growth (Boeri, 2015, p. 103). To contain larger plants, even trees with canopies, the substrate depth should be greater than 25 cm (the maximum depth for a semi-extensive green roof where only small plants can be grown) (Kotze et al., 2020). The “pockets” contain all sorts of biotic elements (e.g., plants, animals, and microorganisms) and abiotic elements (e.g., substrates and water).
- (2) Green pockets are flexible in spatial configuration and can be placed at various locations in a building. They can be three-dimensionally integrated on building surfaces, interiors, and at different levels, rather than merely on surfaces, as in many traditional horizontal and vertical green designs. Green pockets do not simply partition indoors and outdoors; they are transitional spaces between natural (green) and artificial (grey) environments.

- (3) Green pockets are accessible green spaces in the urban environment, allowing humankind to co-exist with other living species and dwell nearby trees, shrubs and plants in cities rather than exclusively in suburban houses with gardens. They are living spaces for plants and other species that are built in human habitats. They also form micro-ecosystems and connect with larger ecosystems.

## 1.3. Case studies overview

This study selected two representative green pocket cases in the Netherlands for analysis: (1) Erasmus University Medical Center (Erasmus MC), a project that incorporates a variety of green spaces for diverse circumstances in the healing environment, and (2) Hotel Jakarta, an energy-neutral building (certified as BREEAM Excellent), in which the most identifiable feature is a large-scale indoor subtropical garden (Fig. 4). These two projects merit in-depth investigation and comparison for several reasons.

First, both projects were designed and built as exemplars of sustainable architecture but with distinct design goals. They were selected in this study to examine the concept of sustainability in architectural practice and compare diverse strategies chosen under different targets. Second, they are both among the most advanced examples of biophilic architecture, not restricted to the mere integration of plants into the building but featuring a wide range of biophilic design elements. This gives critical reflection to literal greening and demonstrates possibilities for improving green pockets, such as enriching experiences of “nature” and creating engaging settings. Third, choosing built (completed) large-scale green pockets is significant, and provides the opportunity for future research into their actual use and impacts. Although green architecture is a

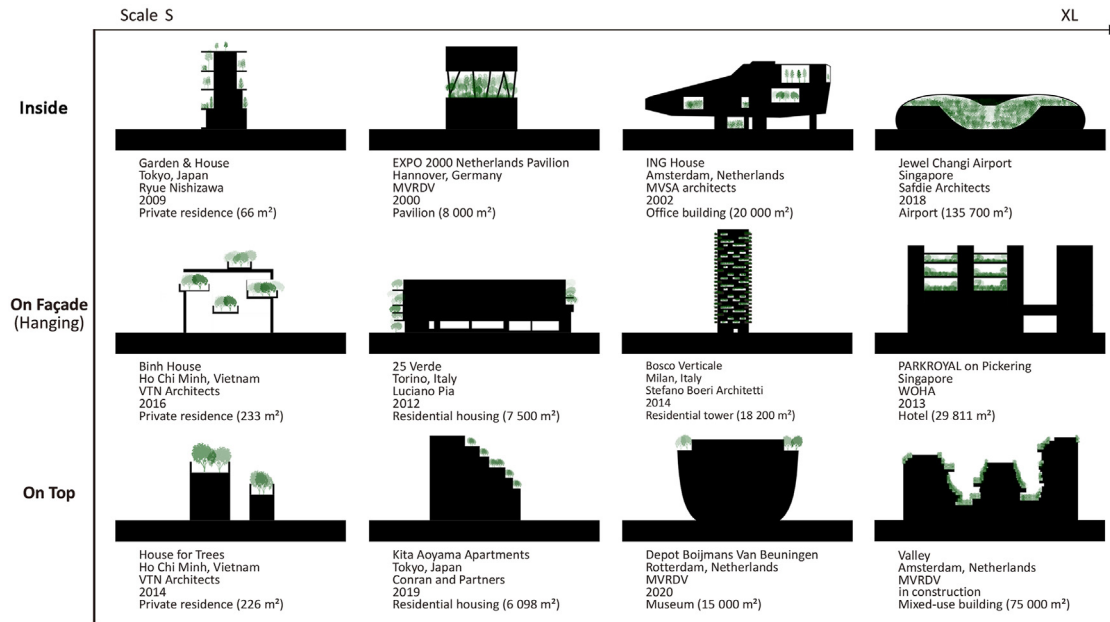


Fig. 2 3D green spaces designed in architectural practice (source: authors).

growing trend and many buildings were designed with lush greenery, the realised green pockets are often much smaller than those shown in the renderings. Fourth, comparing the spatial organisation of green pockets in the complex and the individual building is valuable for spatial analysis. Erasmus MC was transformed from various separate buildings into an ensemble of buildings under one roof, while Hotel Jakarta is a single building with an atrium. Additionally, the green pockets in these two cases are accessible to the public. This is beneficial for studying the

various functions and values of green pockets in different circumstances and for various user groups, as well as for exploring the potential of green pockets as public green spaces in the broader urban context. Moreover, these projects have won several architectural awards. The “European Healthcare Design Award 2019” and Dutch “BNA Best Building of the Year—Stimulating Environments 2019” were awarded to Erasmus MC, and the “Architecture Master-Prize—Green Architecture 2018”, “WAF Award Best Hotel of the Year 2018”, and “European Interior Landscaping

	2D Green Surfaces		3D Green Spaces (Green Pockets)			
Type diagram						
Terms	Extensive/ semi-extensive green roof	Green wall, green façade, living wall, or vertical greenery system	Roof garden, sky garden, or intensive green roof	Green balcony, or three-dimensional green façade	Indoor sky garden, elevated landscape, or green house rooftop	Indoor garden, or atrium garden,
Designed spaces	Surfaces (tops)	Surfaces (façades) and interior walls	External spaces (volumes)		Internal spaces (volumes)	
Substrate depth	≤ 25 cm		> 25 cm			
Vegetation	Mosses, sedums, herbs, grasses, small and creeping shrubs, and climbing plants		Trees, small to large shrubs, ground cover plants (e.g. mosses, sedums, herbs, and grasses), and climbing plants			
Creative design	Low to medium potential		Large potential			
Technical complexity	Low to medium		High			
Maintenance	Low or periodically		Regularly and periodically			

Fig. 3 Comparison of 2D surfaces and 3D green spaces in buildings (source: authors).

Organisation (EILO) Award 2019” were given to Hotel Jakarta.

The case studies comprise three aspects for addressing research questions, including:

- Understanding the interrelation between “green architecture” and sustainability (Section 3)

RQ 1: In how far does the integration of plants into buildings contribute to sustainability, and what design targets were defined in the two cases?

- Exploring the design of “green pockets” (Section 4)

RQ 2: How were the green pockets integrated into buildings in terms of architectural design (e.g., urban context, spatial organisation, and form generation)?

- Evaluating the application of biophilic design in architectural practices (Section 5)

RQ 3: Which biophilic design approaches and elements were chosen in implementing green pocket designs?

In response to these research questions, the next section introduces the methods used in this study to investigate and analyse the two cases.

## 2. Methods

This study draws on a mixed-method approach to analyse the interrelation between “green architecture” and sustainability, the integration of green pockets into buildings, and the application of biophilic design in architectural practice. Green pocket case studies explore the design process to reveal how these projects developed from initial ideas to concrete buildings. We collected information on the two projects through semi-structured interviews, analysis of design documents, and site observations.

### 2.1. “Green architecture” and sustainability (RQ 1)

Our case study analysis was preceded by the development of a framework based on the sustainability benefits of green spaces in buildings, as identified in the existing literature. Rather than a comprehensive review of previous research on green spaces, we aimed to establish a connection between plant-integrated architecture and sustainability and to raise awareness of the potential impacts of “green architecture” on sustainability beyond aesthetic value.

For the two design cases, we analysed the challenges envisaged to be addressed by the integration of green pockets and the design targets set. Semi-structured interviews were conducted to develop an in-depth understanding of design practices, retrace project development, and collect data, including retellings of visions, concepts, conflicts, and strategies throughout the design-to-implementation process. We conducted a total of 12 interviews and conversations from September 2021 to May 2022, each lasting 45 min to 1.5 h. The interviewees were organised into four categories according to their

professional backgrounds: clients (building owners), designers (architects, landscape architects, green consultants, and engineers), builders (contractors), and property managers. Our questions concerned initial motivations and inspirations, expertise integrated, choices and actions taken, difficulties and solutions encountered, and lessons learnt from these completed projects. For example, clients were asked about key factors in decision-making and investment; design teams were questioned on key design priorities, sustainability schemes, and challenges in design processes; engineers were interviewed on available technologies, structural requirements, construction difficulties and corresponding solutions; and property managers were asked about the maintenance of operating green pockets. Moreover, we analysed design documents collected from design teams regarding the fulfilment of regulations and additional requirements of municipalities.

### 2.2. Spatial analysis of green pocket cases (RQ 2)

Design document analysis was used during this stage to understand the spatial organisation and form generation of green pockets, supplementing information that was difficult to obtain from interviews within a restricted time and including more visual materials essential to architectural design. Documents were collected from architects, landscape architects, and engineers, as they usually play a vital role in designing and materialising green pockets. Both graphic (e.g., sketches, drawings, renderings, details, and photos) and textual (e.g., design process files, summary reports, and publications) archives were assembled and investigated. We produced axonometric diagrams to illustrate the urban context (relationships between buildings and their surroundings); exploded drawings to demonstrate the form, order, and geometric system of green pockets in buildings; and sections to show the visibility and accessibility of these green pockets.

### 2.3. Biophilic design in architectural practices (RQ 3)

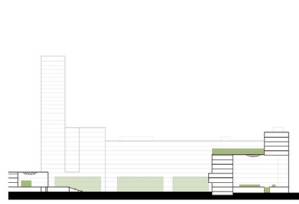
The study of biophilic design applied in the two cases builds upon a developed framework (Zhong et al., 2022). Through semi-structured interviews with design teams, we investigated the viewpoints of different participants and various activities that occurred in the design and construction of green pockets. Focus was on how “nature” was understood and integrated into the architecture. We evaluated and compared the inclusion of biophilic design elements in the two design projects and uncovered missed opportunities in green pocket designs. From the exploration of design practices, we summarised design recommendations for optimising spatial quality and performance from diversified strategies for integrating “nature” into architecture demonstrated in the framework of biophilic design.

## 3. “Green architecture” and sustainability

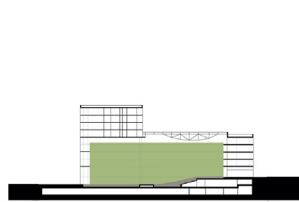
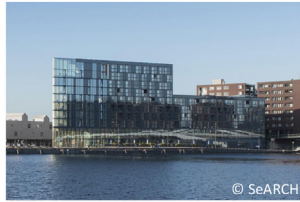
This section synthesises the benefits of green spaces in buildings, as demonstrated in the existing literature, and develops a framework to evaluate the impacts of “green

**Erasmus MC**

Location: Rotterdam, the Netherlands  
 Architect: EGM architects  
 Landscape architect: Juurlink [+] Geluk urbanism and landscape  
 Year: 1998 – 2018  
 Type: Medical center  
 Size: 114 m high, 27 floors, 207 000 m<sup>2</sup> (new construction)  
 Green pocket type: atrium garden, accessible roof garden, and sunken patio

**Hotel Jakarta**

Location: Amsterdam, the Netherlands  
 Architect: SeARCH Urbanism and Architecture  
 Landscape architect: Copijn Tuin- en Landschapsarchitecten  
 Year: 2013 – 2018  
 Type: Hotel  
 Size: 33 m high, 10 floors, 16 500 m<sup>2</sup>  
 Green pocket type: atrium garden



**Fig. 4** Two green pocket cases (section drawings source: authors, based on EGM architects and SeARCH).

architecture” on sustainability, with an analysis of how sustainability was interpreted and enacted in the two green pocket cases.

### 3.1. Benefits of green spaces in buildings

#### 3.1.1. Urban environment and ecosystem

Green spaces in architecture have the potential to address numerous sustainability challenges in urban environments and ecosystems. First, green spaces contribute to biodiversity conservation and restoration, provide habitat, food, and shelter for animals (e.g., bees, butterflies, bats, birds, beetles, and arthropods) and plants (Chiquet et al., 2013; Wang et al., 2017; Wooster et al., 2022), and promote the coexistence of urban architecture and nature (Africa et al., 2019). Second, covering buildings with plants could diminish the amount of sunlight reflected from glass facades (Vanuytrecht et al., 2014), reduce ambient temperatures, lower carbon dioxide (CO<sub>2</sub>) concentrations, and increase relative humidity, thereby altering the urban microclimate and mitigating urban heat islands (Afshari, 2017; Chun and Guldmann, 2018; Moghbel and Erfanian Salim, 2017; Zamani et al., 2018). Third, greenery removes urban air pollutants, such as PM<sub>10</sub>, NO<sub>2</sub>, SO<sub>2</sub>, O<sub>3</sub>, and CO<sub>2</sub> (Barwise and Kumar, 2020; Francis and Jensen, 2017; Li and Babcock, 2014) and attenuates noise by acoustic blocking and the reflection, absorption, or interference of sound waves (Markevych et al., 2017; Van Renterghem et al., 2015; Yan et al., 2022). In addition, in terms of water management, building-integrated green spaces can be an efficient solution for stormwater attenuation in urban drainage systems and can improve rainwater retention and on-site greywater treatment (Hachoumi et al., 2021; Pearlmutter et al., 2021; Razzaghamanesh and Beecham, 2014; Well and Ludwig, 2020).

#### 3.1.2. Decarbonisation

The potential for decarbonisation in buildings with integrated green spaces is another major concern linked to energy issues. An appropriate composition of greening systems can decrease energy consumption on cooling and ventilation by approximately 10%–20% (Han and Ruan, 2020), thereby reducing CO<sub>2</sub> emissions (Ascione et al.,

2013; Coma et al., 2017). The cooling effect of greening systems is produced mainly by plant evapotranspiration, shading, and thermal insulation (Raji et al., 2015). The application of intensive green roofs could considerably reduce building surface temperatures, from 57 °C on the bare roof to 42 °C with only the soil layer, and 25.6 °C with dense vegetation (Lazzarin et al., 2005). Outdoor green balconies can reduce ambient air temperatures by up to 3 °C and boost relative humidity by a maximum of 7% (Papadakis et al., 2001). Simulation results also demonstrate that the energy-saving strategy of incorporating plants into buildings performs better in cooling-dominated regions (e.g., Italy and Spain) than in heating-dominated regions (e.g., the Netherlands, UK, and Norway) (Ascione et al., 2013). Furthermore, there are opportunities for the integration of greening systems with renewable energy production systems. The combination of green spaces and solar photovoltaic systems brings mutual benefits, generating more renewable electricity and shading plants from high radiation exposure (Chemisana and Lamnatou, 2014; Lamnatou and Chemisana, 2015; Shafique et al., 2020).

#### 3.1.3. Physical health

Previous research demonstrates that green spaces within buildings are beneficial to human physical health. In terms of purifying indoor air, the effect of plants in combating indoor air pollution has been extensively investigated, especially since the NASA Clean Air Study in the 1980s (Wolverton et al., 1989). Indoor plants can decrease the concentrations of most indoor contaminants, such as particulate matter (PM), volatile organic compounds (VOCs), and carbon dioxide (CO<sub>2</sub>) (Knowles et al., 2002). Indoor plant systems are found to reduce CO<sub>2</sub> by 10%–20% and eliminate formaldehyde (a typical VOC) in a classroom to zero within 45 min (van Duijn et al., 2011), decreasing aerosol and formaldehyde concentrations by 41%–50% and 23%–37% within 120 min, respectively, even in the absence of an air purification system in the house (Velzeboer et al., 2019). Indoor greenery also contributes to thermal comfort, resulting in a lower ambient air temperature and higher humidity (Hoelscher et al., 2016; Jimenez, 2018; Liu et al., 2022; Raji et al., 2015). In alleviating sick building syndrome, indoor plants have been shown to relieve 37% of

coughing and 23% of throat and facial dryness in offices (Fjeld et al., 1998). Additionally, plants in buildings have positive effects on acoustics and visual performance. Green spaces decrease noise levels for a quieter indoor environment and provide acoustic isolation to enhance privacy (D'Alessandro et al., 2015; Mediastika and Binarti, 2013; Van Renterghem et al., 2013; Yan et al., 2022). Greenery also offers green views for fatigue relief and attention restoration, thereby improving cognitive performance, concentration, and productivity (Gilchrist et al., 2015; Gillis and Gatersleben, 2015; Korpela et al., 2015; Lee et al., 2015; Li and Sullivan, 2016).

### 3.1.4. Psychological health and well-being

Green spaces in buildings promote psychological health and well-being by enhancing accessibility to nature. First, access to green spaces has impacts on emotion regulation, reducing stress and negative emotions (e.g., depression, nerves and anxiety) (Contini et al., 2022; Li et al., 2022; Nejati et al., 2016; van den Berg et al., 2010), while enhancing feelings of tranquillity, and supporting healing and accelerating recovery (Dijkstra et al., 2008; Jamshidi et al., 2020; Ulrich, 1984). Second, exposure to green spaces supports hedonic happiness by providing enjoyment and pleasure, such as improving visual satisfaction or meeting aesthetic preferences for contact with nature, thus further promoting positive emotions (Jungels et al., 2013; Lee et al., 2014; Loder, 2014; Xiao et al., 2022). Finally, green spaces have the potential to generate eudaimonic happiness regarding fulfilment and meaning, contribute to self-identity (Kellert, 1993, 2009; Wilson, 1984), strengthen natural connectedness, and generate a "sense of place" (place attachment) (Andreucci et al., 2021; Boiral et al., 2019; Liu et al., 2018; Zhang, 2022).

### 3.1.5. Social well-being and economic opportunities

Green space design presents opportunities to address many social and economic challenges. For example, in terms of social inclusion and social cohesion, accessible public green spaces encourage people to participate in community activities, promote a sense of belonging and altruistic behaviour, and help to decrease violence and crimes (Beatley and Newman, 2013; Guéguen and Stefan, 2016; Oh et al., 2022; Säumel and Sanft, 2022). Building-based forms of urban architecture, such as rooftop greenhouses, open-air rooftop gardens or farms, indoor farms, and vertical farming, are suggested to address food production and food security (Appolloni et al., 2021; Benke and Tomkins, 2017; Benis et al., 2018; Specht et al., 2014; Walters and Midden, 2018). Green spaces in buildings boost property values, from improved occupant satisfaction and willingness to pay increased rental prices (Han et al., 2020; Manso et al., 2021; Perini and Rosasco, 2016) to a reduction in building operating costs through energy conservation and minimised water consumption (Claus and Rousseau, 2012; Medl et al., 2017; Tabatabaee et al., 2019). The presence of green spaces in workplaces can reduce sick leave days by approximately 10% (Terrapin Bright Green, 2012) and increase work performance by enhancing concentration, creativity, cognitive performance, and workplace satisfaction (Hähn et al., 2021; Lei et al., 2021; Lerner and Stopka, 2016; Nieuwenhuis et al., 2014).

## 3.2. Design targets in the two green pocket cases

Based on the benefits of integrating green spaces into buildings as demonstrated in previous studies, we developed a framework to analyse the interrelation between sustainability and "green architecture" (Table 1). We demonstrated how sustainability is translated into design projects by unpacking a broad range of sustainability challenges, linking these to the UN's (2015) Sustainable Development Goals (SDGs), and comparing them with the design targets set in the two green pockets cases.

Erasmus MC is a large-scale project designed by EGM architects in Rotterdam, which began in 1999 and was completed in 2018. At the outset of the "new" hospital design, the client Erasmus MC set out three principles to guide this complex project: (1) "safety", prioritising human safety (including the prevention of health damage) over environmental aspects; (2) "healing is leading", considering the effective and speedy recovery of patients and the well-being of all users in this healthcare facility; and (3) "sustainability", implementing a series of environmental measures that were expected to achieve positive financial results within ten years. From our investigations of design targets on sustainability, the green pockets in this project were primarily designed to maximise visual and physical accessibility to "nature" in/on the building, thereby reinforcing many health benefits in terms of stress relief, restoration, and healing. In green pocket design, roof gardens were included for the purposes of saving energy and creation of sustainable cities. Comparatively, little attention has been paid to indoor air purification in clinical areas, possibly because of safety considerations (such as allergies to plants), and green pockets were mostly designed in semi-indoor public areas. As a healthcare facility, Erasmus MC was also not considered suitable for developing large-scale urban agriculture for food production.

Hotel Jakarta is a commercial building design project with environmental and social significance considerations. It was designed by the architectural office SeARCH in close dialogue with the client WestCord Hotel 2013 and was completed in 2018. Initially, the municipality of Amsterdam organised a competition and invited tenders to transform the area. The city council asked for a unique hotel concept with three requirements: (1) unique marketing concept (linking the hotel to East meets West because of the history of the spot); (2) spatial quality (architecture and urban planning); and (3) sustainability. The green pocket in Hotel Jakarta was motivated by creating a healthy and comfortable environment and enhancing psychological well-being. The vision of the green pockets for enhancing user satisfaction was not only to form a man-made natural environment, but also to generate positive emotions and enhance happiness from a strengthened connection with nature. Meanwhile, it was conceived that the opening of the green pocket as a public green space to the surrounding residents would bring socio-psychological benefits, and a connection to the history of the place was expected to be established through plant species. In terms of building performance, the green pocket was envisaged to regulate temperature, allow natural ventilation, maintain proper relative



**Table 1** The benefits of “green architecture” in addressing sustainability challenges and the design targets set in the two green pocket cases.

Perspectives	Challenges in sustainability	SDGs	Erasmus MC	Hotel Jakarta
Urban environment and ecosystem	• Biodiversity conservation and restoration	11 and 15	To provide a suitable biotope for urban flora and fauna.	No
	• Microclimate regulation	3, 11, and 13	To decrease the ambient temperature, reduce CO <sub>2</sub> , and raise humidity.	No
	• Urban depollution	3 and 11	To absorb urban air pollution.	No
	• Water management	6, 12, and 13	To retain rainwater for irrigating roof gardens and to prevent flooding.	To collect rainwater for spraying the garden, and to mitigate water runoff.
Decarbonisation	• Energy saving	12 and 13	To improve the insulation of buildings and reduce energy consumption on cooling.	To create a thermal buffer for preheating in the winter with evaporation for cooling in summer to save energy on heating and cooling.
	• Opportunities for integration with renewable energy production systems	7, 12, and 13	No	To enable sunlight to be collected on the photovoltaic panels while supplying the indoor garden.
Physical health	• Indoor air quality	3	To purify the air with plants in offices.	To maintain the relative humidity in a range of 40%–60% and allow natural ventilation.
	• Thermal comfort	3	To reduce heating and limit heat stress.	To maintain a suitable indoor temperature (typically 20 °C–26 °C) throughout the year.
	• Acoustic performance	3	To lower noise levels and provide sound isolation for privacy.	No
	• Visual performance (view)	3 and 4	To support healthcare (e.g. lower blood pressure and reduce pain) and enhance work efficiency (e.g., relieve fatigue and improve cognitive performance).	To enrich the views of greenery from different levels/areas in the building and from the outside.
Psychological health and well-being	• Emotion regulation	3, 4, and 8	To relieve nervousness, reduce stress, and accelerate recovery.	To build a harmonious (man-made) natural atmosphere to support stress reduction and restoration.
	• Hedonic happiness (enjoyment and pleasure)	3	No	To create a pleasant, intriguing, warm and hospitable ambience.

*(continued on next page)*

Table 1 (continued)

Perspectives	Challenges in sustainability	SDGs	Erasmus MC	Hotel Jakarta
Social well-being and economic opportunities	<ul style="list-style-type: none"> <li>Eudaimonic happiness (fulfilment and meaning)</li> </ul>	3 and 11	No	To support place attachment (connected with local history). To provide public green spaces for guests and urban dwellers.
	<ul style="list-style-type: none"> <li>Social inclusion and social cohesion</li> </ul>	10, 11, and 16	To provide public green spaces for all groups (patients, families, staff, and university students). To explore opportunities to produce food (e.g. honey). To reduce operating costs on energy and water consumption.	No
	<ul style="list-style-type: none"> <li>Food production</li> </ul>	2	To create a healthy and comfortable workplace, support restoration and improve productivity.	To boost the retail price and occupancy rate of the hotel and reduce energy and water costs.
	<ul style="list-style-type: none"> <li>Property value increase-ment and operating costs reduction</li> </ul>	8 and 12		No
	<ul style="list-style-type: none"> <li>Labour productivity improvement</li> </ul>	8		

humidity, minimise energy consumption, and operate in synergy with renewable energy production. Water management was another vital target, associated with rain-water harvesting and greywater recycling for plant irrigation. However, since no outdoor green pockets were designed, there was no sustainability scheme for the urban microclimate, pollution mitigation, and biodiversity in this project. In addition, food production was also not in design considerations.

#### 4. Spatial analysis of green pocket cases

The actual design and implementation play a crucial role, as the mere presence of plants does not sufficiently provide insight into the quality of green pockets. In this section, we present two examples to illustrate the effect of green pockets on spatial quality.

##### 4.1. Erasmus MC

The former Erasmus hospital (dating back to 1961) was transformed from several single buildings into an ensemble of buildings under one roof, becoming the largest medical complex in the Netherlands (new construction 207,000 m<sup>2</sup>, total campus area 450,000 m<sup>2</sup>) (Fig. 5). In this project, the green pocket design was used as one of the approaches to assemble existing buildings and new constructions to connect with surrounding urban green spaces and establish internal spatial connections. Three variations of green pockets (atrium garden, sunken patio, and accessible roof garden) were designed in Erasmus MC (Fig. 6). The ground floor of Erasmus MC was lifted to one level higher than that of the urban terra. At each entrance, green pockets constructed with features similar to urban public green spaces alleviate the nervousness of people entering the hospital. The landscape architect Cor Geluk explained, "We tried to create what feels like a living-room atmosphere, where people feel at ease and can briefly get away from the hospital. We opted for wooden seats and planters with a rim for sitting to give people the impression that they are outdoors" (Hilgers, 2016, p. 8). Atrium spaces with glass roofs link diverse buildings to form a coherent unit, strengthen the opportunities for indoor walking, and allow sunlight essential for indoor plants into the building.

The *atrium gardens* were differentiated according to intensity of use and function (Fig. 6(b)). The designers distinguished the use intensity into logistic spaces (to enter, pass and inform), such as the "Plaza", "Atrium" and "Passage", and staying places (to stay, rest and meet), like the "Garden". Functionally, however, the "Plaza" area was also considered a place to meet or have meals and connected with the surrounding children's hospital. For improved privacy and sound isolation, the plants chosen for the "Plaza" were higher than in the "Atrium". Comparatively, the "Garden" was designed as the most peaceful area to stay at ground level, away from the main entrance (Fig. 7(b)). In addition, differences in spatial form, plant species, and scale give these green pockets their own atmospheres and make them identifiable in way-finding.

*Sunken patios* were arranged at the subterranean levels, while the plants here can extend vertically to higher floors (Fig. 6(c)). For example, the plants in the green pockets adjacent to the garage can reach up to three storeys and can also be seen from the ground floor. These green pockets were designed in a linear shape and laid on the central axis (300 m long) of the hospital's backbone (the "Passage" area in Fig. 6(b)). This space is a busy logistics area because it is a major traffic route. In contrast, an atmosphere of tranquillity was emphasised in the sunken patios on the way to radiation rooms, aiming to reduce stress and help patients to relax while waiting. The plants in sunken patios can only be viewed from the atria as radiation rooms are set underground and are not accessible to the public (Fig. 7(c)). To prevent bacterial infection from direct contact with nature and to guarantee safety, these sunken patios were isolated by glass enclosures.

Moreover, two *roof gardens* (3000 m<sup>2</sup>) accessible from inpatient wards were organised on the eighth floor of the Erasmus hospital (Fig. 6(a)). The roof garden is a representative example of the evidence-based design that draws on the Stress Recovery theory (Ulrich, 1983). According to Ulrich et al. (1991), exposure to the natural environment rather than the urban built environment fosters recovery rates and levels. Beyond merely viewing nature (e.g., 2D green roofs), accessible roof gardens encourage physical activity and fresh air, and offer a social place for families and hospital staff (Fig. 7(a)).

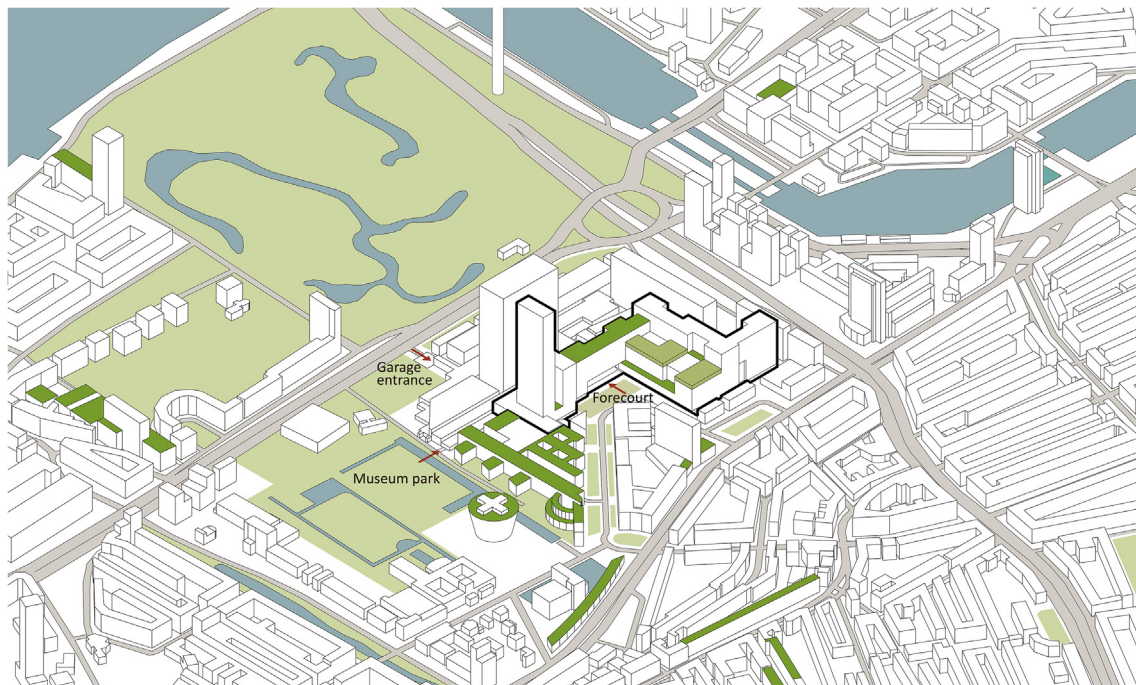
## 4.2. Hotel Jakarta

Hotel Jakarta occupies a prominent location at the tip of Java Island on the IJ River in Amsterdam. The site was

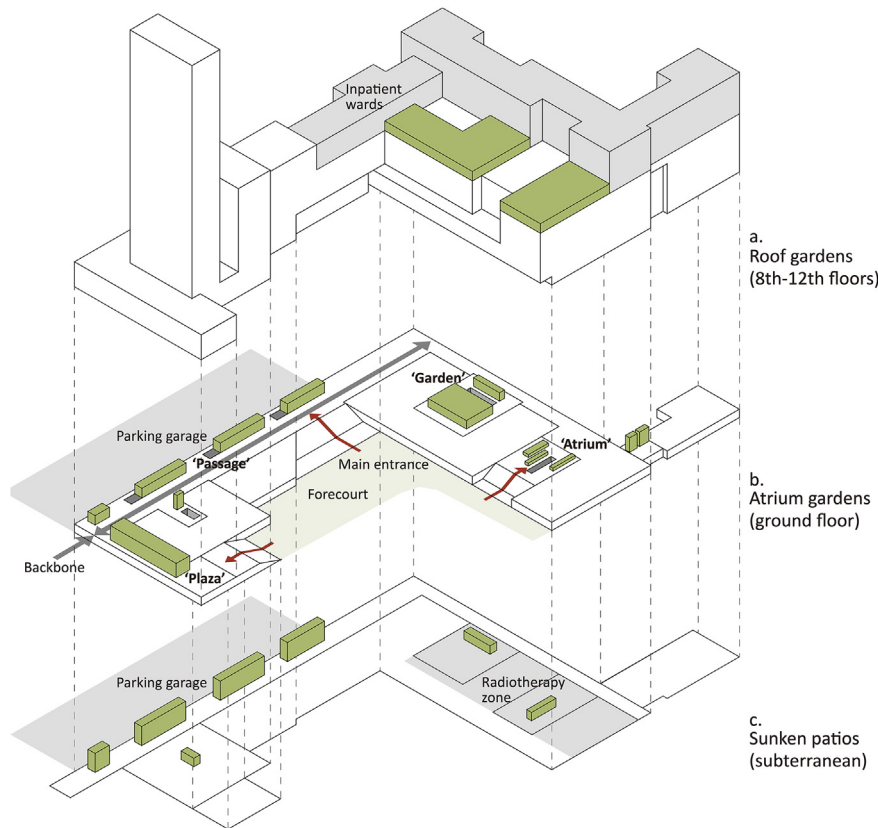
formerly a quay on the Dutch-Indonesian maritime route, where many Asian immigrants first arrived in the Netherlands at the end of the 19th century. Incorporating plants into buildings was first considered as an approach to create an active urban public space and connect with nature. The architects proposed an indoor subtropical garden, the Jakarta Garden, to connect with the surrounding green spaces on the island to form a coherent landscape axis (Fig. 8) and followed the triangular shape of the site to organise the building floor plan (Fig. 9).

The indoor garden was designed on a significant scale (with an area of approximately 350 m<sup>2</sup>, and a height of approximately 12 m) and was arranged in the centre of the building. The architects organised the garden space beyond the atrium to the side of the building, adjacent to the tip of Java Island, to ensure visibility of the garden from all directions. Meanwhile, the building was designed with glass façades (especially on the ground floor) to facilitate views of the interior garden from outside the building, inviting urban residents in (Fig. 10). In addition, the garden design was employed as an adequate solution to manage the 3 m height difference "to make the building accessible from all sides" (Kathrin Hanf, personal communication, November 23, 2021). The Jakarta Garden forms a relaxed and pleasant environment, offering opportunities to view and access nature, and to be exposed to nature even within the building.

To establish a link with this historical location, designers created a Southeast Asian atmosphere in the hotel that was achieved through the deliberate selection of plants for the Jakarta Garden. The landscape design team Copijn collaborated with Hortus Botanicus Amsterdam to pick out some



**Fig. 5** The integration of Erasmus MC with the urban landscape takes advantage of the boundaries to connect with the city and surrounding parks, allowing for multiple entrances, and forming a clear address in the city (source: authors, based on Juurlink [+] Geluk, personal communication, April 25, 2022).



**Fig. 6** Three variations of green pockets were organised in Erasmus MC, considering walking opportunities, use intensity (logistics vs. stay), variety of uses (e.g., lying, sitting, playing, walking, and sunbathing), and sequence (distinctive design for recognisable spaces) (source: authors).

native plants from Southeast Asia, like palms and banana trees. A total of 27 different species and sizes of plants were incorporated into the building, and all of them are subtropical and suitable for growing indoors. The architect Hanf explained this choice as “a way to remind people of being in an Asian surrounding; we are not giving a show of Indonesia, but a certain atmosphere”. The substrate depth of the garden was specified as 110 cm to provide sufficient space for the roots of diverse plants, from small ground covers to large trees that can grow up to 12 m high.

## 5. Biophilic design in architectural practices

In the field of biophilic design, there are numerous approaches and strategies available to connect with “nature”. The two case studies exemplify the realisation of design with “nature” in architecture and design practitioners’ viewpoints on the concept of biophilic design, bridging the theory and design practices. This section will focus on how biophilic design plays a role in understanding “nature” in architectural design. Based on the biophilic design framework of Zhong et al. (2022), the two projects were evaluated through a tabular comparison (Table 2). The criteria and aspects of the evaluation are as follows:

- The inclusion of biophilic design in innovating architectural typologies.

- Strength level of biophilic design approaches and elements (grading with +, ++, and +++).
- The considerations of applying biophilic design to create richer experiences of “nature”.

The concept of biophilic design informed design development in both green pocket projects. In Erasmus MC, empirical evidence from Stress Recovery theory (Ulrich, 1983) was adopted to create a healing environment, especially through the incorporation of natural elements. Nature elements were embedded in the building, such as plants were incorporated through the design of green pockets, and sunlight was brought indoors through glass roofs in the atriums. Natural features were also introduced in the hospital by utilising bio-based materials, such as bamboo, to create seating with greenery. Landscapes and buildings were merged by green pockets built not only at ground level but also at subterranean and upper levels, where nature is normally difficult to access. These green pockets contribute to an emerging understanding of nature: nature is not found “outside” but designed and man-made. They blur the boundaries between indoor and outdoor environments, imitating nature-like environments. As an identifiable spatial feature, green pockets connect different spaces in Erasmus MC, while simultaneously distinguishing zones from their unique forms or arrangements. Moreover, accessible roof gardens invite people to interact with nature and connect to larger ecosystems with other creatures.



**Fig. 7** Section and photographs of the three green pocket variations in Erasmus MC (section drawing source: authors, based on EGM architects and Juurlink [+] Geluk).

In Hotel Jakarta, architects incorporated “nature” by designing an indoor subtropical garden in the atrium. In addition to plants, several other natural elements, such as light and air (natural ventilation), have been introduced into the building to support plant survival indoors and enhance indoor comfort. Irrigation water increases the humidity of the air, and ventilation ensures air exchange and prevents dust accumulation. Wooden materials are used extensively in this hotel, accounting for 90% of the total building materials. This places the green pocket in a warm and friendly atmosphere. Furthermore, a connection to “place” was established in the Jakarta Garden. The subtropical plants in the garden echo the historical link with Indonesia in this area, as many Southeast Asian immigrants reside there. For “nature interaction”, attractive natural environmental characteristics were also organised. The hotel rooms are organised around the garden to allow open views (“prospect”) from all directions and floors, while large plant foliage provides privacy (“refuge”). Also, the winding paths designed in the garden foster a feeling of mystery, an “enticement”, as indicated in the biophilic design framework.

## 6. Discussion

This section discusses the extent to which green pockets contribute to sustainability. In addition, opportunities for advancing green pocket designs are identified from the framework of biophilic design and the two case studies.

### 6.1. Contributions to sustainability

The integration of plants into buildings has become increasingly popular, but controversies have arisen regarding their contribution to sustainability. It is recognised to have extensive benefits from environmental and ecological perspectives, with further social significance, economic implications, building energy, and resource efficiency to human physical health and mental well-being (Table 1). However, its actual effectiveness and the problems caused by plants within buildings have generated criticism.

Green pockets in architectural projects have specific design targets and strategies in their interpretations of

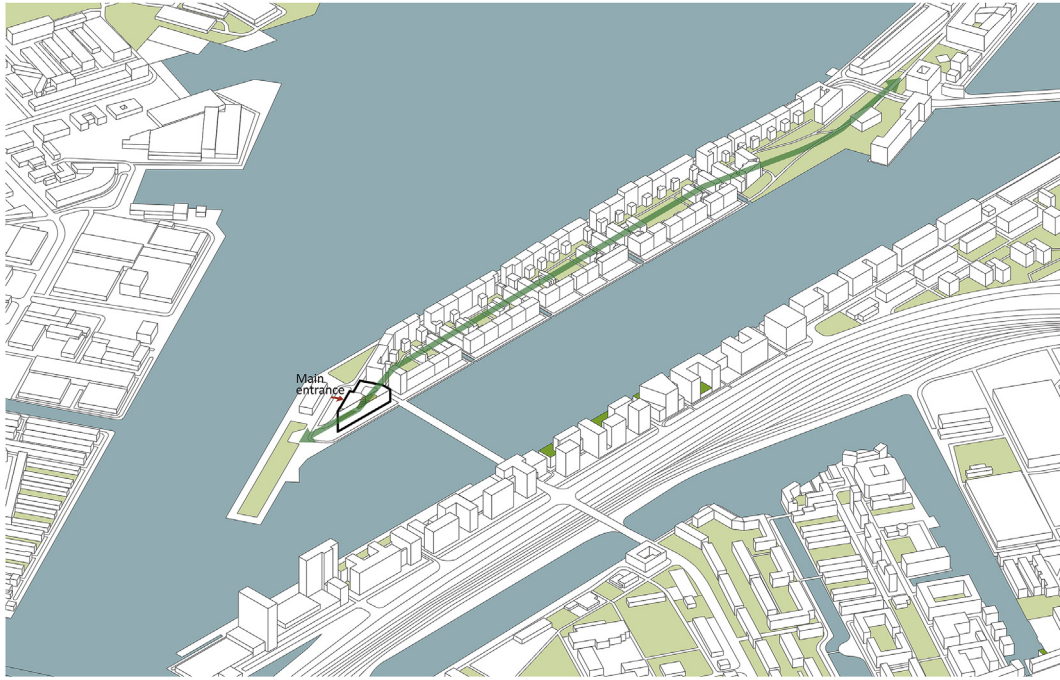


Fig. 8 Hotel Jakarta planned on the landscape axis of Java Island (source: authors).

sustainability. In Erasmus MC, the primary contributions of these green pockets are to human health and the creation of a healing environment. Green pockets built at entrances, public spaces, and waiting areas form a relaxing atmosphere in the hospital to relieve stress and create privacy by blocking views and optimising acoustical performance.

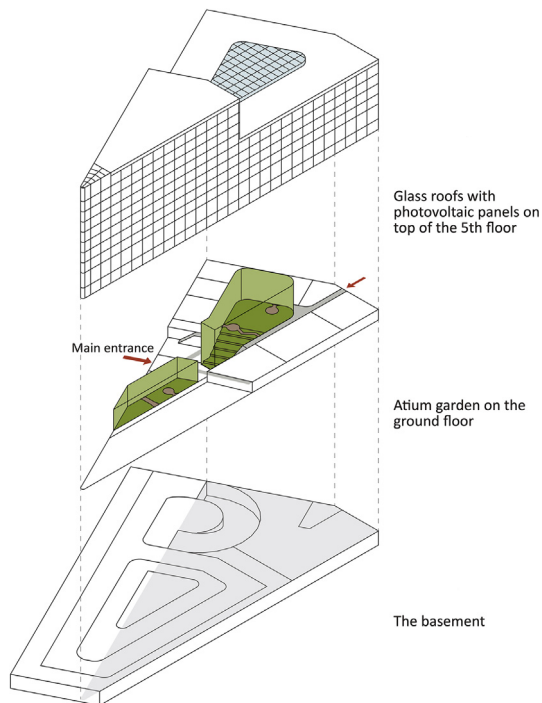


Fig. 9 The spatial layout of the green pocket in Hotel Jakarta (source: authors).

Outdoor roof gardens enable both visibility and accessibility of green spaces from patient rooms to accelerate recovery. They are also a good example of nature-based solutions to improving building insulation and benefiting urban microclimate and biodiversity. In Hotel Jakarta, the subtropical garden connects with local history and culture, provides accessible public green space for city dwellers, and supports the restoration and generation of positive emotions. In terms of building performance, the large indoor garden acts as a thermal buffer to create a climate-neutral building and reduce carbon emissions, and the intelligent irrigation system enhances the efficient use and management of water resources. The choice to plant indigenous Indonesian species also offers the opportunity to experience exotic scenery domestically, bringing economic benefits in guaranteed occupancy, especially when travelling abroad is restricted during the COVID-19 pandemic.

However, greenery in buildings sometimes provokes criticism of unintended side-effects and risks. For instance, transpiration and the evaporation of irrigation water cause an excessively humid environment that does not fit building physical requirements for living and working spaces; negative emotional responses might be generated from viewing wilted plants or spiders; plants may cause allergies and retain dust, leading to respiratory problems, and cause insect trouble indoors; plants cannot survive indoors where light is insufficient; inappropriate tree configurations (e.g., orientation or species) can also lead to higher heating energy costs in winter. Moreover, the construction and maintenance of these green spaces require more building materials and increased energy use. The transportation of plants, particularly those imported from other regions, may also result in higher carbon emissions. Potential threats also exist in the structural problems caused by plants and irrigation, which may shorten the lifespan of green pockets

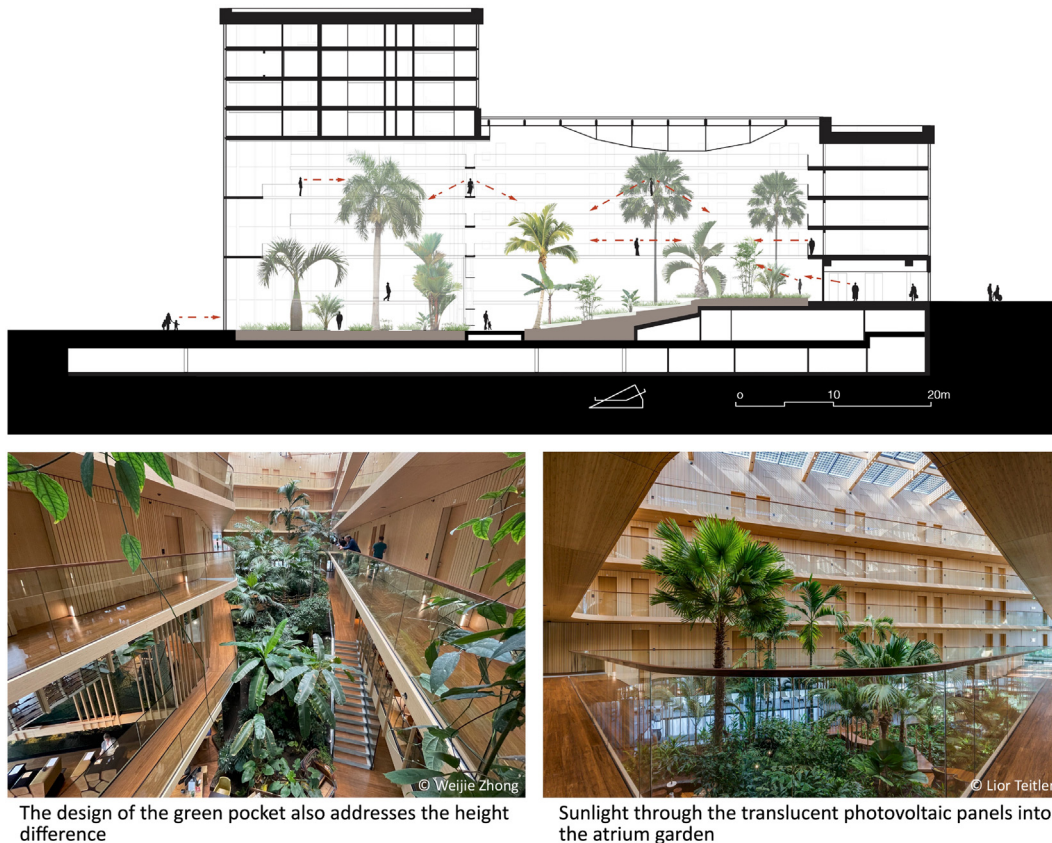


Fig. 10 Section and photographs of the atrium garden in Hotel Jakarta (section drawing source: SeARCH).

and reduce the durability of buildings. Additionally, there are doubts regarding the impact of small-scale green spaces. Indoor-potted plants narrowly improve indoor air quality, with 2.44 plants/m<sup>2</sup> reducing formaldehyde by only 10% (Dingle et al., 2000). To achieve the same level of pollutant removal as typical building air exchangers, the quantity of plants should be at least 10 plants/m<sup>2</sup> (Cummins and Waring, 2020). Another study indicated that 2D green surfaces in buildings have minimal abilities to mitigate and adapt to climate change compared to trees in streets and parks (Albers et al., 2015).

The performance of green pockets (3D green spaces) is expected to improve, typically with stronger impacts as the scale increases. When the substrate depth of green roofs increases from 10 cm to 21 cm, the annual rainwater runoff may decrease from 50% to 25% on average (Mentens et al., 2006). By increasing the leaf area index, solar transmittance can be decreased from 40% to 5% (Schumann, 2007). In addition, a larger quantity and scale of plants potentially enhances air purification and extends nesting and shelter areas for animals with richer plant species. Larger green pockets incorporating more natural elements to enrich experiences of “nature” may intensify psychological well-being; however, larger-scale green spaces inevitably involve more technical challenges. For example, more construction materials are required to build larger plant containers, building structures must withstand damage from stronger root systems, and green pockets on cantilevered terraces have higher requirements for

structural stability. Furthermore, wind resistance should be accounted for in high-rise buildings, and trees and shrubs need more intensive maintenance. Therefore, an in-depth analysis of how green pockets can overcome these drawbacks and improve building quality is required.

## 6.2. Opportunities from biophilic design

The biophilic design framework (Zhong et al., 2022) offers many approaches to integrate “nature” with architecture, using a full range of elements to enrich experiences of “nature”. From the two case studies (Table 2), there are several key biophilic design strategies that make them exemplary of green pockets.

The mutual integration of various biophilic design elements is crucial in producing multiple sensory experiences of vibrant “nature” and establishing connections between spaces. This interaction of natural elements generates effects, for instance, the rustling of plant foliage caused by air movement, dynamic shadow patterns created by daylight reflections on plants, and thriving biotopes developed from the reciprocal benefits of flora and fauna. Additionally, deliberate planting configurations that link buildings to urban green spaces create a connection to “place”. The choice of a common design element (plants) with diverse green pocket forms and plant species allows the different spaces within a building to be connected while presenting their own recognisable uniqueness.

**Table 2** Biophilic design elements applied in the two green pocket design cases.

Biophilic design		Erasmus MC	Hotel Jakarta
Nature incorporation	Water	+ No visible features, but water management (rainwater retention, flood prevention, and safety – Legionella risk control) is considered in the irrigation system.	+ No visible features, but water management (rainwater collection, greywater recycling, and safety – Legionella risk control) is considered in the irrigation system.
	Air	++ Atrium gardens are located in unconditioned spaces and act as semi-indoor thermal buffers; windows can be opened to provide natural ventilation.	++ The indoor atrium garden acts as a thermal buffer; the glass roof can be adjusted to 24° for natural ventilation.
	Daylight	++ Glass roofs in atriums bring sunlight into the building for both humans and indoor plants.	++ 300 m <sup>2</sup> glass roof (50% transparent) with BIPV.
	Plants	+++ Atrium gardens and sunken patios: approx. 1000 m <sup>2</sup> (max. plant height 10 m); Accessible roof gardens: approx. 3000 m <sup>2</sup> (max. plant height 4 m).	+++ An atrium garden: approx. 350 m <sup>2</sup> (max. plant height 12 m).
	Animals	++ The roof gardens provide animal habitats, allowing reciprocal benefits for animals and plants.	No
	Landscape	++ Integration into the urban landscape through the creation of green pockets in and on the building, particularly large-scale roof gardens.	++ The atrium garden forms an indoor landscape that links up with other green spaces on Java Island to form a coherent landscape axis.
	Weather	+ No visible features, but climatic conditions are considered in the selection of plants for the green pockets indoors and outdoors.	No
	Nature inspiration	Time and seasonal changes	No
Forms and shapes		No	No
Patterns and geometries		+ No considerations for green pockets, but bamboo patterns are used for concrete walls at the elevator entrances.	No
Mechanisms		No	No
	Images	+ No arrangements in the green pockets, but photographs with plants/landscapes are placed in patient wards and nearby all other clinical areas.	No



Nature interaction	Materials, texture, and colour	++ The atrium gardens are furnished with bamboo tables and seats, and the roof gardens are complete with wooden seating and garden ornaments.	++ 90% of the building materials used are timber, including the surroundings of the green pocket and the pathways within the garden.
	Prospect and refuge	++ The upper floors surrounding the atrium gardens have distant views of green spaces within the building, and the 8th floor (ward area) and above also have open views of the roof gardens and the parks around the buildings.	++ The hotel rooms built around the atrium and the glass guardrails installed along the corridors allow for views over the gardens from higher levels and ensure safety simultaneously.
	Complexity and order	++ The green pockets are designed in different forms, scales and atmospheres, but they are organised on axes that emphasise the “sequence” of the space.	No
	Enticement (peril and mystery)	No	++ Meandering pathways are arranged to enrich interest in accessing or crossing the garden; glass walkways (with guardrails) are designed above the gardens to provide experiences of risk (with security).
	Connection to place	+ No deliberate designs, but indigenous plant species are chosen for roof gardens.	++ Select plant species from Southeast Asia to connect with local history and generate a “sense of place”.
	Connections of spaces	++ The green pockets at entrances and the roof gardens resemble the arrangements in urban green spaces to connect indoor and outdoor spaces; the green pockets also link the spaces within the complex with “greening”.	++ The glazed facades allow the atrium garden to be viewed from the exterior, connecting to urban green spaces visually.

+++ : the most relevant elements, carefully considered in green pocket designs; ++ : elements directly related to some design choices of green pockets; + : elements not directly designed in green pockets or represented as visible features, but may affect the quality of green pockets.

“Plants”, as the most noticeable natural elements, their scale have a major impact on green pockets. They should be measured not only by ground area but also by quantity, height, branch extension, and foliage density. Trees and large shrubs generate stronger visual stimulation and have greater potential to improve building performance, alongside visual and acoustic isolation in creating privacy that is difficult to achieve by grasses and ground covers.

In addition, the natural atmosphere can be intensified by matching views or plants of green pockets with landscape artworks placed in interiors, as well as by using bio-based materials and natural colours (e.g., green and earth tones) in the surrounding environment.

Moreover, facilitating interactions with “nature” and experiences of intriguing natural characteristics boost positive emotional responses. Paired attributes can be considered, for example, in planning the visibility of green pockets, providing “prospect” (open views) from higher floors and “refuge” (privacy) through the shading of large plants. Organised complexity is another fascinating attribute of “nature”, composed of “complexity” and “order”. A rich variation of well-ordered green pockets can avoid becoming monotonous or over-cluttered spaces. The accessibility of green pockets is also a distinctive and appealing feature of these 3D green spaces, creating scenes that mimic the mystery and risks of the natural environment to enhance immersion.

However, some methods and elements of the biophilic design framework (e.g., the imitation of natural “forms and shapes”, “patterns and geometries” and “mechanism”) have not been adopted in either Erasmus MC or Hotel Jakarta. Given the limited number of projects studied, it is difficult to determine if these methods are applicable to green pockets, or if other opportunities may exist in other cases. Research is required on more advanced examples of green pockets in different regions to develop generalised biophilic design guidelines in the future.

Furthermore, we identify opportunities to improve the designs of green pockets that were overlooked in the two cases. Not all natural elements were explicitly utilised as design features. Instead of considering “water” only in the water supply system, it is suggested to create some fluid water scenes in the vicinity of green pockets to enrich visual and aural experiences. Designing green pockets in uncovered areas (e.g., patios) can provide opportunities to physically experience different weather conditions rather than just visually display the weather. Also, considering “time and seasonal changes” in the planting configuration can achieve rich variations of form and colour, enabling green pockets with dynamic features and strengthening the realistic sensation of “nature”.

## 7. Conclusion

In conclusion, this paper introduces “green pocket” as a distinct typology to overcome the reductionist approach that collectively defines the integration of plants into buildings as “greenery”. It provides a critical reflection (a

framework) to evaluate sustainability as a concept interpreted and implemented in architectural projects, explores how the biophilic design framework can help conceptualise “nature” in architecture, and suggests the use of these two frameworks to advance future green pocket designs.

In contrast to 2D green roofs or walls, green pockets accommodate larger-scale plants such as trees. Green pockets offer opportunities to be creative as they can be designed in various forms and flexibly arranged in different spaces or floor levels. With the increasing size of plants (e.g., larger canopies and more foliage), green pockets play a significant role in enhancing spatial quality. They are accessible green spaces that provide opportunities to interact with nature in the built environment, rather than only being viewed as decorative elements.

Green pockets also address challenges in sustainability and provide benefits to the urban environment and ecosystem, building performance, human comfort, health, and well-being. However, weaknesses and potential threats should be considered, such as high construction and maintenance costs, additional material and energy consumption, limited life span, and uncertainty concerning their performance. The framework we developed to evaluate the impacts of “green architecture” on sustainability can be applied not only in this study but also transferable to other studies related to the greening of buildings.

Each green pocket is unique in its location, climate, context, shape, scale, layout, and plants; however, there are some common approaches that can guide the design. The biophilic design framework uses a wide range of strategies to design green pockets. We propose the following design recommendations:

- The biophilic design framework can be utilised to conceptualise “nature” in architecture and to integrate more natural elements than just plants in designing green pockets.
- The interplay of various biophilic design elements can create multiple sensory experiences and enhance the spatial quality of green pockets.
- Designing green pockets with visibility and accessibility to intensify the connection with nature.
- Considering the mutual benefits between animals and plants to build biotopes within green pockets and foster the coexistence of architecture and nature.
- The choice of plant species is crucial for establishing spatial connections. Planting indigenous species or those that are the same or similar to urban green spaces can create a sense of “Place”. Common natural elements – plants – can link the different spaces in a building, while diverse plants in each green pocket can become a distinct and recognisable feature of those spaces.
- Scale matters. In addition to the number of plants and the area occupied, the height, branch extension, and foliage density of plants are crucial in forming 3D green spaces.
- Employing natural materials, colours, and other related visual products in the surroundings of green pockets can further enhance the atmosphere.

- Simulating spatial characteristics of “nature” (e.g., prospect and refuge, organised complexity, peril, and mystery) can help to generate positive psychological responses from interacting with nature.

This study proposed several biophilic design strategies to advance the design of green pockets. Further studies are needed to solidify these strategies to enhance the performance of green pockets. Future research can be undertaken in the following areas. First, plant selection is important to the quality of green pockets and requires botanical knowledge. The discussion should include plant survival requirements and climate conditions as well as plant size, colour, substrate, root system, canopy, foliage, branch extension, growth rate, wind tolerance, toxicity, pest resistance, benefits to animals, and edibility. In addition, the development of green pockets requires the support of advanced technologies. The optimisation of intelligent irrigation devices and automatic control systems can enhance water management. Regarding construction, further research can determine how to reduce building (concrete) materials and simplify the construction process. Stakeholders may accept higher budgets due to increased building values, but there are also concerns about reducing maintenance costs and boosting financial returns. This relates to energy conservation through strengthened insulation, reducing water consumption and unnecessary resource use, making regular maintenance simple and cost-effective, extending the lifespan of green pockets, providing flexibility for future renovations, and maximising various benefits. More qualitative and quantitative investigations into the performance evaluation and optimisation of green pockets are necessary. We believe that the development of green pockets merits further attention because of their significant potential to innovate architectural typologies and enhance the impacts of designing with nature in the pursuit of more sustainable building environments.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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