The Added Value of Greenery for Sustainable Building: The Perspective from the Netherlands

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Introduction

Human activity is the dominant influence on climate and the environment. Risks to health from high temperatures are increasing with climate change, and new ways to mitigate urban heat island (UHI) effects are needed as nearly three-quarters of the global population will be living in towns and cities by 2050. We have to act responsibly for the future of humanity. In the early 1990s researchers began to discuss the contribution that design could make in the development towards sustainable development (Bhamra 2019). Design for sustainability over the last 30 years has developed and let to good examples of nature-inspired architecture and modern plant breeding by understanding the complexity of sustainable development (Bhamra 2019). Designers started looking for integrated techniques from plant science, building physics and architecture to use plants in the built environment (e.g. green infrastructure: green walls and roofs). This to search for energy reduction and comfort improvement and to identify opportunities for food production within cities. Important is the right balance in the sustainability triangle between environment, economy and society (Bhamra 2019); see Fig. 1; this forms the basis for responsible design.

Responsible design requires the actions of individual designers and design teams, focusing on economical responsible behaviour, environmental responsibility and social responsibility. It comprises three aspects (Eppinger and Maier 2019):

- People: Socially responsible design that enables better work conditions, healthy social interactions, and improvement of the human condition

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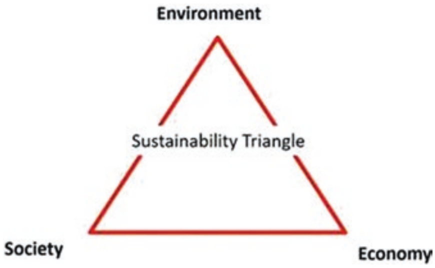

Fig. 1 The sustainability triangle (Bhamra 2019)

- Planet: Environmentally responsible design that meets the needs of the present without compromising the ability of future generations to meet their own needs
- Profit: Economical responsible behaviour design that encourages people and organizations to interact with others in a respectful and sustainable manner

One of the pioneers and promotors looking at the added value of greenery in sustainable building design was Ken Yang (1972). In his book The Green Skyscraper (1999) he laid the basis for designing sustainable intensive buildings and clearly demonstrated the added value of greenery. The Netherlands as densely populated country combined with high standards of living had always to (and knows how to) mould the natural environment to suit its needs (MVDRV 2019). A good example is the Netherlands' specific contribution to the ecological spectrum of the World Fair in Hannover 2000. Demonstrating that technology and nature need not be mutually exclusive, they can perfectly well reinforce one another. Nature arranged on many levels provided both an extension to existing nature and an outstanding symbol of its artificiality (MVDRV 2019).

By working with nature, cities can become more resilient to the changing climate. Embracing green roofs and facades helps to achieve liveable, sustainable built spaces (Young 2014). Furthermore, green roofs retain a high amount of rainwater, so they are perfect for harvesting, thus reducing the amount of water reaching urban sewage systems. With green roofs, water roofs, vertical farming and even high-rise greening with tree like the Bosco Verticale by Stefano Boeri in Milan (Smith 2015)—from large-scale interventions to smaller scale enrichments—cities in the future will need to look vastly different to cities now (Arup 2015; MVDRV 2019). The Nieuw Bergen project of MVRDV architects is such an example (Malone 2017). It is a residential development combining urban and green qualities in the neighbourhood of Bergen, Eindhoven; see Fig. 2.

Vertical farming techniques and urban agricultural systems, such as hydroponics, can potentially be utilized to help address the local food production as well as contribute to the environmental conditions within the cities. As a result of the economic, environmental and social developments, urban agriculture will become part of the urban culture in the twenty-first century (Zoellner 2013). New technology will allow roofs, walls and building facades to be 'greened', creating a filter for pollution, absorbing carbon dioxide by acting as a carbon 'sink' as well as providing

Fig. 2 Nieuw Bergen project MVRDV Eindhoven, Netherlands. (Source: https://mvrdv.nl/projects/290/nieuw-bergen?photo=17070)

natural cooling and insulation to enhance air quality within cities. Bio-inspiration from plants for the future built environment through green infrastructure and bio-based materials might lead to new architectural designs with benefits for (Wootton--Beard 2018):

- Thermal comfort—cooling the atmosphere (indoor and outdoor) to reduce the impact of heat waves
- Energy use/building thermoregulation—applying an external layer to regulate internal temperature and energy use
- Indoor environment—improving air quality, improving hygrothermal conditions and regulating noise
- Outdoor air pollution—trapping pollutants in canopy or substrate, removal by absorption or engineered solutions
- Mental health—visual stimulation, aesthetic quality and evolutionary preferences

All resulting design actions should emphasize the benefits of improved energy efficiency of buildings; new sustainable building technologies; low-carbon, renewable energy production; and reduction of energy demand. Building greenery, plants and architecture and bio-inspiration from plants all offer new opportunities for the future built environment. However, it is important to get a true understanding of its values as well.

The Added Value of Greenery: An Integrated Characterization Framework

The study by Zhao et al. (2019) presents a summary of the added value and benefits of green buildings through a bibliometric research approach. They reviewed in total 2980 articles published in 2000–2016 and the following key research topics were identified: vertical greening systems, green and cool roof, water efficiency, occupants' satisfaction and financial benefits of green building. This study forms the basis for the discussion of the different greenery aspects combined with the overview by Wootton-Beard (2018) and completed with additional recent Dutch research.

Green and Cool Roof

Cool roofs are the roofing systems using the cool materials that present a high albedo. In this cluster, Romeo and Zinzi (2013) found that the cool-roof application on a non-residential building decreased the roof surface temperature by 20 °C, and that it was effective in reducing cooling and total net energy demand. Green roofs, which are the roofs partially or completely covered with vegetation, are also common in green buildings. Santamouris (2014) reviewed the technologies to mitigate heat island phenomenon and analysed the effect of increasing the albedo of cities by cool roofs and using vegetative green roofs on heat island mitigation. Gill et al. (2007) indicated that greening roofs in areas with a high proportion of buildings can significantly lower down the surface temperature and reduce the rainwater runoff.

Akbari et al. (2001, 2012) indicated that urban trees, cool roofs and cool pavements had significant influence on urban air temperature, thereby reducing cooling energy consumption. Similarly, Ng et al. (2012) investigated the cooling effect of urban greening in Hong Kong, and revealed that roof greening was not effective for human thermal comfort near the ground and that grass was less effective than trees in lowering the temperature of pedestrian areas.

Sailor (2008) developed a model that provides energy modeller with vegetated green-roof design options. Additionally, Takebayashi and Moriyama (2007) found that the sensible heat flux was small on the surfaces of green roofs and the roofs with highly reflective white paint.

The representative research on 'land surface temperature' was undertaken by Wong et al. (2003), who performed a field measurement of the thermal impacts of roof gardens in Singapore and confirmed that roof garden provided thermal benefits for both buildings and surrounding environments. Additionally, Santamouris et al. (2007) calculated both the cooling and heating load for a whole building with a green roof and for its top floor, and found the great reduction in the building's cooling load in summer as well as the insignificant effect on heating load in winter.

Substrate can neutralize localized acid rain (Wootton-Beard 2018). Depending on atmospheric deposition rates, green roofs can become a source of pollution in the longer term, particularly metals, e.g. Pb, Cr, Cd, Cu and Zn. Fertilization will create a source of water contamination for N, P and K. It is highly dependent on soil depth, type, age and weather conditions (e.g. wind direction) as well as on urban geometry (Wootton-Beard 2018).

The Netherlands has an estimated 200 million m^2 of flat roofs. Most of these roofs could be made green. Ever more municipalities adopted a policy to actively promote green roofs. Not yet on such a wide scale as in some other countries, but it is a start. Most municipalities opt for a grant scheme for both residents and the business sector which contributes to the cost of installing a green roof, usually 50% of the total cost.

Vertical Greening Systems

These are usually classified into green facades and living walls in accordance with their growing method (Ottelé et al. 2011; Perini and Rosasco 2013). Living walls can support the vegetation that is rooted on the walls or in the substrates attached to the walls (Chen et al. 2013) while green facades are made by the climbing plants attached directly to the wall surface (Perini et al. 2011). Vertical greening systems can be used as passive systems to save energy, with the consideration into the following mechanisms: blockage of solar radiation because of the shadow provided by vegetation, evaporative cooling produced by blocking the wind and by evapotranspiration from substrate and plants, and thermal insulation brought by the substrate and vegetation (Perez et al. 2011). Additionally, Wong et al. (2010) found that vertical greenery systems lowered down the surface temperature of building facades in the tropical area, thereby reducing the cooling load and energy expense. The principal cooling effect is evapotranspiration (evaporation + transpiration) (Wootton-Beard 2018) which is fundamentally determined by the availability of moisture (and wind flow), vegetation cover, precipitation, irrigation and humidity. The vegetation replaces sensible heating with latent heating and reduces the Bowen ratio, the ratio of heat flux to moisture flux near the surface. The vegetation modifies surface roughness and wind flow, thus altering the convective heat exchange. Heterogeneity of the greenery is necessary and leads to best effects on heat loss (Wootton-Beard 2018). There is a minimum size of 50,000 m^2 to have significant cooling effect, so it is only relevant at town/city scale or for large green spaces. There is not yet any evidence for the network of smaller spaces owing to necessary fetch (Wootton-Beard 2018).

Incorporation of vegetation has a potential impact on the building design process and on building energy use. The principal effect of greenery on building thermoregulation is that insulation/shading is provided to building envelope which results in more stable internal temperatures (Wootton-Beard 2018). Plant albedo values are higher than grey surfaces creating more stable roof temperature. Also the shading potential is considerable, and can be a cost-effective mitigation measure (Gupta and Gregg 2012). Rural vegetation reflects 15–25% of short-wave radiation (Armson et al. 2012); however, effectiveness is driven by leaf size, crown area and leaf area index (Santamouris 2014). Mangone and van der Linden (2014) studied the effect of a vegetation shade canopy of an 11,000 m^2 office building on the energy consumption and carbon emissions. The thermal effects of the vegetation canopy were found to have a slightly greater effectiveness than the original shading solution (Mangone 2015).

A special class of vertical greening systems are the vertically integrated greenhouses (VIG) which combine a double-skin building facade (DSF) with a hydroponic greenhouse (Levenston 2019). The DSF can reduce the energy used for space conditioning in modern high-rise buildings considerately up to 20%. A DSF consists of a vertically continuous void space enclosed by a second curtain of glazing over the entire facade. A DSF provides solar heat in winter and buoyancy-driven cooling flows in summer, and allows opening of windows year-round. Already in 2003 van Passen (Stec et al. 2005; Stec and van Passen 2005) started their research aimed at defining the thermal performance of the double-skin facade with plants. Further research by Fang et al. (2011) and among others Larsen et al. (2013) proved that the use of plants in building facades is a useful bioclimatic strategy providing many benefits to the thermal, acoustic and psychological comfort of the inhabitants. The VIG combines a DSF with a novel system of hydroponic food production, for installation on new high-rise buildings and as a potential retrofit on existing buildings. In addition to producing food, plants can reduce building maintenance costs by providing shade, air treatment and evaporative cooling to building occupants.

Occupants' Satisfaction

One of the main disturbances in open-space office buildings is noise. This is something where green partitioning walls can help. The principal positive effect of green living walls inside buildings for sound insulation is that it provides a physical noise barrier and/or sound insulation (Wootton-Beard 2018). It is effective at reducing sound reduction index (15 db) when used as a physical barrier. A sound absorption co-efficient of 0.4 is reachable (Azkorra et al. 2015). It provides some acoustic insulation for buildings (Pérez et al. 2016) but it can also be used to provide a source of pleasant sounds, e.g. bird song and wind through leaves (Irvine et al. 2009).

Indoor thermal comfort is to a large extent determined by the availability of moisture (and airflow) (Wootton-Beard 2018). Important influencing factors of the applied greenery are vegetation cover, irrigation and humidity. They result in positive effects on thermal comfort as proven in controlled studies throughout a range of seasons and temperatures leading to reduced energy consumption (Wootton-Beard 2018). However, large number of plants are required to have significant cooling effect which is then also highly influenced by building characteristics and use patterns. Nevertheless the relatively lower air temperature and higher relative humidity levels proximate to the living wall (Gunawardena and Steemers 2019a, b) could be used as a kind of green air conditioning using indoor green wall systems as a climate control method (Armijos Moya et al. 2017, 2018). Not only passive green air conditioning systems can be applied but also active systems incorporating fans have been designed, e.g. a smart wall (Naava 2019).

Several short-term studies have found evidence that plants may improve occupant thermal comfort, yet this phenomena had not yet been rigorously evaluated (Mangone et al. 2014). Therefore they evaluated in a quasi-experiment the effect of indoor plants on the thermal comfort of 67 office workers within an office building for four separate months, 1 month in each season. The presence of a substantial quantity of plants in the work environment had a significant effect on the perceived thermal comfort of the participants. On average the occupants of the rooms in which the presence of plants was alternated were 12.0% more thermally comfortable when plants were present in the room. This would allow the temperature set point to be raised in the summer and lowered in the winter leading to reduced energy consumption and carbon emission rates (Mangone et al. 2014).

The principal effect of plants on indoor air quality is that they absorb/trap harmful air pollutants and 'clean' the air (Wootton-Beard 2018; Armijos Moya et al. 2018). Already in the 1980s, the NASA Clean Air Study presented some studies about the behaviour of plants regarding IAQ (Wolverton et al. 1984, 1989). Plants trap particulate matters PM2.5 and PM10 which are harmful to health, e.g. the tree cover of West Midlands estimated to reduce PM10 by 4% (McDonald et al. 2007). Its performance is related to canopy density and leaf traits, e.g. waxiness and hairiness (Wootton-Beard 2018). In addition plants can absorb some pollutants, e.g. NO_x and SO2, and the substrate can be a sink for heavy metal deposition and pollutants, and is preferable to surface dust for water quality.

There are active green wall products available that include either absorbents or a rhizosphere, the vicinity of plant roots together with the rhizobacteria (Torpy et al. 2016). House plants (Kapoor 2017) can remove some harmful chemicals, e.g. formaldehyde, benzene, xylene, ammonia, trichloroethylene, acetone and some VOCs. Leaves trap PM10/PM2.5 to varying degrees based on physiology. However, the effectiveness is strongly dependent on building users and behaviour (i.e. opening a window). Furthermore, a large number of plants are needed in the average-sized home (10–20 per room).

Wolverton (2010) compiled a list with 50 of the best, most useful, easiest-to-maintain plants after his research, plus information regarding exactly what you need to do with them, and combined all this knowledge (Wolverton 2008). The most practically applicable part of the book is the assessment of a total of 50 houseplants. Wolverton (2008) has done this based on the following points:

- The degree to which hazardous substances are filtered
- Ease of maintenance
- Sensitivity to diseases
- The degree of water evaporation

The golden cane palm, also known as the areca palm or in Latin *Chrysalidocarpus lutescens*, is one of the best houseplants for removing all air pollutants in a house (Wolverton 2008). The broadleaf lady palm, or the *Rhapis excelsa*, is just slightly less effective in purifying, but is more user friendly and more resistant to diseases. Every plant has its own strength. Studies to the effects are mainly based on small-scale, controlled-chamber experiments, not real living scenarios (Wootton-Beard 2018). Plants absorb CO2 during the day. Improving the air quality in school classrooms, where the pupils produce high levels of CO2, using plants proved to be a practically executable solution. Research by van Duijn et al. (2011) showed that the classrooms from the third group, with plants and plenty of light, achieved some excellent scores (IntoGreen 2019): 10–20% CO2 reduction and degradation of

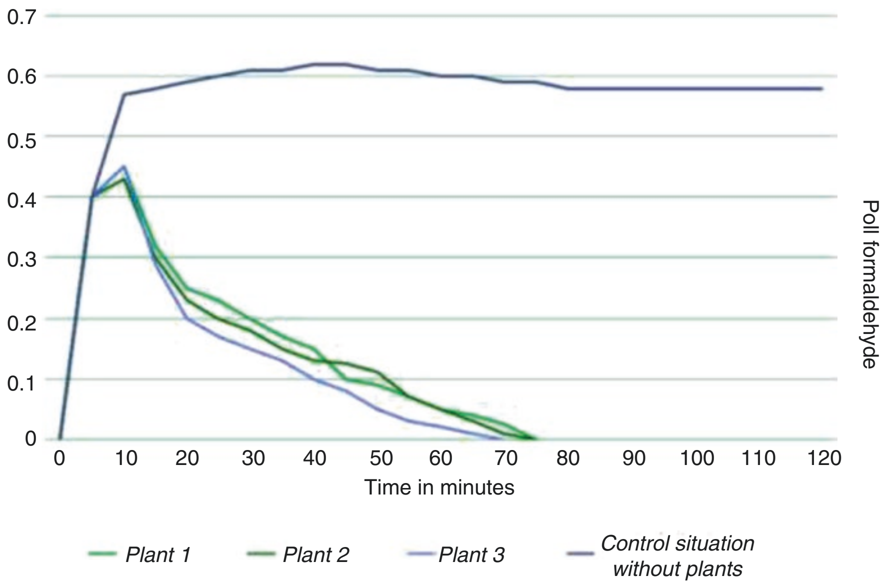

Fig. 3 Degradation of pollutant formaldehyde within 45 min to 0 level, as a result of the plants' air-purifying properties (Velzeboer et al. 2019)

formaldehyde within 45 min to 0 level, as a result of the plants' air-purifying properties. Figure 3 shows the breakdown of formaldehyde in a classroom without plants, the blue line; in classrooms with plenty of light and plants, the pink/magenta line; and in classrooms with plants with little light, the blue and purple lines. So plants can even significantly contribute to the breakdown of this substance in darker classrooms.

Velzeboer et al. (2019) studied the potential of air-purifying plant systems (plants with ventilation systems) to remove particulate matter (PM) and volatile organic compounds (VOC) from air. A new experimental set-up (a climatic chamber) was used with high-end reference equipment to measure air quality and where specific concentrations of PM and VOC can be generated. They selected six air-purifying plant systems and two mechanic air-purifying systems that use classical filters. For the plant systems the removal ranged between 41% and 50%. The mechanical systems showed a much higher aerosol removal ranging from 71% to 87%. The study nevertheless showed how plant systems can contribute to an improvement of the indoor air quality.

Visual/aesthetic qualities of transforming grey-green have positive psychological effects (Wootton-Beard 2018). There is a clear link between well-being and green space (Takano et al. 2002; de Vries et al. 2003). Well-managed greenery increases the sense of community attachment (Kuo et al. 1998). Viewing greenery ameliorates attention fatigue and stress (Ulrich 1983; Ulrich et al. 1991); it is naturally superior to urban for attention function and emotional state (Hartig et al. 2003). Effects have been replicated in hospital patients, school children, office workers, etc. Leaman and Bordass (2007) examined the occupants' opinions on British green buildings, and found that green buildings were difficult to manage and usually repeated past mistakes in conventional buildings. Additionally, Paul and Taylor (2008) compared occupants' perceptions on the aesthetics, serenity, lighting, acoustics, ventilation, temperature, humidity and satisfaction of a green building with those of two conventional buildings, but did not find that green buildings were more comfortable. Still the positive effects of greenery in urban working environments have been becoming more clear in the last years as shown by Hiemstra et al. (2019). Greenery in and around offices and other working environments is good for both the indoor and outdoor climate. It has a positive effect on the health and general well-being of employees. It aids concentration, reduces stress and increases staff productivity (Hiemstra et al. 2019). Hermans et al. (2019) developed a conceptual model, describing the short-term, medium and long-term effects of plants on the indoor climate and the health and well-being of people. They tested the model by means of intervention research at three companies and eight homes for the elderly. The effects of plants on the physical indoor climate were measured with sensors, and the effects on the employees concerning health and well-being were measured with questionnaires. At the companies, significant effects were found on relative humidity (up), attractiveness of the workplace (more attractive), state of mind (more positive), satisfaction with own functioning (higher) and sickness absence reporting (less). The need for recovery after a working day showed a reversed effect (rising).

Although the Netherlands is a very small country it is big when it comes to green. The Dutch sector associations VHG (horticulturists and interior landscapers) and VGB (trade in plants and flowers) promoted that plants are so much more than just pretty. The conclusive insights were published on the online platform Into Green; see Fig. 4.

Financial Benefits of Green Building

Kat (2003) investigated the financial and cost performance of green building projects, revealing that the premiums for green buildings in the USA were below 2% and that energy consumption was on average 28% less than conventional buildings (Wootton-Beard 2018). However, more upfront cost is usually needed for green sustainable office buildings than non-green buildings (Davis Langdon 2007). In addition, Newsham et al. (2009) surveyed 100 institutional and commercial buildings with LEED certification, and indicated that 28–35% of these buildings had higher energy consumption than non-green buildings, despite an average energy saving of 18–39% per floor area. As for the residential developers, Deng and Wu (2014) indicated that the Singaporean developers paid for nearly all the extra expenses for higher energy efficiency occurring in the construction process but cannot receive significant financial benefits from the development of green residential buildings. However, Zhang et al. (2011) argued that green strategies can offer developers competitive advantages, and Eichholtz et al. (2010) revealed that investment

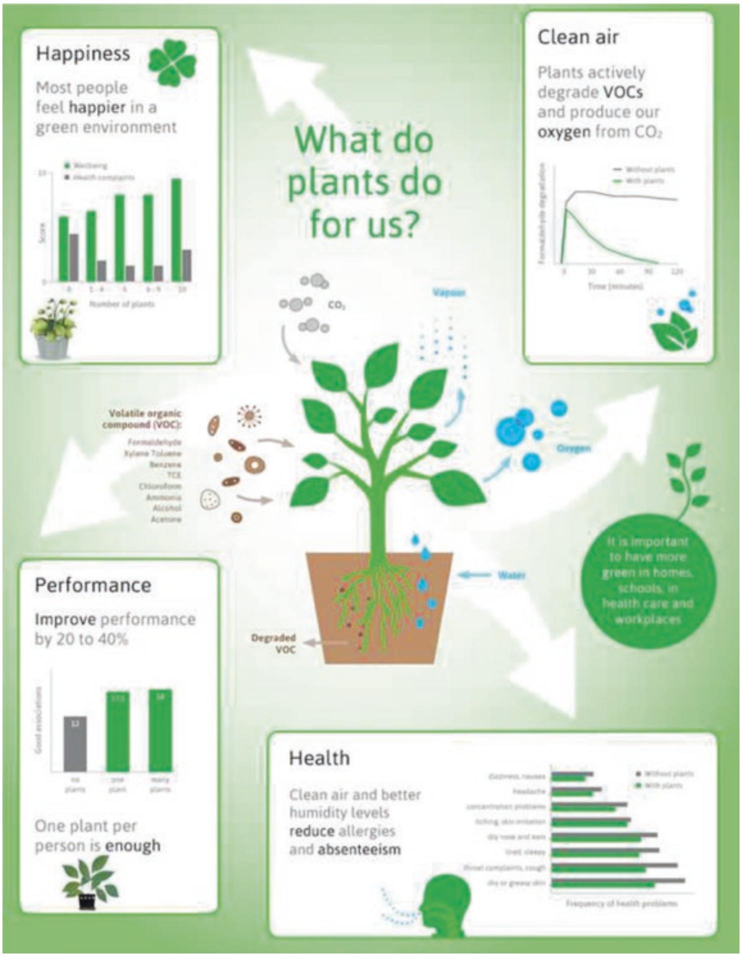

Fig. 4 The benefits of plants for occupants (IntoGreen 2019)

in green building could provide developers with economic benefits. Organizations revolve around returns and profit, and in most organizations this is generated by the employees (Wootton-Beard 2018). The potential of greenery for buildings to influence the level of sick leave and to affect productivity positively has been scientifically proven for decades (Wootton-Beard 2018). Potential effect of designs on revenues is not easy to calculate and 'prove', but the financial payback is much shorter than for example energy for energy reduction. For example: measures that improve productivity of office employees typically create 25 times more gain than measures that save energy costs! While numerous studies have been conducted on its potential benefits and its environmental impacts, there has been little focus on its life cycle cost (LCC) which is a crucial factor for building owners to adopt greenery such as a VGS as well as to compare among various types of system (Huang et al. 2019). To fill this gap, the study by Huang et al. (2019) aims to identify and calculate the LCC of main types of VGS available in Singapore. The cost incurred during each life cycle stage including initialization, installation, operation and demolition, is recorded based on eight completed and ongoing cases selected in Singapore. The framework provides a systematic perspective for building stakeholders to understand the life cycle costing of VGS by including the calculative processes, cost components and earnings from greenery benefits (Huang et al. 2019).

Water Efficiency

Mentens et al. (2006) found that the annual rainfall-runoff relationships for green roofs were significantly influenced by the depth of the surface layer, and indicated that the use of green roofs can significantly reduce the rainfall-runoff for a region and individual buildings. Berndtsson (2010) discussed various factors influencing runoff dynamics from green roofs and the influence of a green roof on runoff water quality. Green walls, installed on the side of the buildings, mainly for their aesthetics and microclimate benefits, could become effective on-site grey water treatment solutions (Fowdar et al. 2017; Prodanovic et al. 2019). A first step in the development of grey water-treating green walls is to examine how variation in plant spaces and operational conditions (hydraulic loading rate, inflow concentrations and intermittent drying) influences nutrient removal from light grey water. Prodanovic et al. (2019) conducted an experiment over 12 months on a large-scale pilot green wall located in a laboratory. They showed that ornamental plant species can play an important role in nitrogen and phosphorus uptake from grey water (Prodanovic et al. 2019). However, more research is needed to convert these nature-based systems into truly robust and effective low-cost water purification technologies.

Summary of the Benefits of Greenery

To summarize the benefits of greenery Xing et al. (2017) describe an integrated characterization framework (to aid the mainstreaming of urban green planning, design and retrofit). To make greening design decisions in relation to the importance of greenery in sustainable buildings (plants, substrate/supporting elements, irrigation and maintenance) is complex. He identifies ten categories of potential benefits (Fig. 5, left) and four key design decisions (Fig. 5, right).

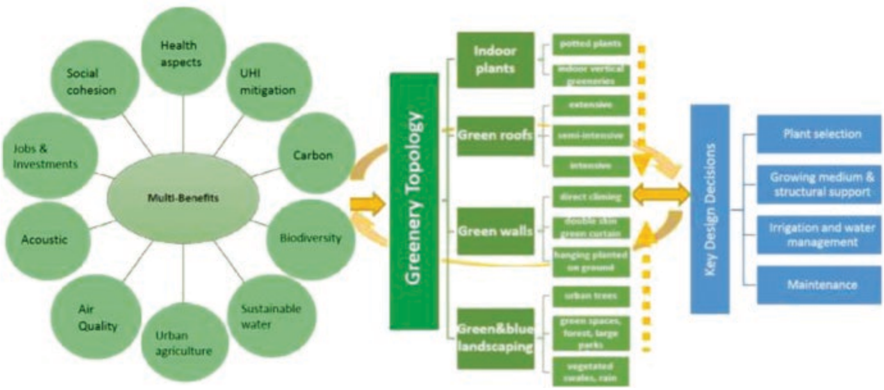

Fig. 5 A generic characterization framework for the multi-benefits of greenery and the related key design decisions (after Xing and Bosch 2017)

Examples of Greenery in Sustainable Buildings in the Netherlands

Green House Technology

The Netherlands is a small, densely populated country, lacking almost every resource necessary for large-scale agriculture. Despite this, the small country of the Netherlands is the world's number two exporter of food, second only to the USA, which is incomparable in size! It is this lack of resources and not-so-optimal climate conditions that has let the Dutch greenhouse industry grow into what it has become today. They took control over the climate by growing in a protected environment and by applying smart technology and improved yields significantly on the same growing area (Raus 2018). By using the world's most efficient agricultural technologies, the Netherlands is able to do far more with less. This important aspect of the Dutch culture was also transferred to the built environment where greenhouse technology was applied.

Lumen: Wageningen—1998

One of the Dutch pioneer buildings was the Alterra building, now called Lumen, in Wageningen, designed by Behnisch and Behnisch (Behnisch 2019) in 1993 and finished in 1998; see Fig. 6. The design brief was for a functional, user-friendly research facility working in harmony with nature, versatile and ecologically sound. Its design is centred around the building's users and surroundings. The building facilitates researchers at the Agricultural University in Wageningen in a centralized, collaborative work environment. The institute's scientists are engaged in work on

Fig. 6 Lumen—Wageningen (Behnisch 2019)

forestry, urban landscapes, soil microbiomes, biodiversity and climate adaptation through the world. Lumen is characterized by light, natural materials, greenery and water, on the inside as well as on the outside. The building was designed not to dominate its rural setting, but to embrace the landscape, with all workplaces in direct contact with indoor and outdoor gardens. Two indoor gardens provide the focus for daily activities and function as informal meeting areas. Beyond this, they are an integral component of the building's energy concept, improving the performance of the external envelope. The office building has two gardens (2000 m^2) inside the building. The gardens help with the building's climate control and create a better environment to the people working in this building. All the rooms are connected to the garden for optimal benefits.

The regional landscape structure of 'polders'—small rectangular fields divided by wind breaks and canals—served as an organizing principle for the building's form. On either side of the building, the gardens reflect distinct native Dutch landscape forms, while between the office wings of the building the gardens are roofed, and the more temperate microclimate allows for subtropical species, external circulation, outdoor meetings and chance encounters between colleagues. The lab wing to the north is the only portion of the 12,000 m^2 building with mechanical cooling, while the water features and vegetation within the greenhouses (designed in collaboration with the artist Michael Singer) play a key role in the environmental control.

Villa Flora: Venlo—2011

One other interesting example is the Villa Flora by Kristinsson (2011) that was built in Venlo in 2011. It is a combination of a greenhouse and an office building, designed to reach for the sustainable synergy between both building elements and building service systems. In 2009 it became part of the Dutch Government UKP NESK programme to stimulate innovation for energy-neutral buildings. UKP means unique chance projects and NESK means 'towards energy-neutral schools and offices' (Naar Energieneutrale Scholen en Kantoren). This programme of the Dutch Government gave in 2010 funding to projects which show exceptional innovation in the area of energy conservation, sustainability or organization within the building industry. Characteristics of the Villa Flora project are very-low-temperature heating at 25 °C, very-high-temperature cooling at 15 °C and seasonal storage of heat and cold in the groundwater. By the sloping roof and many glasses the transparent building looks very much like a greenhouse; see Fig. 7. There is, therefore, the use of smart energy-saving applications from the greenhouse horticulture and an optimal use of solar energy.

The concrete skeleton of the building is demon table, flexible and reusable. That makes a fast construction time as possible and also provides for a simple integration of all to apply techniques. The building can therefore keep pace with the development in the field of sustainability.

The seasonal surplus of heat and cold from the solar power system is stored in the aquifer approximately 50 m beneath the building. The building is equipped with a heating system based on very low temperatures (24–25 °C), enabled by fine-wire heat exchangers recently invented. The cooling of the indoor climate in summer is based mainly on the same system.

The vacuum sewer system and organic waste collection are aspects of ecological innovation. By means of an anaerobic bioreactor and a micro-turbine, electricity can be produced on location with addition of organic waste. The filtered exhaust gases are used as nutrients up till 1000 ppm, in order to take care of the CO2 balance. Pure water can be retained within this process, which takes 2 or 3 days.

Hogeschool Dronten: Dronten—2012

Hogeschool Dronten is a college focusing on education, research and application of agricultural knowledge. Its new premises are encased in a glass structure with a height of just over 16 m: the tallest glass casing in Europe; see Fig. 8. Definitely

Fig. 7 Villa Flora—Venlo—Netherlands (Kristinsson)

worthy of the name 'BrightBox'! Hogeschool Dronten wanted its college building to have a unique look befitting its agricultural character. And it was to incorporate a smart, open area suitable for large events, to compensate for the lack of such a venue in the city centre of Dronten. It was decided not to make use of traditional curtain walls and roof systems for the new build of this large-scale daylight structure. Instead, an entirely new daylight solution was introduced for utility facilities inspired by greenhouses which design concept offers Hogeschool Dronten many advantages:

– Great appeal—the building's look and the possibility of organizing events in the large meeting area are very attractive for students.
– Lower exploitation costs—the new building implies a saving of more than a 100,000 euros a year in energy costs for the Hogeschool relative to its last premises.
– Greater welfare—the pleasant indoor climate and large amount of daylight make the employees and students feel fitter and more energetic and alert.

The solution was realized in a short space of time and for the same budget as a traditional college building. The enormous glass structure is a highly distinctive

Fig. 8 CAH in Dronten, the Netherlands (BDG Architecten Zwolle)

eye-catcher in the world of education. Many people still visit Hogeschool Dronten to find out precisely how the architecture and the technology behind it work.

The entire building for advanced education is placed within a high glasshouse, which refers to the kind of education. This has great advantages on the field of energy consumption and exploitation and results in extra space for a more informal way of education. The two buildings for education are placed in the glasshouse and are connected to each other on the ground floor. Two big stairs on each side of the building lead you to the inner plaza on the first floor. The classrooms, auditoria and offices are placed in the two buildings; the stairs and the plaza are meant as places where student and teacher can meet and discuss with each other. The space between the buildings and the glasshouse functions like an air duct, which is regulated by a smart climate system. By using proved technologies from the greenhouse sector, like the solar blinds and the printed glass panels, the need for active cooling in the summer is limited. The rainwater is collected and being reused for the toilets and cleaning of the building.

Green Walls

SportPlaza Mercator: Amsterdam—2006

Sustainable architecture has to do with optimizing the quality of life, energy efficiency and use of materials in the design. The cultural context and the direct surroundings of the building play an important part in this, because a significant part of the quality of life and the life expectancy is determined by the relationship between a building and its environment. It is also possible to achieve gains in terms of energy and materials in relation to the larger network environment (Venhoeven 2012). An integrated approach reveals that a building is not a static, isolated object, but interacts with its environment as if it is a living organism. Designers draw inspiration from the natural world and use this to improve technology in all areas. This biomimicry offers the foundation for a new type of functionalism. Eco-functionalism, the new style that is emerging right now all over the world, connects a diversity of functions and use, decentralized intelligence energy generation, exchange of waste flows and maximization of use options with optimizing relationships with the environment; see Fig. 9. This approach makes it possible to combine affordable, low-tech measures with the advantages of profitable advanced technology. The search for smart opportunities to coordinate production and use of multiple buildings, building sections or building clusters, not only functionally and energetically, but also socially, economically and ecologically, is the foundation for this new eco--functionalism. This leisure centre SportPlaza Mercator in Amsterdam by Dutch architects VenhoevenCS (Venhoeven 2009) was designed as a fortress covered in plants. SportPlaza Mercator is positioned at the entrance to a park. The architects

Fig. 9 SportPlaza Mercator, Amsterdam (photography by Luuk Kramer)

wanted it to fit in with its surroundings, so they added a camouflaging facade of bushy plants and flowers. Windows nestle in among the planted exterior but feature tinted glass to reduce visibility into the swimming-pool halls. Skylights were also added to bring in more natural light (Frearson 2013). From a distance, it seems like an overgrown fortress flanking and protecting the entryway to the nineteenth-century city. The building was designed as a city—a society in miniature—inside a cave. The building is full of lines of sight and keyholes that offer perspectives on the various visitors, activities and cultures in the building. Sunlight penetrates deep into the building's interior through all sorts of openings in the roof. Low windows frame the view of the street and the sun terrace (Frearson 2013).

City Hall: Venlo—2017

The City Hall of Venlo was designed by Kraaijvanger (2019) on the basis of cradle-to-cradle (C2C) principles (C2C center 2019); see Figs. 10, 11 and 12. With 630 flexible workplaces and public functions, the building embodies the ambition to have the entire city and region function. Well-being of the occupants was the starting point: a good building makes people happier and boosts productivity. The spatial design is based on three goals:

- To bring as much daylight and greenery into the interior as possible
- To create routes through the building that stimulate people to move around
- Encounter others, and to use only healthy materials

Around a patio with a helophyte filter for water purification, people can enjoy the greenery, the water and the views. The building refers to the agricultural tradition of this city and its top floor features a greenhouse with seasonal workplaces and room to grow regional products that also heats and humidifies the air that enters the

Fig. 10 City Hall—Venlo (Kraaijvanger 2019)

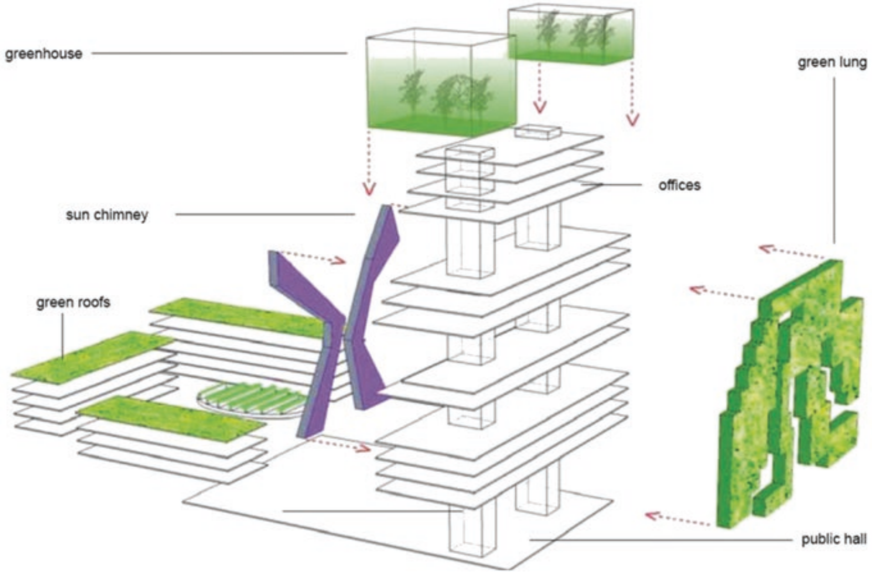

Fig. 11 Climate concept, City Hall, Venlo (Kraaijvanger 2019)

building. The green air-purifying facade is the largest green building facade in the world and forms a protective shell against traffic and railway pollution. The air in Venlo's new city hall is purer than the air outside and purifies air in a 500 m radius around the building. Cradle-to-cradle principles and holistic thinking should be in action in a city's buildings.

Green Roofs

Library Technical University of Delft: Delft—1997

Technical University of Delft originally designed their library with its intensive green roof from 1993 to 1995, resulting in construction from 1996 to 1997; see Fig. 13. Although nearly 15 years old, the visionary TU Delft Library is still an excellent example of forward-thinking sustainable design. The 15,000 m^2 library contains extensive underground book archives, reading rooms, university publisher, offices, study spaces and a book binder and book shop. It won the National Steel Award 1998 and Corus Construction Award 2000. Mecanoo Architecten's (Mecanoo 2019) vision was to develop a light-filled landmark that would serve as 'a gateway to the digital highway'. The library is designed as a sloped plane, extending the grass from the ground to the very edge of the roof allowing people to walk to the top. What they achieved is a public place that not only is a core for information, but

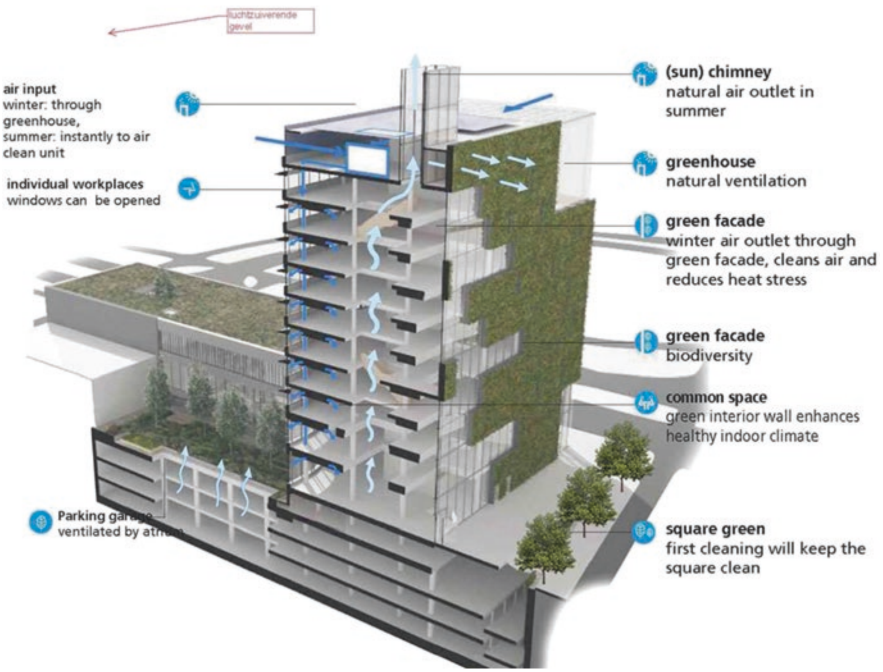

Fig. 12 Greenery aspects, City Hall, Venlo (Kraaijvanger 2019)

also features a prodigious public green roof for people to explore, relax and play (Mecanoo 2015). Enjoyed throughout the year, the green roof is converted into a sledding hill in the winter for further recreation. Visitors can catch some sun on the inclined lawn during the warmer months, and when it snows the roof makes for the best sledding in town—after all, where else are you going to find a hill in the Netherlands? The green roof also provides the interior with a much-reduced need for cooling and helps the Delft University of Technology campus control storm water runoff (Michler 2011). With a renovation in 2009, the green roof has continued to benefit the university, continuing to meet expectations more than two decades after its opening. The roof is supported by slender, splayed steel columns in a huge hall enclosed with canted, fully glazed walls. The base of the slope to the west is marked by a broad flight of steps leading up to a recessed entrance. The library is topped by a huge steel cone which houses four levels of traditional study spaces connected by a helical stair. Within the cone, a central void provides daylight from a glazed roof to the internal reading spaces. Extending 40 m above grade and floodlit at night, the cone acts as a beacon on the campus day and night.

Fig. 13 The library is a building that does not really want to be a building, but a landscape (Mecanoo 2019)

Urban Rooftop Farms Dakakker: Rotterdam—2017

In Rotterdam, an architecture collective ZUS has reclaimed an old building in the centre of the city and built an urban farm on top of the roof; see Fig. 14. The Dakakker is a 1000 m^2 rooftop farm on top of the Schieblock in Rotterdam in the Netherlands (Dakakker 2019). The Dakakker is the largest open-air roof farm in the Netherlands and one of the largest in Europe. The Smartroof is located on the roof of the rooftop pavilion. It is a test site for smart water storage and management as it has a smart flow control that is driven by the weather forecast. When predicting extreme rainfall, the smart flow control responds by making extra water storage capacity available 24 h in advance. The rooftop system is made up of different layers: a protective absorption layer (not roof resistant), a drainage buffer layer and a filter layer with the rooftop vegetable garden substrate on top. The conditions on the Dakakker are comparable to a Mediterranean climate: dry rocky soil and a lot of wind sometimes quite warm. That is why herbs such as mint, lemon verbena and lavender are grown on the Dakakker, as well as vegetables such as Jerusalem artichoke, beetroot, carrot, radish and garlic varieties such as onion, leek, garlic and strong plants such as raspberry, rhubarb and pumpkin. The edible flowers of the roof are the top product and are delivered to six restaurants in the immediate vicinity of the rooftop farm.

Fig. 14 Dakakker—Rotterdam (Dakakker 2019)

Based on the gained experience, with a total potential of 18.5 km^2 of flat rooftops in Rotterdam, the city has set a target of putting 1 km^2 of that space to good use by 2030, by greening it with plants and trees, adding solar panels and utilizing it for recreation or even homes.

Hotel Roof Garden: Zoku, Amsterdam—2016

The existing 'Metropoolgebouw' is a new hotel that was built in 2016: Zoku, Amsterdam. It provides a home base for travelling professionals who are living and working in a city for periods from a few days to a few months; see Fig. 15. Zoku created a new category in the hotel industry: a re-invented apartment hotel, a home--office hybrid, which is a relaxed place to live, work and socialize with like-minded people while getting wired into the city (Zoku 2019). With a beautiful green-roof garden, it has an outdoor area on both sides of the hexagon-shaped greenhouse on the roof. 'Hexagons' are the theme of the hotel and this was implemented in the design of the roof park as well.

Roof Park Vierhavenstrip: Rotterdam—2011

On the roof of the shopping centre, an area of 1 km by 80 m and with a soil depth of 1.5 m has been used to create good growing conditions for trees and other plants; see Fig. 16. Steel mesh was implemented as an extra anchoring for the trees. The majority of the trees planted are multi-stems, including a number of monumental specimens. A varied range of trees was chosen, to ensure striking colours in every season. The eastern edge of the park is characterized by a high-rise urban design, with tall trees and hedges acting as structural elements. The western edge is oriented towards the district and has a very green character with themed gardens at the main entrances. Large trees, lawns, a playground, a community garden and a Mediterranean

Fig. 15 Hotel Roof Garden, Zoku, Amsterdam (De Dakdokters 2019)

garden with an orangery offer local residents a great place to relax and meet, and of course to enjoy a spectacular view of the city and the harbour. The main paths are bordered by water and there is a 70 m-by-7 m step waterfall on the roof. The Vierhavensstrip rooftop park connects living, shopping, working, study, culture and recreation in a unique way. The roof park has a drainage system with a perforated core for podium decks on an inverted roof. The drainage system prevents the build-up of hydrostatic pressure on the waterproofing membrane. The vapour-permeable filter geotextile glued (not thermally bonded) to the dimpled core on the back protects the XPS insulation from mechanical loads and ensures that vapour is able to evaporate freely (Nophadrain 2019).

Discussion and Conclusion

Nature-inspired architecture and modern plant breeding both seek to increase tolerance to climate extremes and try to make the built environment more resilient and also allow efficient use of energy, materials, water and light (Wootton-Beard 2018). Besides green roofs and green walls, plant factories with artificial lighting (PFAL), also known as indoor plant production systems, are expected to play a vital role in greenery within urban development (Kozai et al. 2016). Urban agriculture and vertical farming will grow enormously in the forthcoming decades as it has a tremendous potential. Therefor PFAL is attracting much interest among researchers,

Fig. 16 Roof park Vierhavenstrip—Rotterdam

community developers, architects, designers and entrepreneurs. In the next few decades, urban agriculture and vertical farming will not be just a modified form of existing agriculture and farming practices. It will provide entirely new social services in urban areas which are facing ecological, economic and social constraints.

The relationships between indoor building conditions (thermal aspects, ventilation, lighting, moisture and noise) and well-being (health and comfort) of occupants of office buildings, schools and homes are complex (Bluyssen 2019). Therefore it is also difficult to determine the positive effects of greenery in sustainable buildings as effects occur often in settings with a lot of changing circumstance. Nevertheless there is an overwhelming number of research outcomes that show that greenery has a positive effect within buildings as well as on city scale.

This chapter reviews the importance of greenery in sustainable buildings and their effect on the indoor and outside environmental quality (IEQ), based on scientific studies from the past 30 years. Indoor greenery can be used to reduce sound levels as a passive acoustic insulation system. Living wall systems in combination with biofiltration are emerging technologies to provide beneficial effects on the improvement of indoor comfort. Quite a number of studies have shown that biophilic workspaces and interaction with plants may change human behaviours and improve productivity and the overall well-being. Evapotranspiration from plants helps lowering the temperature around the planting environment and this can be utilized for air cooling and humidification on city scale as well. In addition to literature overview several recent applications of greenery in projects in the Netherlands are presented to illustrate the architectural added value as well.

References

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy, 70*, 295–310.

Akbari, H., Damon Matthews, H., & Seto, D. (2012). The long-term effect of increasing albedo of urban areas. *Environmental Research Letters, 7*(2), 024004.

Armijos Moya, T., van den Dobbelsteen, A., Ottelé, M., & Bluyssen, P. M. (2017). Green Air Conditioning, using indoor living wall systems as a climate control method. *REHVA Journal, 2017*, 27–31.

Armijos Moya, T., van den Dobbelsteen, A., Ottelé, M., & Bluyssen, P. M. (2018). A review of green systems within the indoor environment. *Indoor and Built Environment, 28*(3), 298–309.

Armson, D., Stringer, P., & Ennos, A. R. (2012). The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban Forestry & Urban Greening, 11*, 245–255.

Arup. (2015). Cities Alive. Retrieved from http://www.arup.com/Homepage_Cities_Alive.aspxJournal.

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Bures, S., Álvaro, J. E., Erkoreka, A., & Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. *Applied Acoustics, 89*, 46–56.

Behnisch. (2019). Retrieved from https://behnisch.com/work/projects/0022, https://behnisch.com/content/2-work/1-projects/0-0022/022-e-ibn-wageningen.pdf.

Berndtsson, J. C. (2010). Roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering, 36*, 351–360.

Bhamra, T. (2019). *Back to the future … of design for sustainability, Proceedings ICED 19*. Netherlands: Delft.

Bluyssen, P. M. (2019). *The need for understanding the indoor environmental factors and its effects on occupants through an integrated analysis, 10th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings (IAQVEC 2019), 5–7 September*. Italy: Bari.

C2C Center. (2019). Retrieved from http://www.c2ccentre.com/sites/default/files/Case%20Study%20City%20Hall%20Venlo_Final.pdf.

Chen Q., Li B., Liu X. (2013). An experimental evaluation of the Living Wall system in hot and humid climate, Energy and Buildings *61*, 298–307.

Dakakker. (2019). https://dakakker.nl/site/?lang=en.

Davis Langdon. (2007). *The cost & benefit of achieving green building*. Sydney, NSW: Davis Langdon.

De Dakdokters. (2019). Retrieved from https://dakdokters.nl/portfolio-items/zoku/.

de Vries, S., Verheij, R. A., Groenewegen, P. P., & Spreeuwenberg, P. (2003). Natural environments—Healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A: Economy and Space, 35*(10), 1717–1731.

Deng, Y., & Wu, J. (2014). Economic returns to residential green building investment: The developers' perspective. *Regional Science and Urban Economics, 47*, 35–44.

Eichholtz, P., Kok, N., & Quigley, J. M. (2010). Doing well by doing good? Green office buildings. *American Economic Review, 100*, 2492–2509.
Eppinger, S., & Maier, A. (2019). *Responsible design: Recognising the impact of how we design, Proceedings ICED 19*. Netherlands: Delft.
Fang, W., Xiaosong, Z., Junjie, T., & Xiuwei, L. (2011). The thermal performance of double skin façade with Tillandsia usneoides plant curtain. *Energy and Buildings, 43*, 2127–2133.
Fowdar, H. S., Hatt, B. E., Breen, P., Cook, P. L. M., & Deletic, A. (2017). Designing living walls for greywater treatment. *Water Research, 110*, 218–232.
Frearson A. (2013). *SportPlaza Mercator by VenhoevenCS*. Retrieved from https://www.dezeen.com/2013/03/13/sportplaza-mercator-by-venhoevencs/.
Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment, 33*, 115–133.
Gunawardena, K. R., & Steemers, K. (2019a). Living wall influence on microclimates: An indoor case study. *Journal of Physics: Conference Series, 1343*, 012188.
Gunawardena, K. R., & Steemers, K. (2019b). Living walls in indoor environments. *Building and Environment, 48*, 478–487.
Gupta, R., & Gregg, M. (2012). Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment, 55*, 20–42.
Hartig, T., Evans, G. W., Jamner, L. D., Davies, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology, 23*, 109–123.
Hermans, T., de Vries, S., Jeurissen, L., Kraan, J., Oppedijk, B., & van Duijn, B. (2019). *Planten vooreen prima binnenklimaat: Industriële spoor*. Wageningen, Netherlands: Regional Development and Spatial Use, WASS, Wageningen Environmental Research rapport No. 2952. Retrieved from https://library.wur.nl/WebQuery/wurpubs/551856.
Hiemstra, J. A., de Vries, S., & Spijker, J. H. (2019). *Greenery and Work: The positive effects of greenery in urban environments*. Wageningen, Netherlands.: WASS Nature and Society Wageningen University & Research. Retrieved from https://edepot.wur.nl/418847.
Huang, Z., Lu, Y., Wong, N. H., & Poh, C. H. (2019). The true cost of "greening" a building: Life cycle cost analysis of vertical greenery systems (VGS) in tropical climate. *Journal of Cleaner Production, 228*, 437–454.
IntoGreen. (2019). *Air quality in classrooms drastically improves with plants*. Retrieved from https://intogreen.eu/air-quality-in-classrooms-drastically-improves-with-plants/.
Irvine, K. N., Devine-Wright, P., Payne, S. R., Fuller, R. A., Painter, B., & Gaston, K. J. (2009). Green space, soundscape and urban sustainability: An interdisciplinary, empirical study. *Local Environment, 14*(2), 155–172.
Kapoor, M. (2017). Managing ambient air quality using ornamental plants-an alternative approach. *Universal Journal of Plant Science, 5*, 1–9.
Kat, G. H. (2003). *Green building costs and financial benefits*. Westborough, MA: Massachusetts Technology Collaborative.
Kozai, T., Niu, G., & Takagaki, M. (Eds.). (2016). *Plant factory, an indoor vertical farming system for efficient quality food production*. Amsterdam: Elsevier.
Kraaijvanger. (2019). Retrieved from https://www.kraaijvanger.nl/en/projects/city-hall-venlo/.
Kristinsson, J. (2011). Retrieved from http://www.kristinsson.nl/.
Kuo, F. E., Sullivan, W. C., & Coley, R. L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. *American Journal of Community Psychology, 26*, 823.
Larsen, S. F., Filippin, C., & Lesino, G. (2013). Thermal simulation of a double skin façade with plants, Proceedings ISES Solar World Congress. *Energy Procedia, 57*, 1763–1772.
Leaman, A., & Bordass, B. (2007). Are users more tolerant of 'green' buildings? *Building Research and Information, 35*, 662–673.
Levenston M. (2019). *Vertically integrated greenhouse, city farmer news*. Retrieved from https://cityfarmer.info/vertically-integrated-greenhouse/.

Malone, D. (2017). *A sustainable mixed-use development springs from a Dutch city center like a green-fringed crystal formation*. Retrieved from https://www.bdcnetwork.com/sustainable-mixed-use-development-springs-dutch-city-center-green-fringed-crystal-formation.

Mangone, G. (2015). *Performative microforests*. PhD Thesis TU Delft: Delft, Netherlands.

Mangone, G., & van der Linden, K. (2014). Forest microclimates: Investigating the performance potential of vegetation at the building space scale. *Building and Environment, 73*, 12–23.

Mangone, G., Kurvers, S. R., & Luscuere, P. G. (2014). Constructing thermal comfort: Investigating the effect of vegetation on indoor thermal comfort through a four season thermal comfort quasi-experiment. *Building and Environment, 81*, 10–426.

McDonald, A. G., Bealey, W. J., Fowler, D., Dragosits, U., Skiba, U., Smith, R. I., Donovan, R. G., Brett, H. E., Hewitt, C. N., & Nemitz, E. (2007). Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations. *Atmospheric Environment, 41*(38), 8455–8467.

Mecanoo. (2015). *Delft University of Technology among greenest in the world*. Retrieved from https://www.mecanoo.nl/News/ID/180/Delft-University-of-Technology-among-greenest-in-the-world.

Mecanoo. (2019). *Library Delft University of Technology*. Retrieved from https://www.mecanoo.nl/Projects/project/27/Library-Delft-University-of-Technology?t=0.

Mentens, J., Raes, D., & Hermy, M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape and Urban Planning, 77*, 217–226.

Michler, A. (2011). *Mecanoo's TU Delft Library Crowned with a Massive Green Roof, Inhabit*. Retrieved from https://inhabitat.com/mecanoos-tu-delft-library-crowned-with-a-massive-green-roof/.

MVDRV. (2019). *EXPO 2000*. Retrieved from http://www.mvrdv.nl/projects/EXPO/#.

Naava. (2019). *Not a normal green wall*. Retrieved from https://www.naava.io/.

Newsham, G. R., Mancini, S., & Birt, B. J. (2009). Do LEED-certified buildings save energy? Yes, but …. *Energy and Buildings, 41*, 897–905.

Ng, E., Chen, L., Wang, Y., & Yuan, C. (2012). A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. *Building and Environment, 47*, 256–271.

Nophadrain. (2019). Retrieved from https://www.nophadrain.com/inspiration-projects/vierhavenstrip-roof-park/.

Ottelé, M., Perini, K., Fraaij, A., Haas, E., & Raiteri, R. (2011). Comparative life cycle analysis for green façades and living wall systems. *Energy and Buildings, 43*, 3419–3429.

Paul, W. L., & Taylor, P. A. (2008). A comparison of occupant comfort and satisfaction between a green building and a conventional building. *Building and Environment, 43*, 1858–1870.

Perez, G., Rincon, L., Vila, A., Gonzalez, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. *Applied Energy, 88*, 4854–4859.

Pérez, l. G., Coma, J., Barreneche, C., de, G. A., Urrestarazu, M., Burés, S., & Cabeza, L. F. (2016). Acoustic insulation capacity of vertical greenery systems for buildings. *Applied Acoustics, 110*, 218–226.

Perini, K., & Rosasco, P. (2013). Cost–benefit analysis for green façades and living wall systems. *Building and Environment, 70*, 110–121.

Perini, K., Ottelé, M., Fraaij, A., Haas, E., & Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment, 46*, 2287–2294.

Prodanovic, V., McCarthy, D., Hatt, B., & Deletic, A. (2019). Designing green walls for greywater treatment: The role of plants and operational factors on nutrient removal. *Ecological Engineering, 130*, 184–195.

Raus, T. (2018). *How on earth have the Dutch done it?* Retrieved from https://dutchgreenhouses.com/blog/how-on-earth-have-the-dutch-done-it.

Romeo, C., & Zinzi, M. (2013). Impact of a cool roof application on the energy and comfort performance in an existing non-residential building. A Sicilian case study. *Energy and Buildings, 67*, 647–657.

Sailor, D. J. (2008). A green roof model for building energy simulation programs. *Energy and Buildings, 40*, 1466–1478.
Santamouris, M. (2014). Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy, 103*, 682–703.
Santamouris, M., Pavlou, C., Doukas, P., Mihalakakou, G., Synnefa, A., Hatzibiros, A., & Patargias, P. (2007). Investigating and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. *Energy, 32*, 1781–1788.
Smith, A. (2015). Garden city. *CIBSE Journal, 2015*, 46–50.
Stec, W. J., & van Passen, A. H. C. (2005). Symbiosis of the double skin façade with the HVAC system. *Energy and Buildings, 37*, 461–469.
Stec, W. J., van Passen, A. H. C., & Maziarz, A. (2005). Modelling the double skin facade with plants. *Energy and Buildings, 37*, 419–427.
Takano, T., Nakamura, K., & Watanabe, M. (2002). Urban residential environments and senior citizens' longevity in megacity areas: The importance of walkable green spaces. *Journal of Epidemiology & Community Health, 56*, 913–918.
Takebayashi, H., & Moriyama, M. (2007). Surface heat budget on green roof and high reflection roof for mitigation of urban heat Island. *Building and Environment, 42*, 2971–2979.
Torpy, F. R., Zavattaro, M., & Irga, P. J. (2016). Green wall technology for the phytoremediation of indoor air: A system for the reduction of high CO2 concentrations. *Air Quality, Atmosphere and Health, 5*, 151–167.
Ulrich, R. S. (1983). Aesthetic and affective responses to natural environment in: I. Altman, J.F. Wohlwill (Eds.), Behavior and the natural environment, human behavior and environment. *Advances in Theory and Research, 6*, 85–125.
Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*, 201–230.
van Duijn, B., Klein Hesselink, J., Kester, M., Jansen, J., & Splitters, H. (2011). *Rapport Project Plant in de klas*. Productschap Tuinbouw: Projectnummer 13908.
Velzeboer, I., Blom, M. J., & Duyzer, J. H. (2019). *Effects of plants on air quality, TNO report R10896*. Netherlands: Petten.
Venhoeven, T. (2009). *The wonderful world of venhoeven*. CS: Episode Publishers.
Venhoeven, T. (2012). Retrieved from https://venhoevencs.nl/vision-and-research/sustainable-architecture/?project=357.
Wolverton, B. C. (2008). *How to grow fresh air: 50 house plants that purify your home or office*. London: Weidenfeld & Nicolson.
Wolverton, B. C. (2010). *Plants: Why you can't live without them*. New Delhi: Roli Books.
Wolverton, B. C., Mcdonald, R. C., & Watkins, E. A. (1984). Foliage plants for removing indoor air-pollutants from energy efficient homes. *Economic Botany, 38*, 224–228.
Wolverton, B. C., Johnson, A., & Bounds, K. (1989). *Interior landscape plants for indoor air pollution abatement. Final report NASA (NASA-TM-101766, NAS 1.15:101766)* (pp. 1–22). Mississippi: National Aeronautics and Space Administration.
Wong, N. H., Chen, Y., Ong, C. L., & Sia, A. (2003). Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment, 38*, 261–270.
Wong, N. H., Tan, A. Y. K., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., Chiang, K., & Wong, N. C. (2010). Thermal evaluation of vertical greenery systems for building walls. *Building and Environment, 45*, 663–672.
Wootton-Beard, P. C. (2018). *Building greening for urban wellbeing, What to think about when specifying on-building green infrastructure, Presentation ASBP Healthy Buildings Conference & Expo*. London, UK: UCL Roberts Building, Torrington Place. Retrieved February 14, 2018, from https://asbp.org.uk/wp-content/uploads/2018/04/Peter-Wootton-Beard-Aberystwyth-University-HealthyBuildings18.pdf.

Xing, Y., & Bosch, M. (2017). Exploring design principles of biological and living building envelopes: What can we learn from plant cell walls? *Intelligent Building International, 10*(2), 78–102.

Xing, Y., Jones, P., & Donnison, I. (2017). Characterization of nature based solutions for the built environment. *Sustainability, 9*(1), 149.

Yang, K. (1972). Bases for ecosystem design. *Architectural Design, 1972*, 434–436.

Yang, K. (1999). *The green skyscraper: The basis for designing sustainable intensive buildings*. Munich: Prestel Publishing.

Young, L. (2014). Into the blue. *CIBSE Journal, 4*(6), 24–27.

Zhang, X., Shen, L., & Wu, Y. (2011). Green strategy for gaining competitive advantage in housing development: A China study. *Journal of Cleaner Production, 19*, 157–167.

Zhao, X., Zuo, J., Wu, G., & Huang, C. (2019). A bibliometric review of green building research 2000–2016. *Architectural Science Review, 62*(1), 74–88.

Zoellner, T. (2013). *Sexy fish and rocking berries, presentation international strawberry congress, Antwerp*. Retrieved from http://hoogstraten.eu/presentations/thursday/9_TomZollner_UrbanFarmers_Stra wberryAntwerpEnTZ.pdf.

ZOKU. (2019). Retrieved from https://livezoku.com/.