The Relationship between Environmentally Sustainable Design Elements and Healthy Design Elements in Office Buildings

van Spronsen, Wiebe B.

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Graduation research: The Relationship between *Environmentally Sustainable* Design Elements and *Healthy* Design Elements in Office Buildings

Colophon

The Relationship between *Environmentally Sustainable* Design Elements and *Healthy* Design Elements in Office Buildings

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STUDENT
Name: Willem Bert van Spronsen
Student ID: 1377825
Contact: w.b.v.spronsen@student.tue.nl

GRADUATION COMMITTEE

Chairman/First supervisor
Dr.ir. H.A.J.A. (Rianne) Appel-Meulenbroek
Real Estate Management and Development
Eindhoven University of Technology

Second supervisor
Dr.ir. A.G.M. (Lisanne) Bergefurt
Real Estate Management and Development
Eindhoven University of Technology

Third supervisor
Dr. V. (Valeria) Caiati
Urban Planning and Transportation
Eindhoven University of Technology

DATE
19 December 2024

This graduation thesis is publicly available.
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Acknowledgement

This master thesis completes my master’s degree in Architecture, Building, and Planning: Urban Systems & Real Estate at the Eindhoven University of Technology and marks the end of my academic journey. The finalization of the graduate program means I will leave the City of Eindhoven.

I would like to start by expressing my gratitude to my first supervisor, Rianne Appel-Meulenbroek, for her unlimited and invaluable support during this journey. The consistent encouragement and expertise during this process have been fundamental to the success of this thesis. I am also deeply grateful to my second supervisor, Lisanne Bergefurt, for her support, unlimited criticism on *mental health* and constructive feedback. Lastly, I would like to extend a heartful thanks to my third supervisor, Valeria Caiati, for her perspective on sustainability, which was always presented with warm encouragement. During the journey, I was often surprised by the extensive feedback and regular contact moments, and for that, I would like to thank all three of you.

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Finalizing my master’s degree leaves me with a double feeling; on the one hand, I am sad my student days are over, but I am mostly eager to explore the world as a young professional. I look back at the past six years in Eindhoven with great joy!

Executive Summary

Introduction

Office buildings can be a resource for the environment and employees' *health*. However, they are often not designed to fully utilize their environmental and *health* potential, they even cause drawbacks. Firstly, the office may cause an environmental drawback through its GHG emissions, water use, waste generation and impact on local biodiversity. The greatest part of these emissions are generated during the operational phase of an office by its energy expenditure. Consequently, the environmental drawback contributes to climate change, threatening life on Earth and affect *human health* indirectly. Secondly, a *health* drawback may be created by an office; people spend most of their time indoors and a large proportion of it is spent at the workplace. Physical inactivity due to sedentary behaviour as well as mental sick leave, mainly due to stress, greatly contributes to rising *health* costs. Research shows that a 'sustainable' building combines the two previously discussed concepts and may positively impact either one or both. A 'sustainable' office design may reduce GHG emissions during the operational phase, greatly impacting worldwide emissions, and may also influence *health* positively. However, 'sustainable' design elements focussed on reducing GHG emissions may negatively influence *health*, or vice versa.

Objectives

This thesis focussed on the relationship between *environmental sustainability* and *health* in office design during the operational phase of an office. In literature, no holistic overview on the relationship between the *environmental sustainability* and the *health* of an office building is present yet. By researching the trade-offs or synergies between *environmental sustainability* and *employee health in* office design elements this thesis aims to provide this holistic overview. The results can be used by workplace managers and asset managers to make a deliberate choice between design measures, based on their effects on the *environment* and *health*. This thesis thus aimed to answer the research question: *What are the trade-offs and/or synergies between office building design elements that create an environmentally sustainable and those that create a healthy* office *building?*

Findings: Literature Study

Environmental benefits

An office building influences the environment in a multifaceted manner, focusing on the efficient use of resources—energy, water, and waste—and its impact on local biodiversity and the urban environment. A critical aspect of resource management is its energy expenditure, which contributes to greenhouse gas (GHG) emissions, negatively affecting the environment. Key components influencing a building's energy use include thermal, air, and lighting systems. Energy-efficient buildings reduce GHG emissions and lower operational costs, making 'sustainability' economically attractive.

Effective resource management extends to water and waste. Efficient water use is vital for quality of life. At the same time, thoughtful waste management can enhance recycling efforts, aligning with broader sustainability goals, such as the Dutch government's ambition for a circular economy by 2050.

Due to their dense nature, urban environments often pose challenges to biodiversity. However, by designing buildings that connect with local urban and green structures, their negative impacts can be minimized. Integrating greenery into building designs can serve as a "stepping stone" for local ecosystems, helping to reduce habitat fragmentation and support biodiversity.

The integration with the urban environment may also benefit employees' transportation behaviour by providing amenities that promote active transportation, limiting indirect (local) emissions.

Social benefit; health

The *social benefit* mainly concerns the *health* of building occupants, as well as general accessibility and safety. This thesis focussed only on *health* and defined it according to the WHO definition (2010): *'A state of complete physical, mental and social well-being, and not merely the absence of disease'*.

The *health* dimensions (physical, mental, and social) are interconnected; for instance, physical illness can lead to mental *health* issues such as stress or depression. Factors influencing *health* in office environments include indoor air quality, thermal comfort, lighting, noise levels, office layout, and biophilic design elements. To foster a positive social climate and encourage interaction, specific design elements—such as furniture arrangement, layout, and greenery—are essential. Lastly, since effective office design goes beyond merely addressing diseases; it utilizes design elements as resources to promote overall *health*, and it should be recognized that individuals can experience varying levels of *health* regardless of the presence of disease.

Methodology

Interviews

Due to the complexity of combining two concepts it was expected that the results would be rather nuanced. Therefore, a (semi-)structured interview method has been chosen. It provides the opportunity to gather detailed information in a structure manner.

Shearing Layer Concept

This structure was provided by the shearing layer concept, it conceptualises a building. This is important due to a building's complexity and use of different functions, materials and elements; while integrated in a rigid system. This integration often ignores the difference in durability; the lifespan of individual elements is often shorter than the total lifespan of a building. The *Shearing Layers*, divides a building into different layers based on their lifespan, the differentiation is as follows: *Site* (>300 years), *Structure* (50-300 years), *Skin* (20-50 years), *Services* (10-20 years), *Space Plan* (3-10 years) and *Stuff* (1> year). The shearing layer concept provide also structure to the literature review and results.

Findings: Interviews

Relations; Trade-off or Synergy

This thesis identified multiple relationships, trade-offs, and synergies. Trade-offs are predominantly located in the skin and services of an office and are mainly concerned with the thermal and lighting quality of designs, in both active and passive strategies. Active strategies utilize energy to maintain the IEQ, and the latter do not. Based on intuition, one would expect only active strategies to be trade-offs. For instance, the indoor environment is actively influenced by Heating Ventilation and Air Conditioning (HVAC) systems, traditional lighting, and windows. These design elements use energy to benefit *health*. Hence, they are an active strategy and *environmental* trade-offs. Passive strategies can also be identified as *environmental* trade-offs due to their indirect effect on an office's energy expenditure: windows, window orientation, indoor green elements, and openable windows. Windows use energy indirectly through their relatively low isolation value, providing lighting and views to the outside while causing energy leakage.

Synergies are predominantly located on the site or in the layout of an office. This thesis found that bike parking, outdoor green elements (greenery on site and/or on skin), and attractive staircase design solely benefit environmental sustainability and health. Hence, they are defined as a synergy. Design elements causing a positive synergy are often not essential for an office to function.

Design elements causing a negative synergy are a drawback for *environmental sustainability* and *health*, but may be essential for an office to function. They can be implemented due to users' existing preferences (car parking) or for economic benefits (open floorplan).

Effectiveness

Previously mentioned effects may be influenced by the physical context or the availability of comparable design elements. The importance of considering these two before implementing design measures cannot be understated. The effectiveness of more than half of the identified design elements, in this thesis, is influenced either by external factors or by comparing them to other options.

The external situation influences the effectiveness of design elements through a building's energy expenditure. All experts identify window orientation as a design element that can effectively gain or block solar heat and natural lighting as well as prevent overheating and glare. Its effectiveness depends on its orientation. Furthermore, all experts consider indoor green elements beneficial for *environmental sustainability* and *health*, but their effectiveness is be diminished by its implementation indoors in comparison to outdoors. Additional consultation with experts in the applicable field is advised to determine the actual influence of design elements in the specific context that the office design would be located.

The effectiveness of design elements also depends on the availability of comparable design elements. Several design elements may be considered essential in an office: car parking, windows, HVAC system, and artificial lighting. Other design elements, in relation to the previous ones, have been found that could benefit *environmental sustainability* and/or *health*. Car parking can for example be accompanied by bike parking, bike sharing or car charging amenities to benefit *environmental sustainability* and *health*. Traditional windows might be compared to energy-saving windows to benefit *environmental sustainability*. Additional consultation with experts in the applicable field to determine the influence is also advised.

Recommendations

Implications for theory

The theoretical effectiveness of several design elements' does not match the practical effectiveness as argued by this thesis. A mismatch is noticeable between scholars and experts. For example, translating elements from its outdoor context to indoor context, such as indoor green elements, is complicated for scholars and experts. For example, the experts indicated that indoor green elements are a drawback for *environmental sustainability* due to their energy demand by space use and 'grow'-lamps. On the other hand, scholars argue that Indoor Air Quality (IAQ) benefits are created by air filtration. The perception that indoor greenery is inherently beneficial may stem from its 'natural' appeal, but external environmental conditions greatly influence its effectiveness. As discussed, considering the physical context is essential for determining the effectiveness of design elements.

Besides that, the findings of this thesis challenge the prevailing view that passive ventilation is a resource for *health* in office buildings. Key reasons include that: (1) IAQ is significantly affected by local outdoor air pollution and temperature, and (2) the air displacement provided by passive systems is often insufficient for adequate ventilation. The potential of sealed-off buildings is highlighted by this thesis, advocating for modern HVAC systems that can maintain IAQ in an *environmentally-friendly* manner, thereby creating an optimal indoor climate for *health*.

Both this thesis and scholars argue that providing control is essential to create *health* benefits. However, the design elements (e.g., dynamic sunlight shading or smart lighting) proposed by scholars are not echoed by experts as controllable design elements. On the contrary, the design elements often were referred to as a *health* trade-off.

The *environmental* benefits of an open floorplan and private offices remain scarce in the literature. Experts also experienced difficulties in identifying *environmentally sustainable* benefits. The effects on *health* are primarily researched by both scholars and discussed by experts. A gap in literature may exist on the effectiveness of layout types for *environmental sustainability*.

Lastly, scholars often only mention that energy-efficient design elements benefit the *environment* and lack the discussion on the effects for *health*. This thesis has shown that it is relevant to consider the *health* effects as well, since they are often negative (e.g., energy-efficient windows, dynamic shading).

Implications for practice

The site of a building is an easy-to-hit target if one wants to benefit *environmental sustainability* and *health*. Transportation amenities and greenery on site are synergetic and should be implemented if possible. Besides that, workplace and asset managers could focus on limiting the dependency on car use since it is a drawback for *environmental sustainability* and *health*. Investing in offices at intercity locations might contribute to this. The building's skin and services experience contrasting effects if one wants to limit energy expenditure while maintaining *health*; a great number of trade-offs are noticeable in these layers. Workplace and asset managers are advised to seek additional consultation with experts in the applicable field to simultaneously aim to enhance *environmental sustainability* and *health* in the skin and services.

Limitations & suggestions for future research

This thesis has several limitations. The quality of the thesis is influenced by the quality and completeness of the literature review, primarily since this thesis aims for a 'holistic' overview. Even though the literature review is as complete as possible, the list of design elements will likely remain incomplete due to the wide variety of options. The interview method limits the quality of the results due to potential interview bias. Besides that, the interviews did not include the magnitude of the benefits and drawbacks, limiting the possibility of concluding on actual trade-offs and synergies. The quality and completeness of the interviews also depend on the selected sample and the knowledge of experts. Lastly, the scope of this research is a limiting factor since the embodied carbon of the element may be relevant for its *environmental* benefits.

Conclusion

In this thesis, only a limited number of trade-offs and synergies have been identified. The greatest part of the design elements are identified as simultaneously trade-off and synergy by the same experts or by different experts. This shows the complexity of *environmental sustainability* and *health* individually, and their relation. The limitations and suggestions for future research are only a small part of the research needed to create robust conclusions on the relationship between *environmental sustainability* and *health*.

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1. Introduction

Background & Societal Relevance

Office buildings have the potential to be a resource for the environment and employee's *health*. However, often they are not able to live up to this potential; and are a drawback.

The building sector accounts for 21% of Green House Gas (GHG) emissions and 31% of CO2 emissions worldwide, with 57% of these emissions emitted during the operational phase. One-third of these emissions are produced by non-residential buildings, such as offices, making a great contribution to GHG emissions (Cabeza et al., 2023). Not only do these emissions negatively affect the climate, but an office's impact on local biodiversity, water use, and waste generation also does this. The environmental impact negatively indirectly affects *human health*. For example, extreme weather conditions are worsened by GHG emissions, deterioration of biodiversity and poor water management, increasing the chance of injury, illness or death. Additionally, worsening air pollution levels can cause cardiovascular disease (NIEHS, n.d.). An office can thus influence *health* indirectly through its emissions.

Besides that, it can influence *health* directly, as people spend most of their time indoors (90%), of which a large proportion is spent at the workplace (Al Horr et al., 2016). The shift from manufacturing towards service and knowledge-based jobs has led to more sedentary behaviour among employees (Haynes, 2008; IJmker et al., 2007), causing physical inactivity at work. Consequently, the estimated physical *health* costs have risen to $53 billion (WHO, 2018). *Mental health* costs are not yet considered in this financial figure. Sick leave is often lengthier (Kelloway et al., 2023), suggesting that the total *health* costs might be even higher.

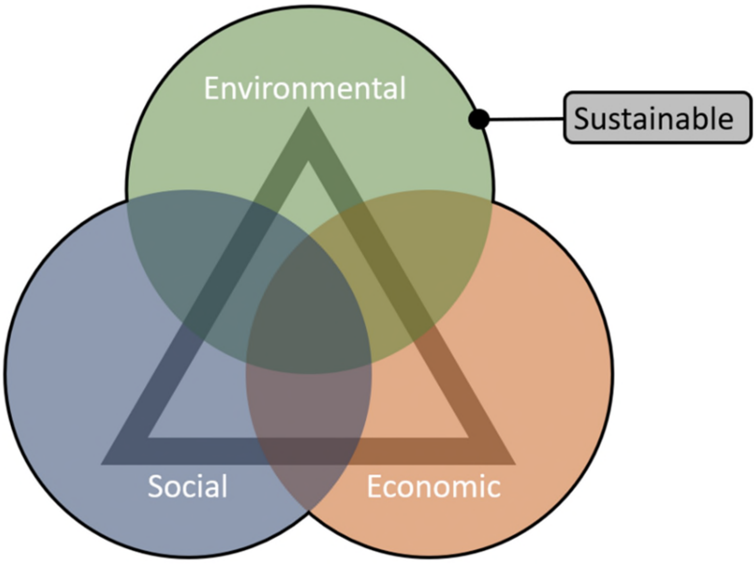

Figure 1; The sustainability triangle (Rodrigues et al., 2023).

Research shows that 'sustainable' buildings have an impact on both the environment and the users' *health* (Zuo & Zhao, 2014). Reducing GHG emissions in a commercial building's operational phase can greatly impact worldwide emissions, influencing *human health* indirectly. Besides that, an office building can also influence *human health* directly through its design. To concretise the benefits of sustainable buildings, the *people (social), planet (environmental), and profit (economic) principle* (Zuo & Zhao, 2014) is used, see Figure 1. This principle aims for a building that is a resource for its users, the global environment, and the economy. From this principle, multiple pillars can be derived that show in what ways buildings influence society. These focus on a buildings environmental (planet), social (people), and economic (profit) benefits.

The *environmental benefit* of a building concerns the efficient use of resources, biodiversity, and its location. Its aim is to reduce the GHG emissions and ecological footprint of a building. To achieve this, the *Paris Agreement* (UN, 2015) and subsequent governmental policies have been implemented. These policies include, among others, the requirement for office buildings to have a minimum energy label of C (Rijksoverheid, 2018), the obligation and guidelines to disclose the CO_2 emissions of the business chain (EC, 2019), and the requirement for reporting on ESG (Environmental, Social, and Governance) targets and performances. The latter requires financial institutions to disclose non-financial data on their policies and actions. This concerns a building's environmental impact through GHG emissions, water use, waste management and biodiversity. Reporting on this is still voluntary but will become mandatory from 2026 onwards (EC, n.d.). These policies create the incentive for occupants to reduce their environmental footprint and for investors to invest in properties with a high envir*onmental benefit* or take actions accordingly (Bertoldi et al., 2018).

The *social benefit* of a building concerns the *health* of building's occupants, as well as general accessibility and safety. The societal relevance becomes apparent when considering the workplace-related annual *health* costs due to physical and mental illnesses mentioned earlier (Kelloway et al., 2023). Since part of the *health* costs are a burden for the employer, they incentivise workplace managers to increase the *social benefit* of the workplace design. Scholars have shown that design elements in the workplace can contribute to the prevention of mental and physical diseases and may help to influence the employee's *health* (Al Horr et al., 2016; Kelloway et al., 2023). By adopting design strategies, a *health*ier lifestyle among employees is promoted (Bergefurt et al., 2022; Feige et al., 2013a; Jin et al., 2021; Kwon et al., 2019a), potentially decreasing annual *health* costs (Feige et al., 2013a; Heerwagen, 2000).

Lastly, the *economic benefit* of a building concerns its value stability, which is inherently important since the primary motive of commercial companies is financial return and value creation (Rodrigues et al., 2023; Zimmermann et al., 2019). This may also be important when considering the *environmental* and *social benefits* of commercial office buildings, since sustainable buildings are becoming increasingly popular, increasing the value of sustainable design (Kats, 2003; Matisoff et al., 2016).

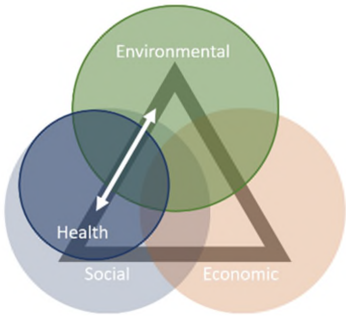

Figure 2; Visual representation of the scope of this thesis.

Scope

Increasing the *environmental* and *social benefits* of a building can be done through design implementations, which are the most effective compared to managerial practices and changing behaviour in the workplace (Chenari et al., 2016; He et al., 2021; Pombo et al., 2016). This thesis will solely focus on the design elements of an office building. The operational phase is considered the most-relevant due to its significant contribution to lifetime GHG emissions, furthermore the operational phase also influences the employee *health* in the building (Cabeza et al., 2023). Thus, this thesis will focus on the relationship between *environmental sustainability* and *health* in the office design, as shown in Figure 2, during its operational phase.

Academic relevance and gap

Currently, no holistic overview is present in literature on the potential relations between the *environmental benefit* and the *social benefit* of an office building on society. The design elements causing trade-offs and synergies experienced between *environmental sustainability* and *health* by workplace managers to achieve a 'sustainable' building are unclear. Scholars have researched the concept of 'sustainable' buildings extensively. However, limited research is present at the intersection of *environmental sustainability* and *health* in office buildings. If the relationship is discussed, only one part of *health* is considered, primarily physical (Smith & Pitt, 2011a). The literature review by Smith and Pitt (2011) and other scholars (e.g. Jin et al., 2021) do consider a wide variety of factors influencing the 'comfort' and 'satisfaction' of occupants -which find their basis in sustainable measures - but does not consider the *mental* and *societal* aspects of *health* explicitly. 'Comfort' is often used in the terminology to address the full scope of *health*, while the definition is left open for discussion (Hanc et al., 2019). Lastly, considering papers on ESG-reporting in the building sector consider *environmental* and *social benefits* of an office building independently without explicitly acknowledging potential interrelations (Kempeneer et al., 2021; Zimmermann et al., 2019). Therefore, this thesis aims to provide a holistic overview of the trade-offs and/or synergies between *environmentally sustainable* building design elements and *healthy* building design elements. This will help workplace managers, investors, and policymakers in considering the different design measures and their effects on the office building's *environmental* and *social impacts* by answering the following questions:

1. What are the trade-offs and/or synergies between office building design elements that create an *environmentally sustainable* and those that create a *healthy* building?
    a. What defines an *environmentally sustainable* office building?
        i. How is *environmental sustainability* defined in the context of an office building?
        ii. What building design elements have been shown to affect the *environmental sustainability* of office buildings?
    b. What defines a *healthy* office building?
        i. What is the definition of (physical, mental, and social) *health*?
        ii. What building design elements have been shown to affect *occupant health* in office buildings?
    c. What are the potential trade-offs between a *healthy* office building and an *environmentally sustainable* office building?
    d. What are the potential synergies between a *healthy* office building and an *environmentally sustainable* office building?

This thesis will answer the previously stated research questions by researching the concept and components of *environmental sustainability* and the concept and components of *health* in office buildings separately through a literature review. Consequently, answering research questions (1a) and (1b). The final section of the literature review will combine the design elements from literature utilizing the shearing layer concept and show the potential trade-offs and synergies in a visualization, text and tables. The research methodology will be discussed afterwards. Followed by the results, discussing the interview results utilizing the shearing layers. The results chapter will be finalized by a combination of the results, showing the results independently from the layers. This thesis will be finalized by a conclusion and discussion, presenting the answers to research questions 1a, 1b, 1c, and 1d. As well as the implications for theory, implications for practice and limitations.

2. Literature Review

In this chapter, the literature review will explore the key concepts and research related to office buildings' *environmental sustainability* and *health*. The chapter will define an *environmentally sustainable* office and the related building elements; besides that, it will define a *healthy* office and the related building elements. Respectively answering research questions 1a and 1b. The chapter will be finalised with a combined representation of the findings. This section will highlight potential trade-offs and synergies between building design elements that contribute to an *environmentally sustainable* office building and those that promote a *healthy* office building. To do so, the review will discuss ‘sustainable’ office buildings from two perspectives. First, the *environmental benefits* of a building will be considered, beginning with a definition of *environmentally sustainable* buildings and their relevant components. After this, the *social benefit* of a building will be considered, particularly the component *health*. A *healthy* building will first be defined by considering different types of *health*: *physical, mental*, and *social health*. The literature on *healthy* buildings related to these dimensions will be presented. The chapter will then introduce the Shearing Layer concept (*6S concept*) by Brand (1994) as a framework to organise the findings, categorising the previously defined *environmentally sustainable* and *healthy* building elements. These elements will first be analysed separately before being cross-referenced in a crosstabulation. This structured approach will enable the identification of potential trade-offs and/or synergies between *environmental sustainability* and *health* in office buildings.

2.1 *Environmentally Sustainable* Building

This section of the literature review will cover a range of *environmentally sustainable* building elements, including energy, waste, and water management, as well as the effect of a building on the local urban (green) structure.

Literature on *environmental sustainability* in an office building primarily considers resource management of energy (Wijesooriya & Brambilla, 2021), which consists of a thermal component (Pombo et al., 2016; Rodrigues et al., 2023), air component (Calcagni & Calenzo, 2023) and lighting component (Hashempour et al., 2020; Rodrigues et al., 2023). Energy generation, however, negatively influences the environment through the emission of GHGs, including CO2 emissions, one of the greatest contributors to climate change (IPCC, 2014). The focus on energy efficiency in literature arises partly from its significant environmental impact. Besides that, energy-efficient buildings provide economic benefits through reduced energy use and lower operational costs (Chwieduk, 2003; Wen et al., 2020; Zuo & Zhao, 2014). These benefits are often a primary motivation for building owners and users to undertake ‘sustainable’ renovations. The yield from these measures is typically higher and more immediate compared to other measures, such as enhancing urban biodiversity (Pombo et al., 2016). Furthermore, the Paris Agreement has prompted a broader commitment to energy efficiency, encouraging technological and behavioural changes to meet energy consumption goals (UN, 2015). Multiple scholars see Energy-efficient buildings as a ‘fundamental step’ towards an *environmentally sustainable* building (Chwieduk, 2003; Wijesooriya & Brambilla, 2021).

Additionally, scholars found that resource management of water (Calcagni & Calenzo, 2023) and waste (Park et al., 2024) are important in achieving an *environmentally sustainable* building. The following paragraphs will highlight the importance of both.

Freshwater is a limited resource, and consumption has tripled over the past 60 years, partly due to the demand for the built environment (Asman et al., 2019). Currently, the building sector uses about 10% of the globally available freshwater supply yearly, so reducing water consumption has great potential (Calcagni & Calenzo, 2023; Meena et al., 2022). The efficient use of water will have a direct social and economic global effect (Asman et al., 2019) since clean water is an indispensable resource influencing the quality of life. Besides that, the supply of fresh water is not unlimited due to climate change causing droughts and heavy industries causing contamination of freshwater sources like rivers (Boon, 2024). The importance of water is reflected in the Sustainable Development goal for 'Clean Water and Sanitation', which recognizes the risks of waterborne diseases (UN, n.d.).

The Dutch government has the ambition to become circular in 2050, including operational waste (Rijksoverheid, 2024a). Waste generation during operation can be influenced by the design of building elements, such as recycling bins for waste (Asman et al., 2019). However, the effectiveness of waste management depends on the recycling companies.

Lastly, integrating the building with the local urban and green structure can minimise its impact on the surrounding environment and local biodiversity. The dense character of cities often leads to environmental (and socio-economic) drawbacks, such as rising local temperatures, increased pollution and decreased biodiversity, negatively influencing the environment (Tian et al., 2021). Designing a building in harmony with its surroundings can become a resource rather than a burden (Pinho et al., 2021; Tian et al., 2021). The connection can be established by integrating greenery as a 'stepping stone' for the local green structure. The 'stepping stone' may limit habitat fragmentation and decrease the disturbance from city activity for office building occupants (Pinho et al., 2021). The Dutch government promotes nature-inclusive design by providing guidance tools and the obligation to include nature-inclusive plans for new developments (Rijksoverheid, 2017; Rijksoverheid, 2024b).

The urban connection of a building can also be strengthened by providing transportation amenities. While car use has a great negative environmental influence, providing amenities that promote biking can help mitigate this effect. Sustainable transportation amenities can reduce the indirect emissions of an office building (Gallo & Marinelli, 2020; Park et al., 2024; Wen et al., 2020). Companies in the Netherlands with more than 100 employees must report the distance employees travel to work (Rijksoverheid, 2014c), incentivising the reduction of these emissions. Besides that, amenities like a canteen or gym can be implemented to enhance a building's connection to the urban structure and simultaneously reduce a building's indirect carbon emissions. Combining functions trips of employees can be combined, reducing the travel demand, thus reducing carbon emissions (Khavarian-Garmsir et al., 2023).

Hence, scholars considers the *environmental sustainability* in relation to office buildings from multiple perspectives, as concluded in Figure 3.

2.1.1 Building Elements

This section will discuss the building design elements outlined in Figure 3. First, the resource management of energy, water, waste, and materials is discussed. This will be followed by an examination of the building's impact on its local biodiversity and the urban structure, through biophilic design, transportation and building amenities. A summary of the literature reviewed is structured in a Table 45 in Appendix A.

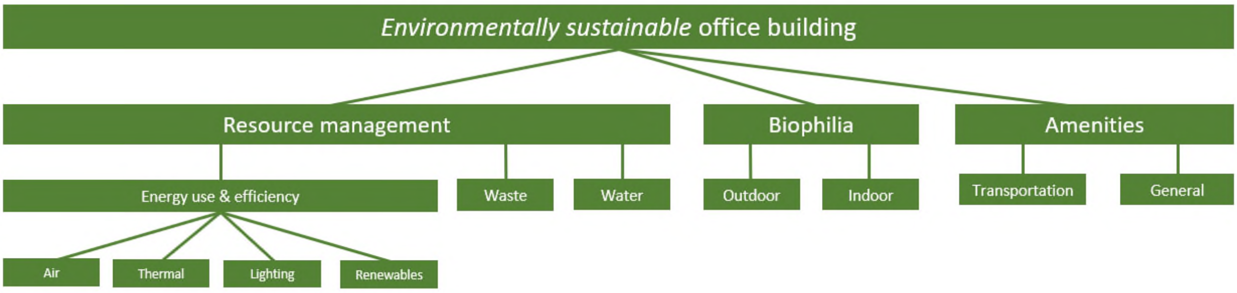

Figure 3; Environmentally sustainable building elements.

2.1.1a Resource Management: Energy Use & Efficiency

The objective of energy-saving and energy-efficiency measures is to reduce the energy consumption of a building (Zimmermann et al., 2019b; Zuo & Zhao, 2014), ultimately leading to a reduction in its carbon emissions (Chwieduk, 2003; Zimmermann et al., 2019b). During renovation, energy-related measures are the most common and effective for commercial buildings (He et al., 2021b). Regarding certification methods, energy efficiency is the most frequently measured element of a 'sustainable' building (Robinson & McIntosh, 2022; Wen et al., 2020; Zimmermann et al., 2019b). Since a great number of design elements require or provide energy, the following subsections address each one separately. The design elements are shown in Figure 4 and discussed in the section below.

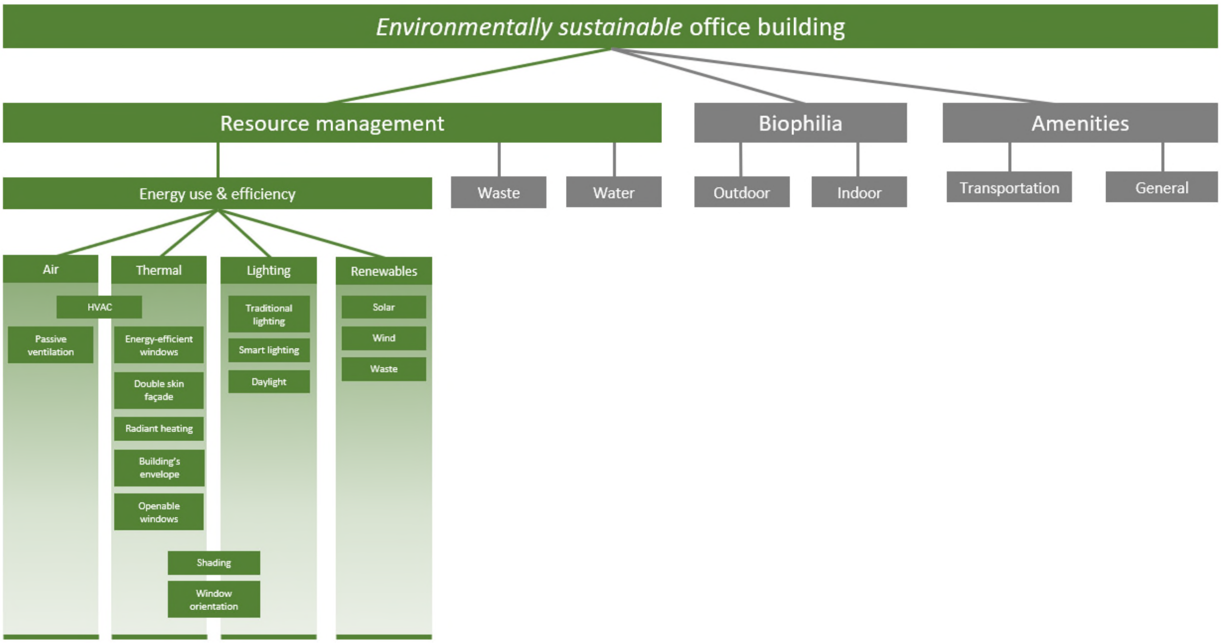

Figure 4; Building design elements in offices influencing the energy use & efficiency.

Air

The energy efficiency of the first component 'Air' is influenced by the Heating, Ventilation, and Air Conditioning (HVAC) equipment, which actively controls the air quality using replacement, recirculation and/or filtration of air (Calcagni & Calenzo, 2023; Felius et al., 2020; Hashempour et al., 2020; Meena et al., 2022; Pombo et al., 2016; Rodrigues et al., 2023; Si et al., 2016). The energy burden from these activities can be reduced by implementing a passive ventilation strategy. This strategy is an energy-efficient method since the replacement and recirculation of air is (mainly) done by using the natural airflow from outside (Dimitroulopoulou et al., 2023).

Passive ventilation strategies depend on the natural airflow from the outside environment; it should be combined with an open building envelope (Calcagni & Calenzo, 2023; Kumar et al., 2023; Meena et al., 2022; Norton et al., 2021) for example, openable windows (Felius et al., 2020; Hafez et al., 2023; Kim & Yu, 2018; Kumar et al., 2023) and/or an atrium (Calcagni & Calenzo, 2023; Chwieduk, 2003; Dimitroulopoulou et al., 2023; Kim & Yu, 2018). Passive ventilation can be implemented as the primary ventilation 'system' or in combination with an HVAC as a hybrid ventilation system (Chenari et al., 2016; Dimitroulopoulou et al., 2023; Zhang & Srinivasan, 2020).

Thermal

The thermal efficiency of a building is a great contributor to its total energy use. The HVAC system (Calcagni & Calenzo, 2023; Felius et al., 2020; Hashempour et al., 2020; Meena et al., 2022; Pombo et al., 2016; Rodrigues et al., 2023; Si et al., 2016) and a building's envelope (Calcagni & Calenzo, 2023; Chwieduk, 2003; Felius et al., 2020; Kim & Yu, 2018; Pombo et al., 2016; Rodrigues et al., 2023; Si et al., 2016) are both important for the thermal efficiency of a building. The most common strategies to reach or maintain energy efficiency concern the previous two building design elements (He et al., 2021b).

Actively controlling the thermal conditions is done by heating installations, for example, HVAC systems (Calcagni & Calenzo, 2023; Chenari et al., 2016; Dimitroulopoulou et al., 2023; Hashempour et al., 2020; Kumar et al., 2023) and/or radiant heating (Chwieduk, 2003; Norton et al., 2021). Both use energy, while radiant heating uses less energy and maintains a more constant Indoor Air Quality (IAQ); thus, it is more energy-efficient in comparison (Chwieduk, 2003; Norton et al., 2021).

Passive strategies to control the thermal conditions of a building include the building's structure (Chenari et al., 2016; Dimitroulopoulou et al., 2023; Felius et al., 2020; Kim & Yu, 2018) and envelope (Chenari et al., 2016; Chwieduk, 2003; Hafez et al., 2023; Meena et al., 2022; Wen et al., 2020). Unlike an open building envelope, which allows for natural ventilation, a closed building envelope is considered thermally efficient. This structure primarily recirculated air, reducing the energy burden of the HVAC systems (Chenari et al., 2016; Felius et al., 2020; Kim & Yu, 2018; Spiru & Simona, 2017). The thermal conditions of a building can also be maintained by its skin utilizing energy-efficient windows (HR++, triple, vacuum glazing) (Chwieduk, 2003; Hafez et al., 2023; Hashempour et al., 2020), a double skin (Calcagni & Calenzo, 2023; Chenari et al., 2016; Kim & Yu, 2018), shading systems (Calcagni & Calenzo, 2023; Hashempour et al., 2020; Kim & Yu, 2018), or an efficient window orientation (Calcagni & Calenzo, 2023; Felius et al., 2020; Hafez et al., 2023). The latter three systems aim to gain as much solar energy as possible to heat in the winter or to shield as much solar energy as possible to 'cool' the building in the summer (Chwieduk, 2003).

Lighting

Lighting systems' energy consumption is influenced by their energy efficiency, which can easily be influenced by the lighting system's 'smartness' or by optimizing indoor daylight conditions.

Smart lighting systems automatically dim or switch the light off in spaces that are not in use, preventing unnecessary use of energy (Hashempour et al., 2020; Meena et al., 2022; Norton et al., 2021). Optimizing daylight conditions can reduce the need for lighting and thus reduce the energy demand (Hashempour et al., 2020; Si et al., 2016). This can be done through window orientation (Calcagni & Calenzo, 2023; Kim & Yu, 2018), colour use (Calcagni & Calenzo, 2023; Hafez et al., 2023), double façade (Chenari et al., 2016), an inner courtyard (Calcagni & Calenzo, 2023; Chenari et al., 2016). However, as mentioned before, solar-oriented windows allow heat to enter the building, increasing the energy use of cooling systems and, thus, the need for shading systems (Calcagni & Calenzo, 2023; Hashempour et al., 2020; Kim & Yu, 2018). A balanced situation needs to be designed using shading, optimizing energy efficiency without reducing the lighting or thermal conditions of a building (Hashempour et al., 2020; Kim & Yu, 2018).

Renewables

In addition, renewables are found to be important in influencing the GHG intensity of a building (Rodrigues et al., 2023; Wen et al., 2020; Zuo & Zhao, 2014). If implemented correctly, the previously discussed building elements reduce both energy and GHG intensity. Energy generation on-site can be done by PV panels, small wind turbines (Chwieduk, 2003; Si et al., 2016; Zuo & Zhao, 2014), solar heat harvesting systems (Hashempour et al., 2020), or biomass boilers to regenerate ecological waste (Si et al., 2016; H. Wang et al., 2012).

2.1.1b Resource Management: Waste & Water

Resource management includes more than energy alone. The use of water and waste is commonly considered by scholars (Calcagni & Calenzo, 2023; Pombo et al., 2016; Scrucca et al., 2023; Wen et al., 2020; Zuo & Zhao, 2014). The design elements are shown in Figure 5 and discussed in the section below.

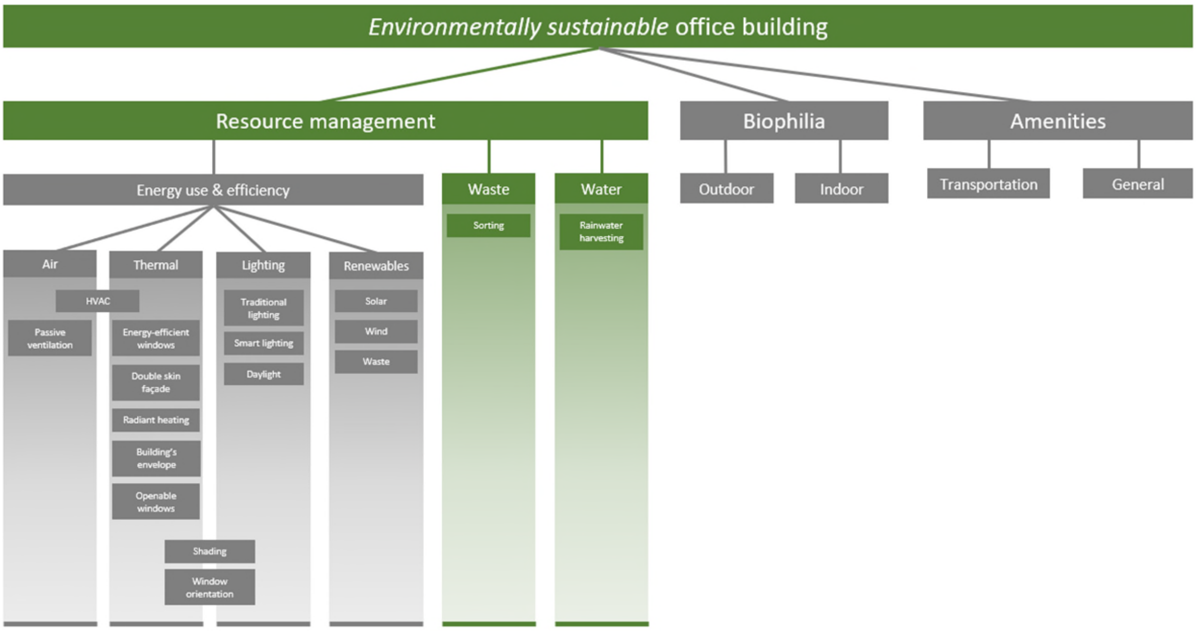

Figure 5; Building design elements in offices influencing the Waste, Water & Material.

Waste

Reducing waste consumption also benefits the environment (Asman et al., 2019; Pombo et al., 2016). Although it is not possible to annihilate waste, sorting and recycling can help further counteract the problem (Chwieduk, 2003; Norton et al., 2021; Si et al., 2016; Wen et al., 2020) depending on the reusability of the materials. For example, the biomass boiler can be connected to waste sorting management, as discussed in the previous section. By using ecological waste, heat or electricity can be generated (Si et al., 2016; C. Wang et al., 2024), increasing the *environmental benefit* of a building by reducing its energy use and by reducing its waste consumption.

Water

Reducing freshwater consumption benefits the environment (Asman et al., 2019; Calcagni & Calenzo, 2023; Meena et al., 2022). Buffering the rainwater supply during peak rainfall hours makes a great water source for flushing toilets or watering greenery. Besides that, the building's ability to store rainwater can make it more climate-resilient (Calcagni & Calenzo, 2023; Wen et al., 2020). Due to climate change, the occurrence of heavy rainfall is expected to increase (STOWA, 2019).

2.1.1c Biophilia

Implementing biodiversity-enhancing building design elements influences *environmental sustainability* inside and outside the office. Biophilia is a building element that could bridge the gap between energy efficiency strategies and a human-centric design approach, which will be discussed in more detail in Chapter 2.3. The design elements are shown in Figure 6 and discussed in the section below.

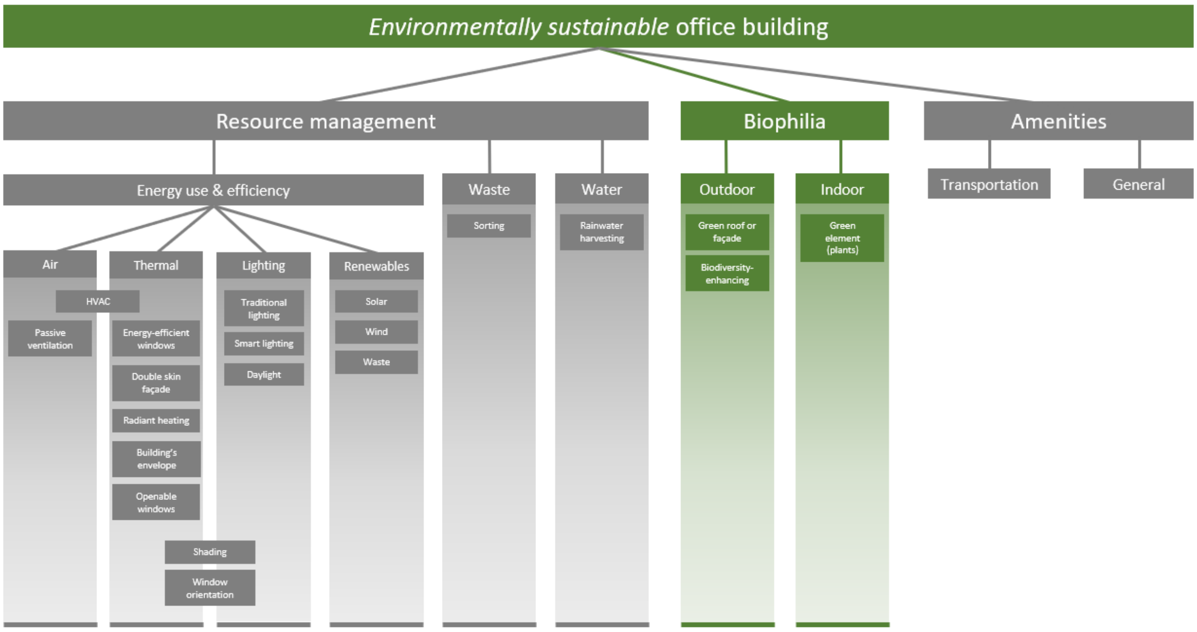

Figure 6; Building design elements in offices influencing the Biophilia.

Indoor biophilic design

Biophilic design, using green elements like plants, influence the building's energy performance (Calcagni & Calenzo, 2023; Norton et al., 2021). If they are applied indoors, green elements can increase the IAQ, by filtering and cooling the air (Wijesooriya & Brambilla, 2021). This may decrease the energy demand for HVAC services while maintaining comfortable user conditions (Smith & Pitt, 2009).

Outdoor biophilic design

Outdoor biophilic design elements connect a building with the local urban green structure by incorporating local plant species in the biophilic design and providing nesting places for birds and insects (Kempeneer et al., 2021), enhancing the local biodiversity (Chwieduk, 2003; Wen et al., 2020; Zimmermann et al., 2019b; Zuo & Zhao, 2014). Furthermore, living green façades or roofs provide cooling through evaporation and shading, which decreases the energy demand for building services (Si et al., 2016; Wijesooriya & Brambilla, 2021). Green elements also provide storage for rainwater (Calcagni & Calenzo, 2023; Park et al., 2024; Robinson & McIntosh, 2022; Rodrigues et al., 2023; Zuo & Zhao, 2014). Lastly, implementing greenery decreases air pollution (C. Wang et al., 2024) and Urban Heat Island (UHI) effect due to CO2 take-up and its cooling qualities (C. Wang et al., 2024; Wijesooriya & Brambilla, 2021).

However, biophilic design may also negatively influence *environmental sustainability*. The design often requires regular maintenance, which is not only costly but also a burden on the environment. Greenery has a limited lifespan - especially in comparison to the lifespan of a building - and needs to be replaced regularly. Some scholars have linked this to additional carbon emissions from the equipment to maintain greenery and the equipment for growing and transporting new greenery (Wijesooriya & Brambilla, 2021).

2.1.1d Transportation & Amenities

The following section discusses multiple design elements that can create a connection with the local urban area. As mentioned, establishing a connection can minimise a building's influence on its local urban environment. It can become an *environmental benefit* by influencing indirect emissions from transportation (Gallo & Marinelli, 2020; Park et al., 2024; Wen et al., 2020). The design elements are shown in Figure 7 and discussed in the section below.

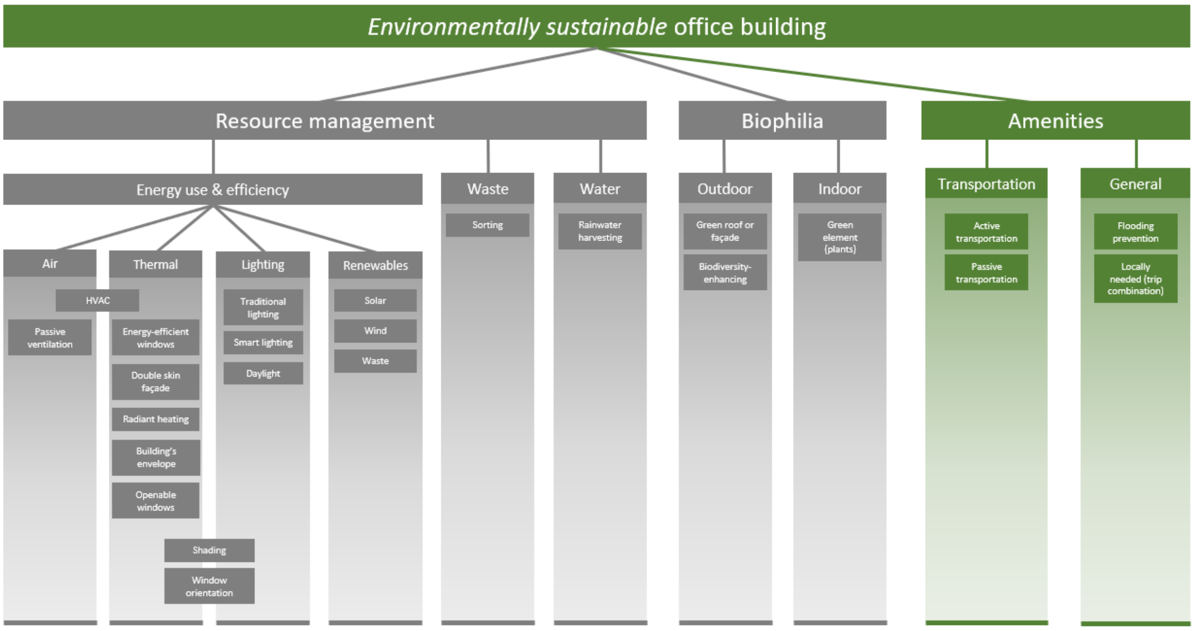

Figure 7; Building design elements in offices influencing the Transportation & Amenities.

Transportation

The indirect CO2 emissions due to transportation can be decreased by using active (e.g. bike or foot) (Gallo & Marinelli, 2020; Park et al., 2024; Wen et al., 2020) or public transportation (e.g. train) (Gallo & Marinelli, 2020; Wen et al., 2020), in comparison to the use of passive transportation (e.g. car) (Khavarian-Garmsir et al., 2023). However, to promote these forms of transportation, the urban environment must facilitate active and public transportation (Khavarian-Garmsir et al., 2023; Wiik et al., 2023). Facilitating transportation options in and surrounding the office building and plot by providing amenities is also possible (Gallo & Marinelli, 2020; Wiik et al., 2023). A practical example is the provision of facilities like bike parking (Park et al., 2024; Wen et al., 2020) or bike-sharing (Gallo & Marinelli, 2020). It is further suggested that providing showers, changing facilities and/or bike charging facilities can increase active transportation use and decrease passive transportation (Wen et al., 2020). However, this is not widely supported in academic literature despite its adoption by employers (Rijksoverheid, 2024d). Besides that, it should also be noted that a location close to public transportation hubs can increase the use of public transportation. If not close by, the perceived proximity can be decreased by, for example, implementing shared biking facilities (Gallo & Marinelli, 2020). Lastly, if the options for active and public transportation are limited, passive transportation can be more sustainable by providing charging infrastructures to decrease GHG emissions (Gallo & Marinelli, 2020).

Amenities

The previous paragraph discussed how a building can utilize its surroundings by connecting to the available transportation facilities. Additionally, a connection to the urban structure can be made by incorporating functions that benefit both the building's occupants and those of nearby buildings. For example, a building can provide locally needed amenities, such as space for a doctor's office, restaurant, or gym. These additions can indirectly reduce GHG emissions from employee travel by promoting 'trip combination', thereby decreasing the total travel distance and, consequently, the total GHG emissions (Khavarian-Garmsir et al., 2023).

2.2 Occupant's *Health*

This section will discuss the current industry's status on *health* in a corporate environment, followed by a description of *physical*, *mental*, and *social health* and their assumed key indicators. Furthermore, an overview of the different building elements influencing employees' *health* will be given.

An industry's shift is noticeable within workplace management, from '*avoidance of risk and disease'* to '*adding value through fostering* [*health* and] *well-being'* (Hanc et al., 2019). Employers are starting to manage employee *health* actively since *health* costs – caused by increased sick leave or low productivity levels – are a burden for the employer (Feige et al., 2013). By increasing the employees' comfort through workplace design, their *health* could potentially be increased (Feige et al., 2013; Jin et al., 2021; Kwon et al., 2019), which could improve their performance and engagement (Feige et al., 2013; Heerwagen, 2000) and may heighten their monetary productivity (Feige et al., 2013). The introduction of *green building rating tools* – e.g. *WELL,* which focuses on the social part of sustainability and primarily on *health* – made it possible for workplace managers and tenants to value *health*-related investments in the workplace (Zimmermann et al., 2019).

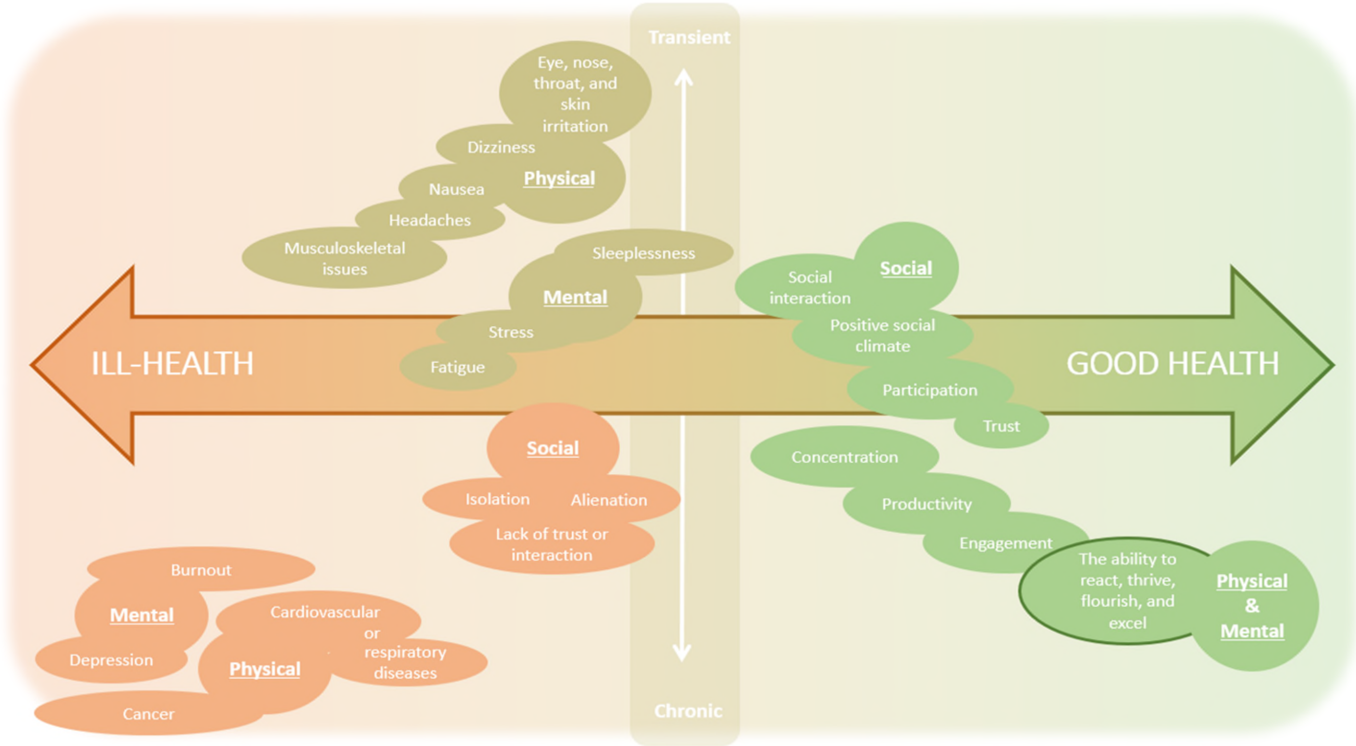

Figure 8; Experimental representation of the Health-Disease Continuum for the three types of health.

This thesis defines *health* following the definition given by the WHO (2010): 'A state of complete physical, mental and social well-being, and not merely the absence of disease'. This definition of *health* contains multiple relevant elements, such as that *health* consists of multiple sub-parts: *physical*, *mental*, and *social health*. These parts cannot be viewed separately since interconnections exist between the stated subparts. For example, a physical illness has an impact on *mental health* since it can cause depression or stress (Hanc et al., 2019; Lindberg et al., 2018). In addition, based on the definition of the WHO, *health* is *'… not merely the absence of disease'.* The WHO acknowledges that managing *health* is much broader than only focusing on curing diseases (Antonovsky, 1996). Managing *health* is done through using design elements in the workplace as a resource for *health* (Bergefurt et al., 2022; Hanc et al., 2019).

The last part of the definition by the WHO addresses the fluid character of *health*; a person can experience ill-*health* without having a disease, or a person can experience 'good *health*' with a disease. Keyes (2002) proposed a continuum scale to visualise and understand *health* better. An individual's *health* can fluctuate between 'being ill' and 'being *healthy*' levels. Multiple scholars acknowledge this interpretation; an employee's *health* can be placed on a *Health-Disease Continuum* based on transient and chronic factors (i.e. Kelloway et al., 2023). This scale is often used concerning *mental health* but can also serve as a *physical* and *social health* tool. The *physical, mental* and *social health* indicators, discussed in the following paragraphs, are visualised in clouds in Figure 8. To show the impact of time the transient or chronic character of *health* issues is also considered, as their duration significantly affects employees. Figure 8 is an experimental visualisation of how *physical* and *social health* may be placed in the *Health-Disease Continuum* and serves as a tool to visualise the *health indicator*s in this thesis.

Physical *health*

The WHO defines the Sick Building Syndrome (SBS) symptoms as a *collection of nonspecific symptoms, including eye, nose and throat irritation, mental fatigue, headaches, nausea, dizziness, and skin irritations, which seem to be linked with occupancy of certain workplaces'* (WHO, 1983). They provide a starting point for understanding the concept of *physical health*. Combining these with the present literature results in several physical *health* issues, including SBS symptoms and musculoskeletal issues (Al Horr et al., 2016; Clements-Croome, 2018; Colenberg et al., 2021; Ghaffarianhoseini et al., 2018; IJmker et al., 2007; WHO, 1983). These issues can lead to visual, noise, and physical discomfort (Ghaffarianhoseini et al., 2018), affecting *physical health*. Long-term exposure to these symptoms can cause, among others, respiratory diseases (Ghaffarianhoseini et al., 2018), cardiovascular diseases (Ghaffarianhoseini et al., 2018; Lindberg et al., 2018), or even cancer (Ghaffarianhoseini et al., 2018), see Figure 8 for the physical *health* symptoms in the *Health-Disease Continuum*.

Workplace managers can consider specific building elements to maintain or increase *physical health* in the workplace. The IAQ can be optimized (Ghaffarianhoseini et al., 2018; Heerwagen, 2000), or the seating arrangements can be adjusted (Colenberg et al., 2021; Lindberg et al., 2018; Michalchuk et al., 2022; Zhu et al., 2020). Ultimately, they opt for the absence of physical pain, such as musculoskeletal issues, to increase concentration, productivity, and engagement. This provides the employee with the ability to react, thrive, flourish, and excel at work. Al Horr et al. (2016) identified eight physical workplace factors that influence *physical health* by researching employee productivity through *physical and mental health*: indoor air quality & ventilation, thermal comfort, lighting & daylighting, noise & acoustics, Office Layout, Biophilia and Views, Look & Feel, and Location & Amenities. Apart from 'Location & Amenities', these building elements are also relevant if SBS symptoms are experienced by employees as Ghaffarianhoseini et al. (2018) show in their paper. They identify IAQ (temperature, humidity, ventilation, chemical & biological contributors), lighting conditions, acoustical conditions, material & colour use, external view, and plan layout related to employees' physical *health.*

Mental *health*

Furthermore, the past decade showed an increased interest in mental *health* in relation to the workplace (Bergefurt et al., 2022), but it is still a relatively unexplored subject. The one mental *health* issue mentioned in the SBS symptom definition of the WHO (1983) is 'mental fatigue'. However, mental *health* also includes general happiness and stress, as well as mental diseases like burnout and depression. Stress can result in the inability to concentrate in the short term and disability or sick leave in the long term (Kropman et al., 2023). Eventually, it can influence employees' sleep quality, productivity, engagement, concentration, and day-to-day physical *health* (Bergefurt et al., 2022). The workplace is a rather complex structure, where mental *health* is influenced not only by physical elements but also by social (*health*) elements (Firoz et al., 2020; Sahai et al., 2021).

Kropman et al. (2023) used the study by Al Horr et al. (2016) and Bergefurt et al. (2022) to identify seven building elements influencing the mental *health* of employees. They are comparable to the eight building elements defined for physical *health*, excluding 'location & amenities'. Thus, the indoor air quality & ventilation, thermal comfort, lighting & daylighting, noise & acoustics, office layout, biophilia and views, look & feel. These elements can allow employees to react, thrive, flourish, and excel at work by maintaining or increasing their mental *health*.

Social *health*

Due to the increase in remote working, the workplace has become a place where employees connect (Aubouin-Bonnaventure et al., 2023; Colenberg et al., 2023). Consequently, *social health* is slowly considered more regularly in today's literature on *health* in the workplace, while it remains relatively unexplored (Colenberg et al., 2023). If scholars describe *social health,* terms like 'participation', 'interaction', 'knowledge sharing', 'trust', and 'social climate' are used. No typical *social diseases* can be defined from the literature (Firoz et al., 2020; Hanc et al., 2019). Social isolation or workplace isolation and feelings of alienation or anomie are caused by a negative social climate and a lack of interaction (Colenberg & Jylhä, 2022; Sahai et al., 2021). *Health effects* experienced by employees range from physical cramps to depression; these effects are in the scope of *physical* and *mental health*. Hence, *social health* is linked to p*hysical* and *mental health*(Firoz et al., 2020; Sahai et al., 2021).

To maintain a positive social climate, design elements in the workplace should invite, encourage, and facilitate connection and conversations (Olsson et al., 2020). Colenberg et al. (2021) identified multiple interior building elements influencing employees' social *health*, namely furniture, layout, and greenery. A complete state of *social health* in the workplace can be achieved if employees 'engage in meaningful conversations' and/or 'feel understood and appreciated' (Reis et al., 2000). Both sound rather simple, but no model thoroughly explains why people feel invited to socialize in specific spaces or what encourages them to visit and linger (Sailer et al., 2021).

Figure 9; 'Healthy' building elements.

Figure 9, '*Healthy*' building elements, shows the conclusion of the previous section: These building elements influence the physical, mental, or social *health* of employees.

2.2.1 Building Elements

The following sections will discuss the building element influencing the *physical*, *mental* or *social health*, as defined in the previous section and shown in Figure 9. The building elements will be supplemented with specific building design elements. An overview of the building design elements Is visualized in section 2.3.2. The literature review is schematically presented in a in Appendix B.

2.2.1a Indoor Air Quality & Climate

Within indoor air quality & climate, the indoor air temperature, relative humidity (RH), ventilation rate, concentration of biological and chemical particles, and specific building design elements are defined in the following section. Although all factors influence occupants' *health*, the indoor air climate, temperature and humidity are the most important factors influencing *physical* and *mental health* (Fassoulis & Alexopoulos, 2015; Kropman et al., 2023; Vimalanathan & Babu, 2014). The design elements are shown in Figure 10 and discussed in the section below.

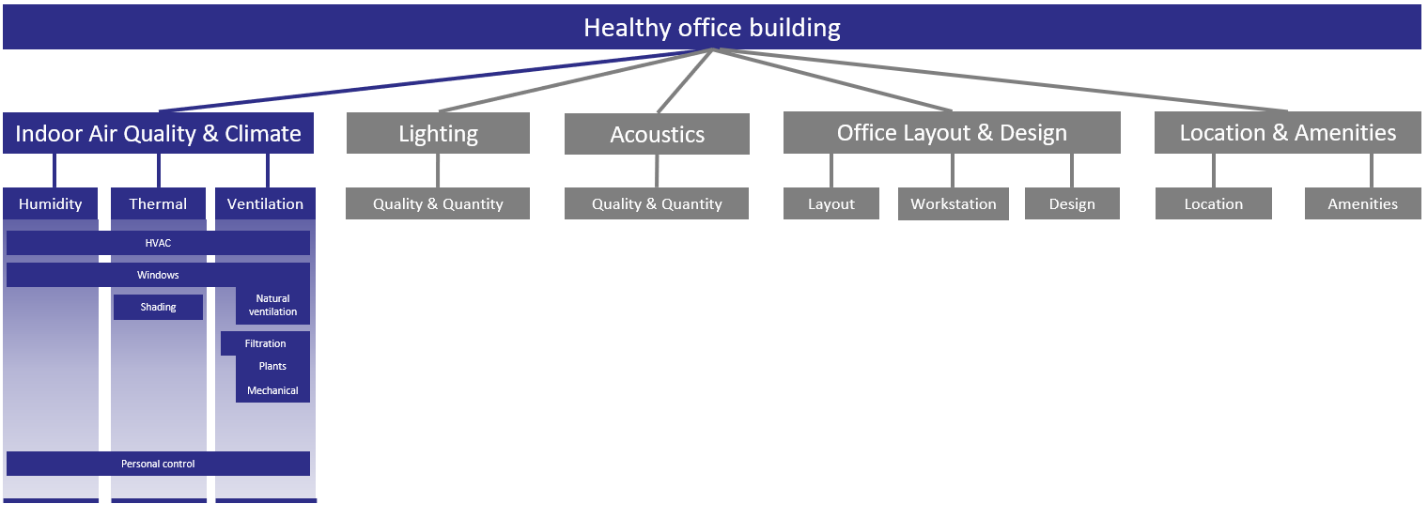

Figure 10; Building design elements in offices influencing the Indoor Air Quality & Climate.

Temperature, Humidity & Ventilation

Temperature, RH, and ventilation rates are influenced by the quality of the HVAC installations (Ghaffarianhoseini et al., 2018; Kim et al., 2011; Smith & Pitt, 2011b). HVAC installations can maintain a constant indoor air temperature and humidity. The WHO advises a temperature between 18 °C and 24 °C (WHO, 2018b) and an RH of 45% at maximum to prevent mould formation (WHO, 2009). Scholars found comparable results: the acceptable boundaries for temperature are between 20 °C and 24 °C, depending on the season. It is recommended to follow the outside air temperature to the extremes of this range since this will limit the experienced 'shock' when entering or leaving the building (Al Horr et al., 2016; Clements-Croome, 2018; Fassoulis & Alexopoulos, 2015; Ghaffarianhoseini et al., 2018; Kropman et al., 2023; Vimalanathan & Babu, 2014). In addition, scholars state that the ideal RH is between 40 and 60% to limit irritations of the throat or eye, as well as other negative influences on *physical health* (Colenberg et al., 2021; Ghaffarianhoseini et al., 2018; Kropman et al., 2023; R. Wiik, 2011). Lastly, too-high temperatures were found to influence the performance of workers more negatively than too-low temperatures (Kropman et al., 2023), and the effects of crossing the boundaries on both ends of the RH range were found equally bad for the *health* of employees (Dimitroulopoulou et al., 2023).

Filtration: Biological and chemical particles

High levels of humidity, in combination with high temperatures, low ventilation rates, improper maintenance of the HVAC system and/or a closed building envelope, can cause the formation of biological particles like mould and fungi (Arundel et al., 1986; Clements-Croome, 2018; Ghaffarianhoseini et al., 2018; Magalhães Rios et al., 2009). These may have an indirect effect on *physical and mental health*, especially the risk of cardiovascular diseases, respiratory diseases, nose and throat irritations, headaches, and mental fatigue (Arundel et al., 1986; Ghaffarianhoseini et al., 2018; Kropman et al., 2023). Furthermore, high humidity levels can cause bad odours from people or the environment. Potentially influencing the *social climate* in the workplace; bad smells decrease tolerance towards colleagues, which could initiate voluntary isolation, leading to a lack of trust and alienation (Colenberg et al., 2021). In addition to biological particles, chemical particles influence the employee's *health*. In 'sealed-off buildings', high levels of chemical particles like benzene and volatile organic compounds (VOCs), including formaldehyde, were found due to the recirculation of indoor air (Magalhães Rios et al., 2009; Sundell et al., 2011). Surprisingly, newly constructed buildings negatively influence employees' physical and mental *health* due to chemical contributors, such as freshly painted surfaces or furniture and office equipment. Often, the used materials are toxic and not natural (Ghaffarianhoseini et al., 2018; Kekäläinen et al., 2010). To prevent the direct and indirect *health* benefits from either biological or chemical particles, ventilation rates up to 25 L/s/person can be implemented (Ghaffarianhoseini et al., 2018; Sundell et al., 2011; Wargocki et al., 2004).

Both Kim et al. (2011) and Smith & Pitt (2011a) show that plants and ventilation can reduce airborne polluters (e.g., formaldehyde) and influence the physical and mental *health* of occupants. Passive ventilation can also prevent high concentrations of biological and chemical particles. It should be noted that outdoor air is not always better than indoor air (Kumar et al., 2023).

2.2.1b Lighting

Lighting quality and quantity influence *physical* and *mental health*. In this section, the different parts of lighting will be discussed: the presence and amount of natural light, glare, personal control Corrected Colour Temperature (CCT) and illuminance. The design elements are shown in Figure 11 and discussed in the section below.

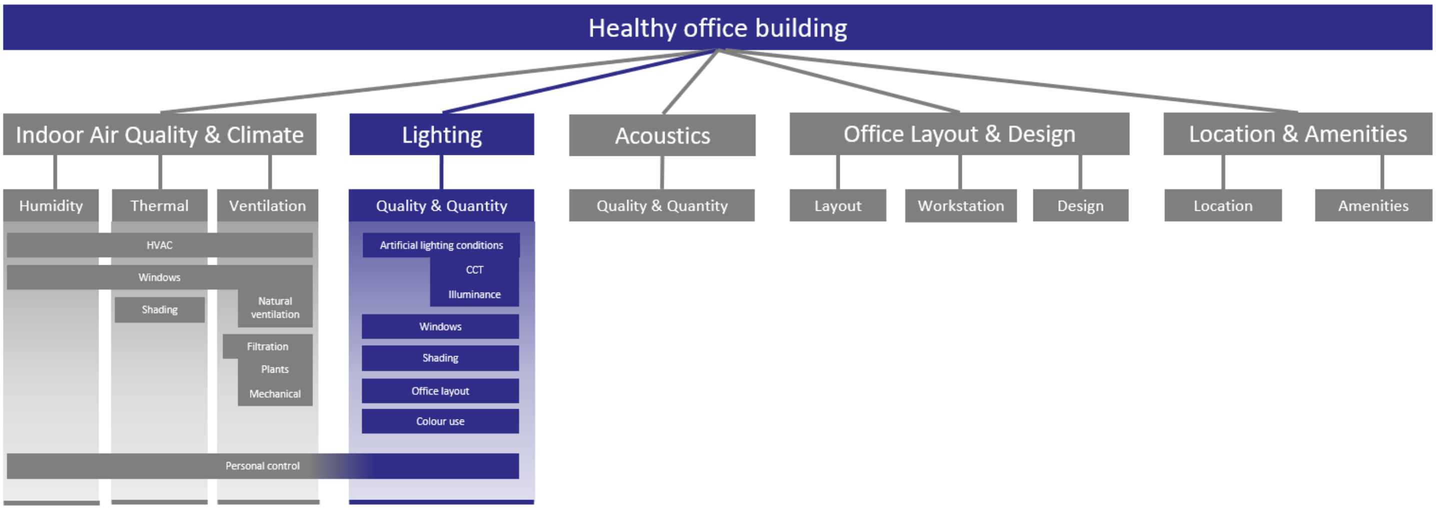

Figure 11; Building design elements in offices influencing the Lighting.

Natural Light & Glare

Daylight exposure can influence the physical and mental *health* of employees. It reduces light-headedness and blurred vision and increases eye *health* (Ghaffarianhoseini et al., 2018; van Duijnhoven et al., 2019). On the other hand, high levels of artificial lighting cause more sleepiness during the day and sleeplessness during the night. However, it is essential to perform a task at the offices. By providing appropriate daylight exposure, potential stress, chance of depression, and mental fatigue can be decreased, while sleep quality can be increased (Colenberg et al., 2021; Kropman et al., 2023). Skylights can provide daylight at locations in the building outside the proximity of windows. The arrangement of the office layout and the use of light colours in the office design can also influence the natural lighting conditions inside the building (Kropman et al., 2023). However, too much daylight or artificial light can result in glare, which decreases employees' visual comfort and mood. Sunlight shading can be implemented inside or outside the building to prevent this (Kropman et al., 2023; van Duijnhoven et al., 2019). Control over lighting and glare, like blinds or individual desk lamps, influences physical and mental *health* through more musculoskeletal comfort (Colenberg et al., 2021) and better mood (Kropman et al., 2023).

Colour Correlated Temperature (CCT)

If artificial light is applied in the workplace, blue-enriched light has been found to provide more visual comfort, indicating that a high CCT is beneficial for employees (Colenberg et al., 2023). A CCT of 17.000 K, on the blue side of the light spectrum, has been found beneficial for the quality and duration of the employee’s night rest (Ghaffarianhoseini et al., 2018; van Duijnhoven et al., 2019) due to better regulation of melatonin (Colenberg et al., 2023). Stressing the impact of a workplace on employees after business hours. An appropriate CCT can also reduce the chances of fatigue, stress (Kropman et al., 2023), light-headedness, eye discomfort (fatigue, irritability), blurred vision and eye strain (van Duijnhoven et al., 2019).

Illuminance

Appropriate illuminance, the lighting density, can be reached by implementing appropriate lighting or exposure to daylight (van Duijnhoven et al., 2019). Illuminance conditions of 1.000 lx benefit *health* compared to (dim) lighting below 51 lx. A relation between the illuminance of light and skin dryness, headache and malaise was found (van Duijnhoven et al., 2019), as well as sleep quality, mood, and mental fatigue (Kropman et al., 2023).

2.2.1c Acoustics

Multiple factors can cause noise in the workplace, influencing *physical, mental, and social health*. Sound is always present as low-frequency noise (20-100 Hz) from building systems, conversations by colleagues, or sounds from outside the building. This sound may be experienced as disturbing by employees, influencing their *physical, mental, and social health*. The layout, used materials, and provision of speech privacy and control may influence *health* positively. The design elements are shown in Figure 12 and discussed in the section below.

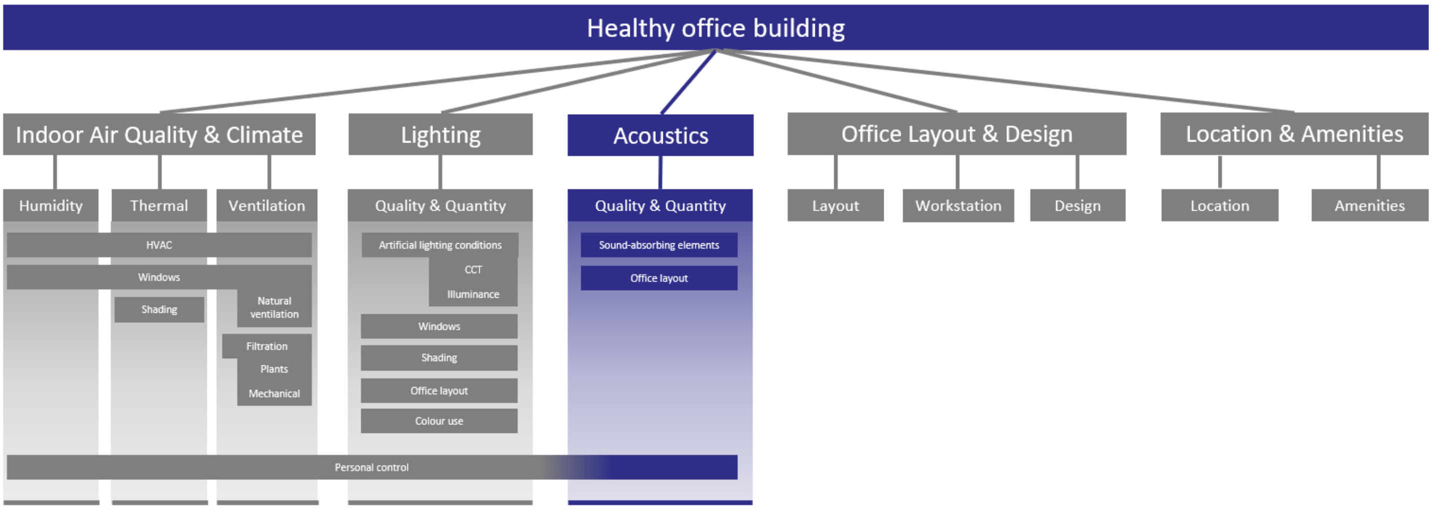

Figure 12; Building design elements in offices influencing the Acoustics.

Sound-absorbing elements

Sound-absorbing design elements are necessary to limit the unbalanced background sound and maintain an appropriate sound level on an open floorplan. The shape of the interior, the materials used, and the textures of the surfaces influence the transmittance of sound. The space design should follow its functions: areas for conversation should invite this, and vice versa (Clements-Croome, 2018; Colenberg et al., 2023). Furthermore, sound-absorbing elements like level-adaptive sound masking in the workplace, providing more control over the sound levels (Bergefurt et al., 2024), could be implemented, increasing the satisfaction rate (Kropman et al., 2023). By creating a clustered layout, implementing level-adaptive sound masking elements or glass can maintain an appropriate sound level while preventing *anonymity* and *alienation* (Colenberg et al., 2023).

Office layout

Sound primarily influences *mental and social health* (Ghaffarianhoseini et al., 2018). Unbalanced background noise can potentially increase mental fatigue, stress, and the chance of depression and/or annoyance towards loud colleagues (Colenberg et al., 2021; Kropman et al., 2023). Physical drawbacks of noise are noticeable in the employees' heart rate, eye activities, and working memory (Kropman et al., 2023). *An open floorplan primarily influences social health* since it lacks dedicated places for social contact and easily transmits sound over a great distance. Due to noise complaints, employees are less satisfied with team members, causing negative interpersonal relationships (Colenberg et al., 2021; Danielsson & Bodin, 2008)., 2021; Danielsson & Bodin, 2008). The same challenges for providing noise control in open-plan offices are faced for air quality control and lighting control (Kropman et al., 2023). Headphones with music are currently the main solution adopted by workers to filter irrelevant speech noise in open-plan offices (Di Blasio et al., 2019).

2.2.1d Office Layout & Design

Office layout and design influence the *physical, mental, and social health* through the type of offices, layout, furniture used, colours, and greenery. The design elements are shown in Figure 13 and discussed in the section below.

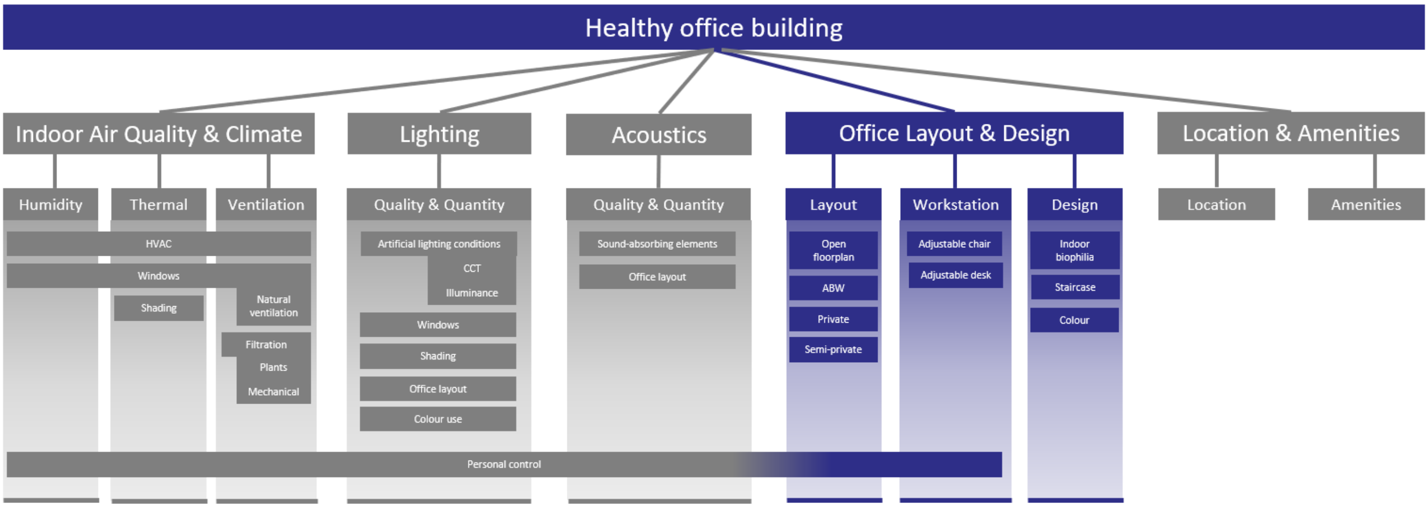

Figure 13; Building design elements in offices influencing the office Layout & Design.

Layout: Type of offices

Private offices were found to be the most beneficial for employees' mental *health* compared to open-plan offices since they reduce stress (Colenberg et al., 2021; Kropman et al., 2023). Private offices also cause fewer colds and lower sick leave rates (Colenberg et al., 2021). However, due to physical separation among employees, private offices cause loneliness and less social cohesion, negatively influencing *social health* (Colenberg et al., 2021).

Semi-private offices with cluster sizes of 2-5 people were found to be ideal for productivity and engagement due to physical activity, a reduction in stress levels, and the formation of friendships (Colenberg et al., 2021). Visual and acoustical separation of clusters is rather important, especially in open-plan offices (Di Blasio et al., 2019; Rasheed et al., 2019), as discussed in section 2.3.1c.

Most frequently, open-plan offices are implemented since they are easier to reconfigure and house more employees. Thus, they are more economically beneficial for employers (Kekäläinen et al., 2010; Rasheed et al., 2019). The open structure creates visibility, supporting connectedness and informal social interactions (Colenberg et al., 2023; Rasheed et al., 2019), reducing the feeling of being ‘locked up’ and benefitting *mental* and *social health* (Colenberg et al., 2023). It also forces people to be more physically active, which is beneficial for the physical *health* of employees (Candido et al., 2019; Engelen et al., 2017; Haapakangas et al., 2018; Lindberg et al., 2018).

Layout: Activity Based Working

Activity Based Working (ABW) is a new workplace design concept, that provides workers with a choice of workplace settings for different activities. The key principle behind ABW is that the space is designed to support specific tasks (collaboration, concentration, and speech privacy). This is done by providing unassigned and shared desks and supporting technology that enables mobility and remote working

(Candido et al., 2019; Haapakangas et al., 2018). ABW can easily be implemented in an open-floorplan design (Haapakangas et al., 2018). Implementing zones (breakout or leisure rooms) dedicated to silent working or conversation (Kropman et al., 2023) or a difference in temperature or lighting provides more flexibility. This flexibility may compensate for the lack of personal control in an open-plan office, increasing the workers' satisfaction (Candido et al., 2019; Haapakangas et al., 2018; Kropman et al., 2023). Without negatively influencing an open plan office's positive physical and social benefits (Haapakangas et al., 2018). Colenberg et al. (2023) found that the ABW concept has some key principles for a socially *healthy* workplace, like 'offering choice' and 'offering facilities for informal activities'.

Workstation

It was found by scholars that standing and cycling as well as an adjustable chair reduce the musculoskeletal discomfort of employees, hence the introduction of the sit-stand desk and a bike desk. (Clements-Croome, 2018; Colenberg et al., 2021).

Design

The implementation of greenery in the workplace has multiple benefits for the *physical*(Smith & Pitt, 2009), *mental* (Kropman et al., 2023), and social *health* of occupants (Colenberg et al., 2021). Using plants can reduce airborne pollutants (e.g. formaldehyde) and increase the physical well-being of occupants (Colenberg et al., 2021; Smith & Pitt, 2009). Plants also reduce the stress and chance of depression. However, too many plants in the workplace can be perceived as chaotic and can cause distraction, which diminishes its benefits (Kropman et al., 2023). The optimal amount seems to be 1 to 3 plants in one room (Smith & Pitt, 2009) (Kropman et al., 2023). Lastly, employees experienced more organisational support due to the sufficient number of real plants in the workspace. Organisational support considers the level of employees' needs and wishes and influences *mental* and *social health* (Colenberg et al., 2021).

An open-floorplan office design may also support the use of the staircase; due to increased visibility, people may use the stairs more often and become *physically healthy* (Michalchuk et al., 2022; Zhu et al., 2020).

Lastly, scholars have shown that a space's look, colours, and feel can influence the employee positively or negatively. Implementing natural materials and colours are often associated with better *health* conditions among employees (Al Horr et al., 2016).

2.2.1e Location & Amenities

The following section will consider outdoor green elements, including access to it and its visual quality, as well as the provision of active and/or public transportation facilities and other amenities to support connection of the building with the surroundings. The design elements are shown in Figure 14 and discussed in the section below.

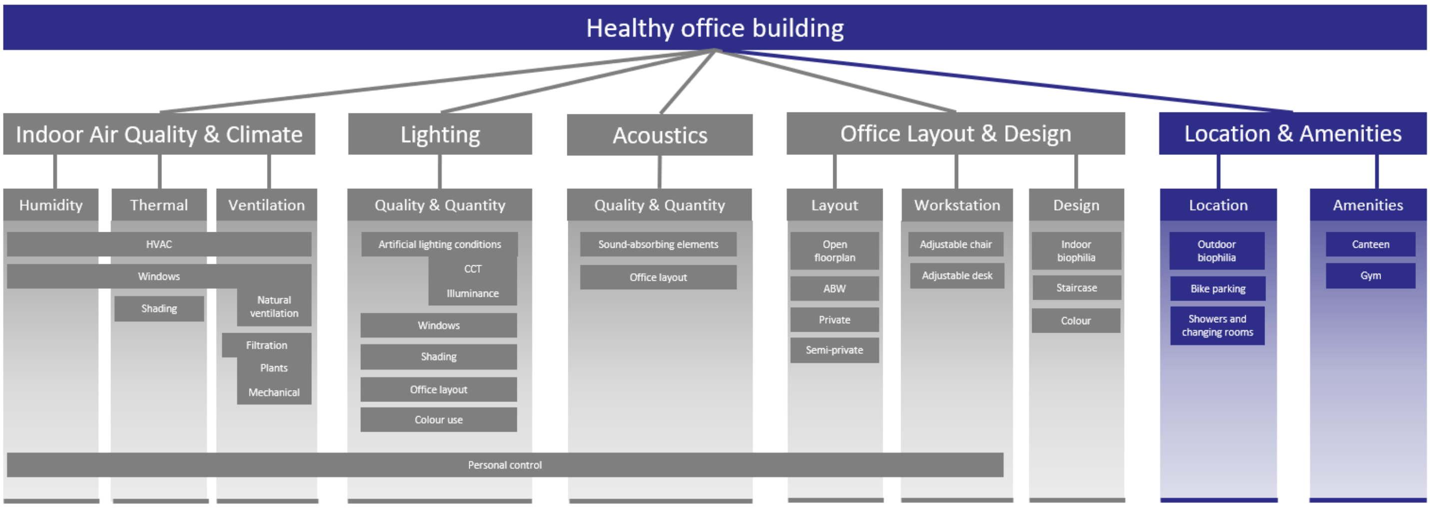

Figure 14; Building design elements in offices influencing the Location & Amenities.

Outdoor Biophilia

A real view of nature has a high restorative quality; it causes stress and mental fatigue to decrease (Kropman et al., 2023). The presence of nature in the surroundings also causes a quicker recovery from physical illnesses (Colenberg et al., 2021). Access to green is found even more effective due to the stimulation of multiple senses. The experience is more intense (Clements-Croome, 2018; Gilchrist et al., 2015; Kropman et al., 2023; Sadick & Kamardeen, 2020). The view, feel, and smell of nature influence the release of hormones, which positively influence cortisol levels, pulse rates, blood pressure, glucose levels, and serotine-melatonin balance. This influences the mood and energy of the employee (Clements-Croome, 2018; Kropman et al., 2023), as well as their sleep quality (Gilchrist et al., 2015; Kropman et al., 2023) and stress (Sadick & Kamardeen, 2020). The duration of physical exposure to green was found to be more important than the frequency (Gilchrist et al., 2015), therefore, greenery should be easily accessible.

Amenities

If amenities are within walking or cycling distance, people are more likely to use active transportation, which is beneficial for *physical* and *mental health* (Khavarian-Garmsir et al., 2023) (Schäfer et al., 2020). A building can facilitate amenities as well (Colenberg et al., 2023; Haapakangas et al., 2018; Kropman et al., 2023); the type of amenities is comparable to the ones discussed in section 2.2.1d. Naturally, providing a gym is beneficial for *physical health* (Zhu et al., 2020). Additionally, a canteen provides an area for social contact (Corvo et al., 2020) and more control by the employer over the *health*iness of the food employees consume (Maes et al., 2012; Zhu et al., 2020). Besides that, facilitating active transportation through specific amenities like bicycle parking, showers, and/or changing rooms is effective (Zhu et al., 2020). The use of active transportation is good for the physical and mental *health* of employees (Fan et al., 2021; Petrunoff et al., 2016), and the use of public transportation is good for the physical and social *health* of employees while less positive for *mental health* (Petrunoff et al., 2016; Zhu et al., 2020). One can reduce the perceived proximity to public transportation options to make its use more enticing.

2.3 *Environmentally Sustainable* & *Healthy* Building Design

This section will introduce the Shearing Layer concept and categorise the building elements of an *environmental sustainable* building and a *healthy* building as discussed in the previous sections using this concept.

2.3.1 Shearing Layer Concept

The relevance of conceptualising a building becomes apparent when considering a building's complexity. A building system consists of different functions, materials, and elements integrated into a closed rigid system. This rigid integration often ignores the difference in durability. The lifespan of individual elements is often shorter than the total lifespan of a building. A building is thus rather difficult to adapt or alter to the changing needs and standards of users and society (Askar et al., 2021), while it is of great importance when creating or maintaining its *environmental* and *social sustainability* (He et al., 2021a; Jensen et al., 2022; Pombo et al., 2016). Yearly, only …% of the building stock is replaced. Thus, the existing building stock needs to be renovated to comply with governmental bodies' and users' future needs and wishes. Interventions to make buildings 'Paris Proof' will be done at different layers of the building and, consequently, will have different magnitudes of effect. By organising design elements in layers, workplace managers and asset managers can make a more informed decision on the potential *environmental sustainability* and *health* benefits (Askar et al., 2021).

Two concepts emerge in relation to 'adapting buildings': The *Open Building concept* (Habraken, 1960) and the *Shearing Layer concept* (Brand, 1994). Both use the same principle: a building design needs to be adaptable to change that may not be foreseen. The Op*en Building concept* divides the building into two: the structure and the infill. The *Shearing Layer concept* provides more nuances and divides the building into six layers: *Site, Structure, Skin, Services, Space Plan*, and *Stuff*. The *Shearing Layer concept* is most often used to conceptualise a building based on the lifespan of different elements, as it relates to the magnitude of influence of the design elements in the layer (Askar et al., 2021; Charef et al., 2022; Nußholz et al., 2023). Using the layers can help design *sustainable* buildings (Askar et al., 2021; Charef et al., 2022; Nußholz et al., 2023), assessing certification tools (Pushkar & Verbitsky, 2018), or categorising design elements (Pushkar, 2015). Comparing the *Shearing Layer concept* to the *Open Building concept*, the first is more detailed and nuanced, which provides a better insight into the effectiveness of measures.

The *Shearing Layers concept* conceptualises a building into different layers, as shown in Figure 15. The differentiation is as follows: *Site* (>300 years), *Structure* (50-300 years), *Skin* (20-50 years), *Services* (10-20 years), *Space Plan* (3-10 years) and *Stuff* (1> year) (Brand, 1994). The first three layers can be

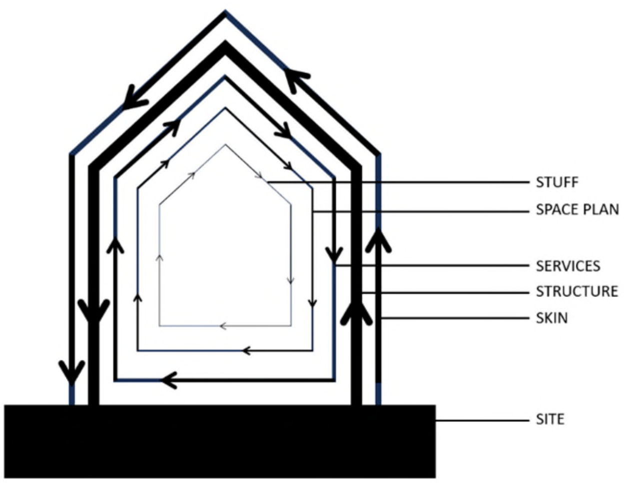

Figure 15; The Shearing Layer concept (Brand, 1994).

combined as the *Building Layer*, while the other three can be combined as the *Service Layer*. Scholars found that due to the 'easiness of change', the *Service Layer* is much more important during the renovation of existing buildings than the *Building Layer*, while for newly constructed buildings, the *Building Layer* is the most important because of its long lifetime (Pushkar & Verbitsky, 2018).

Figure 16, on page 32, shows that the design elements discussed in Chapter 2.1 and Chapter 2.2 are presented and organized according to the *shearing layer concept*. The "T" indicates a trade-off; the design element either benefits *environmental sustainability* or *health*, while causing a drawback for the other. The "S" indicates a synergy; the design element benefits both *environmental sustainability* and *health*. Lastly, a "?" indicates that the effects of the design element remain inconclusive. The design element may cause a drawback and a benefit for *environmental sustainability* or *health* simultaneously. This requires additional discussion. Thus, the effects of the design elements on *environmental sustainability* and *health* of the office building will be discussed in the sections after the figure.

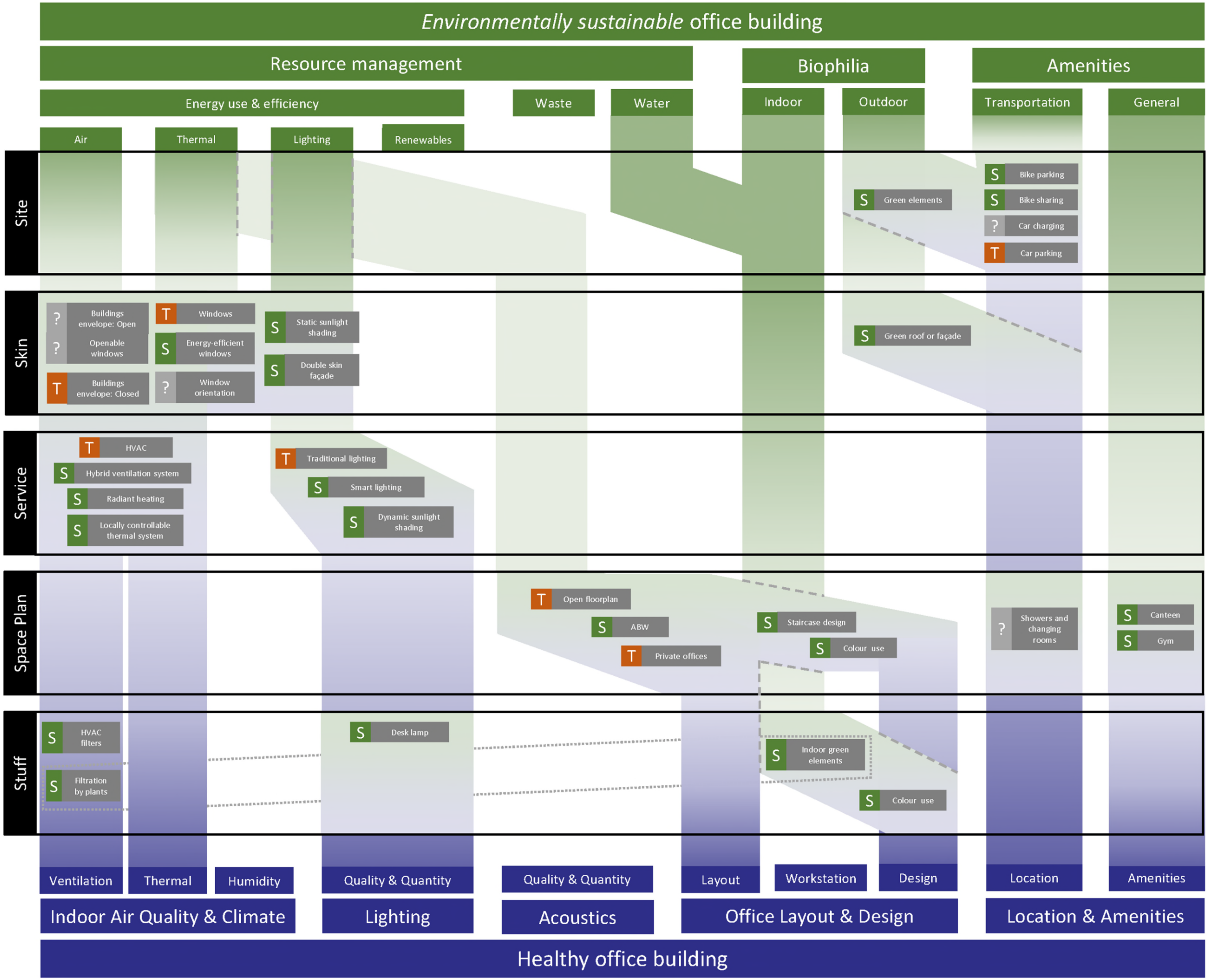

Figure 16; Combination of relevant design elements for environmnetal sustainability and health.

2.3.1a Site

The first shearing layer, the site of a building, has a lifespan of more than 300 years. Brand (1994) states the importance of the connection and fit of a building with its surroundings using greenery, transportation facilities and other amenities on the *Site*. Table 1 shows the results of combining both concepts from the literature review. As has been shown in Figure 16 as well. Most design elements are synergies, only one is a trade-off; they will be explained in more detail below the Table.

Table 1; Design elements in the Site layer.

Site		
	Biophilic design	
	Outdoor green elements	S
	Transportation amenities	
	Bike parking	S
	Bike-sharing amenities	S
	Electric car charging amenities	?
	Car parking	T

Biophilic design

Outdoor greenery has multiple benefits; by means of implementing biodiversity-enhancing green elements, the connection of the site with the urban greenery is made (Calcagni & Calenzo, 2023; Rodrigues et al., 2023; Zuo & Zhao, 2014). Outdoor greenery can also protect a building from flooding during extreme rainfall, which can be combined with rainwater harvesting to decrease water use. These measures benefit *environmental sustainability*.. Simultaneously, on-site greenery can increase *health* by providing a view or access on/to nature (Al Horr et al., 2016; Ghaffarianhoseini et al., 2018; Kropman et al., 2023). Combining these benefits shows that outdoor green elements serve as a synergy, as indicated in Table 1.

Transportation amenities

The site is influenced by, and can influence, the availability of transportation options. It can facilitate amenities that reduce the perceived proximity to public transportation (e.g. shared biking) (Gallo & Marinelli, 2020) or the availability of active transportation amenities (e.g. bike parking) (Park et al., 2024). Both positively influence *environmental sustainability* by reducing indirect GHG emissions and *health* by providing physical activity. Active transportation methods may experience a synergetic relationship between *environmental sustainability* and *health*. However, since active and public transportation availability remains location-dependent, facilitating this may be complex. Passive transportation methods have different effects on *health*; travelling by car may positively influence *mental health* but can be a drawback for *physical health.* Passive travel is experienced as more comfortable than active travel, influencing *mental health* for some people positively (Al Horr et al., 2016; Chatterjee et al., 2020). However, at least partially, this can be mitigated by providing car charging amenities.

2.3.1b Skin

The *Skin Layer* is the exterior surface, envelope, of a building. It includes the façades, windows and roof of a building. The *Skin* has a lifespan of approximately 20 to 50 years (Brand, 1994), and protects the users of a building from external factors like weather conditions, pollution, and sunlight. It is an important layer for both *environmental sustainability* and *health* (Pushkar & Verbitsky, 2018).

Table 2; Design elements in the Skin layer.

Skin				
	Biophilic design			
		Green roof or façade		S
	Air ventilation system			
		Building envelope: Open		?
			Openable windows	?
		Building envelope: Closed		T
	Windows			
		Windows		T
			Energy-efficient windows	S
		Window orientation		?
		Static sunlight shading		S
	General			
		Double skin façade		S

Biophilic design

Greenery on the façade or roof of a building has comparable benefits for *environmental sustainability* and *health*, as discussed in the previous section on 'outdoor green elements'. Greenery on the skin can enhance the connection with urban greenery (Calcagni & Calenzo, 2023; Rodrigues et al., 2023; Zuo & Zhao, 2014); it can also function as a water buffer for extreme rainfall. In addition, the environment is positively influenced by the cooling qualities of greenery, potentially reducing an office's energy use. Green façades provide a view on green, and green roofs can provide access to green for building occupants, influencing *health* positively (Al Horr et al., 2016; Ghaffarianhoseini et al., 2018; Kropman et al., 2023). In conclusion, greenery on a building's skin may be a synergy, as indicated in Table 2.

Air ventilation system

Implementation of passive ventilation reduces the energy expenditure of an HVAC system. Passive ventilation can be implemented using an open building envelope, openable windows, or an atrium. The latter will be discussed in the *Structure* layer due to its relation with a building's structure. The effectiveness of passive ventilation for *health* is more nuanced; scholars mention that it can reduce the concentration of biological and chemical particles (Kim et al., 2011; Smith & Pitt, 2011). However, potential drawbacks are presented as well; a constant airflow is required for a sufficient IAQ, but if passive ventilation is implemented, this may not be possible (Al Horr et al., 2016; Calcagni & Calenzo, 2023). Besides that, the outdoor air is not always better than the indoor air; thus, replacing indoor air with outdoor air may not be beneficial for *health*(Kumar et al., 2023). An open building envelope has benefits for *environmental sustainability* and a positive or negative influence on *health*; it could be a synergy or a trade-off depending on the local airflow and the building's location.

A closed building envelope is considered energy-efficient as well; by recirculating air, it reduces the energy burden of the HVAC systems (Chenari et al., 2016; Felius et al., 2020; J. T. Kim & Yu, 2018; Spiru & Simona, 2017). *Health* may be a drawback due to the high dependency on the HVAC system. Malfunction in an HVAC system often happens and causes increased levels of humidity; high temperatures in combination with low ventilation rates cause the formation of biological particles like mould and fungi in a closed building envelope (Arundel et al., 1986; Clements-Croome, 2018; Ghaffarianhoseini et al., 2018; Magalhães Rios et al., 2009). A closed building envelope benefits *environmental sustainability* and causes drawbacks for *health*.

Windows

Windows are a drawback for *environmental sustainability* since they cause energy leakage. The drawback can be minimised by implementing energy-efficient windows. Besides that, windows can also gain energy; solar-oriented windows allow heat to enter the building, and smart window orientation can maximise its benefit. However, too much heat gain increases the cooling needs of the building (Calcagni & Calenzo, 2023; Hashempour et al., 2020; J. T. Kim & Yu, 2018). For *health*, windows are essential; they provide daylight, influencing employees' *physical* and *mental health* (Ghaffarianhoseini et al., 2018; van Duijnhoven et al., 2019). However, too much daylight can result in overheating and glare, which decreases employees' visual comfort and mood (Kropman et al., 2023; van Duijnhoven et al., 2019). A balanced situation needs to be designed using static sunlight shading and window orientation, optimising energy efficiency without reducing the lighting or thermal conditions of a building too much (Hashempour et al., 2020; J. T. Kim & Yu, 2018). Energy-efficient windows are a synergy that saves energy and provides daylight. Window orientation can be synergy depending on the implementation and orientation; too much solar gain causes overheating. Lastly, static sunlight shading is a synergy since it limits overheating and glare.

Other: Double skin façade

The thermal conditions of a building can be maintained by a double skin (Calcagni & Calenzo, 2023; Chenari et al., 2016; J. T. Kim & Yu, 2018). Besides that, a double-skin façade can optimize daylight conditions (Chenari et al., 2016). A thermally comfortable and well-lit indoor area is also beneficial for *heath* (Ghaffarianhoseini et al., 2018; van Duijnhoven et al., 2019). Hence, a double-skin façade may be a synergy.

2.3.1c Services

The *Services layer* includes the building service; the design elements supporting the indoor environment using (mechanical) installations. The building services control the IAQ by heating, ventilation and cooling; they also control the lighting conditions and resource (water) management. This layer contains the most unique design elements influencing *environmental sustainability* and seems to have the potential to influence *environmental sustainability.*

Table 3; Design elements in the Service layer.

Services			
	Heating, Ventilation & Cooling		
		HVAC system	T
		Hybrid ventilation system	S
		Radiant/Floor heating	S
		Locally controllable thermal system	S
	Lighting system		
		Traditional artificial lighting	T
		Smart lighting	S
		Dynamic sunlight shading	S

Heating, Ventilation & Cooling

The HVAC system influences the air and thermal conditions of a building by using energy and is a great (negative) contributor to its *environmental sustainability*(Calcagni & Calenzo, 2023; Felius et al., 2020; Hashempour et al., 2020; Meena et al., 2022; Pombo et al., 2016; Rodrigues et al., 2023; Si et al., 2016). Consequently, the HVAC system influences *health* positively by controlling the temperature, relative humidity and ventilation (Ghaffarianhoseini et al., 2018; Kim et al., 2011; Smith & Pitt, 2011b). The HVAC system ensures that the standards the WHO advises for temperature (WHO, 2018b) and RH (WHO, 2009) are attained. The HVAC system creates a trade-off by benefitting *health* at the cost of *environmental sustainability*.

Due to the high energy expenditure of the HVAC system, scholars have been seeking more energy-efficient methods. A hybrid ventilation system is proposed, utilizing natural airflow to limit energy use in the ventilation system (Chenari et al., 2016; Dimitroulopoulou et al., 2023; Zhang & Srinivasan, 2020). As mentioned in relation to passive ventilation, some scholars also present potential *health* drawbacks; a constant airflow may not be possible, while it is needed for a sufficient IAQ (Al Horr et al., 2016; Calcagni & Calenzo, 2023). Hence, hybrid ventilation may remain a trade-off by benefitting *environmental sustainability* at the cost of *health*. Alternatively, it could be a synergy by benefitting both.

A more energy-efficient method than an HVAC system is radiant heating; it uses less energy and maintains a more constant IAQ; thus, it is more energy-efficient (Chwieduk, 2003; Norton et al., 2021). Besides that, a more constant IAQ is beneficial for *health* as well. Radiant heating may be a synergy.
A locally controllable system answers employees' need to control their workplace. The provision of personal control influences *employees' health*, as it leads to increased satisfaction with the IAQ, benefitting occupants' sleep quality and mood (Kekäläinen et al., 2010; Kropman et al., 2023).

Lighting System
Traditional artificial lighting experiences the same benefits and drawbacks as an HVAC system. Using energy to control IEQ, negatively influences *environmental sustainability* (Hashempour et al., 2020; Meena et al., 2022; Norton et al., 2021) and positively influences *health* (Ghaffarianhoseini et al., 2018; van Duijnhoven et al., 2019). Traditional artificial lighting is a trade-off if natural daylight is ignored.
Smart lighting automatically dims or switches the light off in spaces that are not in use, preventing unnecessary use of energy (Hashempour et al., 2020; Meena et al., 2022; Norton et al., 2021). It optimizes daylight conditions and reduces the need for lighting (Hashempour et al., 2020; Si et al., 2016). Benefitting *environmental sustainability*. On the other hand, smart lighting provides control over IEQ and optimizes daylight conditions (Kropman et al., 2023). Both are beneficial for *health* since they reduce stress, the chance of depression and mental fatigue (Colenberg et al., 2021; Kropman et al., 2023). Smart lighting may be a synergy.

Dynamic sunlight shading is shading which provides control for the occupant. The effectiveness of *environmental sustainability* remains the same; it shields the building from solar heat (Hashempour et al., 2020; J. T. Kim & Yu, 2018). Besides that, it still limits glare, increasing visual comfort and mood of employees (Kropman et al., 2023; van Duijnhoven et al., 2019). Moreover, it provides control over lighting and glare, positively influencing *physical* and *mental health* through higher musculoskeletal comfort (Colenberg et al., 2021) and better mood (Kropman et al., 2023). In conclusion, dynamic sunlight shading has the potential to be a synergy.

2.3.1d Space Plan

The *Space Plan Layer* includes partition walls, ceilings, floors, and doors; its lifespan varies between 3 and 10 years (Brand, 1994). The building user typically furnishes a building, making the owner's influences minimal (Pushkar & Verbitsky, 2018). As was shown in Figure 16, the Space Plan layer seems to have a considerable influence on *health*. The following section will discuss the design elements relevant to both *environmental sustainability* and *health* and will briefly discuss the excluded design elements.

Table 4; Design elements in the Space Plan layer.

Space Plan			
	Amenities		
		Showers and changing rooms	?
		Gym	S
		Canteen	S
	Layout & design		
		Open floorplan	T
		ABW offices	S
		Private offices	T
		Staircase design	S
		Colour use	S

Amenities
The provision of showers and changing rooms may positively influence the use of active (and passive) transportation. Indirect CO_2 emissions caused by transportation can be decreased by promoting

active transportation (e.g. bike or foot) (Gallo & Marinelli, 2020; Park et al., 2024; Wen et al., 2020). Showers use water to function, which may cause environmental drawbacks (Calcagni & Calenzo, 2023). The use of active transportation can be beneficial for *physical* and *mental health* (Khavarian-Garmsir et al., 2023) (Schäfer et al., 2020). The effectiveness of showers and changing rooms is limitedly supported academically (Zhu et al., 2020) while being an often-used approach by employers (Rijksoverheid, 2024). In conclusion, showers and changing rooms can benefit *environmental sustainability* and *health,* while the water use of showers may diminish the environmental benefits.

A gym and a canteen can create a more attractive office, which may cause trip combination; employees combine trips that would otherwise be separated, generating a higher GHG emission (Khavarian-Garmsir et al., 2023). Amenities in an office building have several *health* benefits. A canteen has the potential to provide *healthy* food (Maes et al., 2012; Zhu et al., 2020) and social contact (Corvo et al., 2020), and a gym has the potential to increase physical activity among employees (Zhu et al., 2020). Amenities with *health* benefits may include more than a gym and a canteen alone; only two have been selected to control the total design element included in this research. Amenities like a gym or a canteen can benefit *environmental sustainability* and *health*, causing them to be a synergy.

Layout & design

The layout of an office influences *health* primarily. The arrangement of the office layout can influence the thermal, natural lighting, and acoustical conditions of a building. This may also influence the *environmental sustainability* of a building. For example, the provision of natural lighting reduces the need for artificial lighting (Hashempour et al., 2020; Si et al., 2016).

An open floorplan allows for deep penetration of natural lighting, which benefits *physical* and *mental health* (Kropman et al., 2023) and *environmental sustainability* (Hashempour et al., 2020; Si et al., 2016). On the other hand, an open floorplan often lacks dedicated places for social contact and easily transmits sound over a great distance, influencing *mental* and *social health* (Ghaffarianhoseini et al., 2018). Unbalanced background noise can potentially increase mental fatigue, stress, and the chance of depression and/or annoyance towards loud colleagues (Colenberg et al., 2021; Kropman et al., 2023). Concluding, it may benefit *environmental sustainability* at the cost of *health*; an open floorplan causes a trade-off.

Cellular and ABW offices can be placed between an open floorplan and private offices; they will be discussed as ABW offices in this thesis since cellular offices are most common in the US and less applicable to the Dutch corporate real estate market. In an ABW, the space is designed to support specific tasks (such as collaboration, concentration, and speech privacy). This is done by providing unassigned and shared desks and supporting the technology that enables mobility and remote working. They are considered by multiple scholars as a resource for *health* (Candido et al., 2019; Haapakangas et al., 2018), while their influence on *environmental sustainability* remains uncertain. Scholars have stated that an ABW office layout can compensate for the lack of personal control in an open-plan office, without negatively influencing the positive physical and social effects of an open plan office (Candido et al., 2019; Haapakangas et al., 2018; Kropman et al., 2023). Eliminating the *health* drawbacks of an open floorplan while utilising its *environmentally sustainable* benefits, the ABW office may be a synergy.

Private offices may provide the potential for segmented heating, causing comparable benefits as has been discussed for locally controllable thermal systems. Besides that, private offices are beneficial for physical by limiting the spread of respiratory viruses (Colenberg et al., 2021); it is also a resource for *mental health* by reducing stress and increasing sleep quality (Colenberg et al., 2021; Kropman et al., 2023). However, it negatively influences social *health* due to physical separation, causing lower social cohesion and loneliness (Colenberg et al., 2021). Private offices may also experience a synergy.

An attractive staircase design may attract more people. Reducing elevator usage, consequently reducing the energy expenditure of a building, is beneficial for a building's resource management (Wijesooriya & Brambilla, 2021). Besides that, staircase use has *physical health* benefits (Michalchuk et al., 2022; Zhu et al., 2020). Consequently, a staircase may be a synergy.

Colours can optimise daylight conditions, reducing the need for lighting and thus reducing the energy demand (Calcagni & Calenzo, 2023; Hafez et al., 2023). Colours also influence the natural lighting conditions inside the building (Kropman et al., 2023). The use of natural and light colours may be beneficial for *health* (Al Horr et al., 2016). Colour use has the potential to cause a synergy.

2.3.1e Stuff

The final layer, the *Stuff Layer,* includes the most miniature objects in an office, like chairs, desks, and even phones. The lifespan varies from a few days to a few years (Brand, 1994). The building user usually furnishes a building; thus, the influence of the building owner is limited in this layer (Pushkar & Verbitsky, 2018).

Table 5; Design elements in the Stuff layer.

Stuff			
	Biophilic design		
		Green elements	S
	Heating, Ventilation & Cooling		
		HVAC filters	S
	Lighting system		
		Desk lamp	T
	Layout & design		
		Colour use	S

Biophilic design

Indoor green elements influence the building's energy performance; they are able to increase the IAQ by filtering the air and maintaining comfortable thermal conditions (Calcagni & Calenzo, 2023; Norton et al., 2021) (Wijesooriya & Brambilla, 2021). Additionally, the air filtering capabilities are beneficial for *physical health* (Colenberg et al., 2021; Smith & Pitt, 2009), and the calming capabilities are beneficial for *mental health* (Kropman et al., 2023). In conclusion, indoor green elements may experience a synergy.

Heating, Ventilation & Cooling

The primary function of HVAC filters is to limit the risk of the formation of biological particles like mould and fungi and benefit *physical and mental health*, limiting the risk of cardiovascular diseases, respiratory diseases, nose and throat irritations, headaches, and mental fatigue (Arundel et al., 1986; Ghaffarianhoseini et al., 2018; Kropman et al., 2023). By efficient air filtration, the replacement rate of air could be reduced, increasing the energy efficiency of the HVAC system (Calcagni & Calenzo, 2023; Felius et al., 2020; Hashempour et al., 2020; Meena et al., 2022; Pombo et al., 2016; Rodrigues et al., 2023; Si et al., 2016).

Lighting system

A desk lamp is implemented to benefit *health*. However, it uses energy to light the desk, which causes an *environmental sustainability* drawback (Wijesooriya & Brambilla, 2021). The desk lamp benefits *health* by providing control and influencing *physical* and *mental health* through more musculoskeletal comfort (Colenberg et al., 2021) and better mood (Kropman et al., 2023). A desk lamp may be a trade-off for the environment.

Layout & design

Colours have the Stuff layer also have the ability to optimise daylight conditions, benefitting *environmental sustainability* (Calcagni & Calenzo, 2023; Hafez et al., 2023) and *health* (Kropman et al., 2023) (Al Horr et al., 2016), which may cause synergy.

3. Methodology

This chapter outlines the methodology employed in this research. Due to the complexity of combining two concepts, it was expected that the results would be rather nuanced. Therefore, a (semi-)structured interview method has been chosen. It provides the opportunity to gather detailed information in a structured manner. This structure was provided by the shearing layer concept, as it conceptualises a building. As shown in Figure 16 on page 32, the results from the two concepts from the literature are combined in one visual representation.

This chapter will first discuss the interview method, including considerations of its validity and reliability. Followed by the sample selection process. Finally, the chapter will discuss the process of data analysis.

3.1 Data Collection

This section will shed the light on the interview process, its validity and reliability and the ethical requirements.

3.1.1 Interview research method

Several research methods have been considered, including the Delphi method and a survey. Eventually, a (semi-)structured interview method has been chosen. It provides the opportunity to gather detailed information in a structured manner. The results were expected to be rather nuanced due to the complexity of combining two concepts. An in-depth exploration of the relationship between the two concepts was necessary due to the limited research available on the intersection of both. These nuances are challenging to include in a survey since this research seeks the reason behind the (potential) relationship.

3.1.2 Interview Process

Before the interview, a sample of interviewees was gathered. They were found through the professional network of the first supervisor of this thesis and the professional network of the company supervisor at the researcher's internship. The communication was done by email; a standard contact letter was used as an invitation. The interviews were conducted online in the period between 3 June 2024 and 18 June 2024. The interviews were recorded using Microsoft Teams.

During the interviews, the interviewer's questions were accompanied by slides. To create a comfortable atmosphere, the interviewee started with a personal introduction of the researcher, followed by space for a personal introduction by the expert. After this, the research was introduced, and the status and reason for the interviews were stated. An example of a synergy (outdoor green elements) and trade-off (HVAC system) was provided to limit confusion among experts due to the complexity of the two research fields. During the interview, '*environmental sustainability'* was addressed by '*sustainability'* since, in practice, this is often the case as well. '*health'* was addressed as '*health'*. After the introduction, the design elements were discussed using the shearing layer concept structure. In Appendix C-II, four slides of the Skin Layer are presented, showing the flow of the interviews. First, the layer is introduced, followed by an open question (i.e."What design elements experience a trade-off or synergy, considering *sustainability* and *health*?") and the applicable categories from the literature to guide the expert in a direction. The categories differ per layer; in the Skin layer, they are 'Biophilic Design', 'Air Ventilation', and 'Windows'. After this, the predefined design elements from the literature are shown, and the relationship (trade-off; 'T' or synergy; 'S') was marked. Both the presentation of design elments on the slide as well the act of marking them reduced confudion. The discussion of the layer was finished with the question, "Do you have any additions?"

and a presentation of the predefined design elements in the layer is shown to ensure design elements outside the predefined categories are included as well. Through this sequence, the five shearing layers were discussed.

3.1.3 Internal and External Validity

3.1.3a Internal Validity

Internal validity refers to the degree of confidence that the observed relationships are solely due to the variables being researched, without being influenced by other external factors (Alshenqeeti, 2014). The thesis ensures this by guiding the interviewees using PowerPoint slides. This prompted the expert to explicitly think about each design element separately and consider its influence on both *environmental sustainability* and *health*. By marking each design element with an "X" for either trade-off (T) or synergy (S), as shown in Appendix C-II slide 3, the experts were explicitly provided with feedback from their response, limiting the risk of misperception and misunderstanding.

3.1.3b External Validity

External validity concerns the extent to which the findings of the research can be generalized to other contexts (Alshenqeeti, 2014). The generalization of the results is good within the Netherlands; however, within an international context, the generalisation might experience limitations. The sample selection of experts is focussed solely on the Netherlands, influencing their knowledge and practical experience.

3.1.4 Reliability

Reliability of the results concerns the extent to which research yields the same results on repeated trials (Alshenqeeti, 2014). In this thesis, reliability was ensured through the structure of the interviews, the shearing layer concept, the explicit presentation of design elements and the direct visual feedback of the experts' responses. This provided guidance during each interview and made them rather comparable.

By refraining from presenting the predefined design elements at the beginning of each layer, the researcher ensures that experts are arguing from the experts' expertise without any implications. Avoiding any leading questions.

During the interviews notes were taken, in addition to recording. The PowerPoint slides were used to mark the relationship stated by experts; due to this method, the experts experienced direct feedback from their responses, limiting potential bias. Besides that, as shown in Appendix C-I and C-III, the researcher used a printed-out scrap checklist to make notes during the interviews. It was especially useful to remember that design elements discussed in one layer are actually in another layer. A smooth transition without much repetition for the expert was ensured in this manner. Appendix C-III shows a snipped of a filled-in scrap checklist.

Besides that, the interview results were recorded, coded, and compared to the results on the PowerPoint slides. The results may not perfectly match the verbal argumentation of the experts, but to ensure valuable results, the researcher took these differences into account as well.

A pilot interview was conducted with an expert proficient in the real estate work field but not proficient in *environmental sustainability* or *health*. The interview was not included but provided the opportunity to optimize the interview flow.

3.1.5 Ethics

This research is approved by the Ethics Commission of Eindhoven University of Technology on 17/05/2024 under code ERB2024BE37. All participants of this research agreed with the process of their personal data and visual and vocal recording. Consent has been obtained using the standard TU/e consent form. The research data will be retained for a period of 1 year and included personal information of experts; name, professional email address, and audio/video record. The data is stored on the TU/e computer of the researcher and locked with a password.

3.2 Sample selection and description

The selection of experts is done with care to guarantee rich results from different perspectives. The experts are not only selected based on their *environmentally sustainable* and *health*-expertise, they are also selected based on their expertise during an office's operational phase. To guarantee different fields within the real estate are covered, experts in consultancy, development, corporate real estate, asset and portfolio management, and academic (research) were selected and included in the sample. Table 6 shows the sample selection.

Table 6; Expert sample selection and focus area.

	Information			Expert's focus	
Expert ID	Branche	Company Size	Job Function	ES	H
1	Development	130 employees	Head of Sustainability	X	
2	Insurance	10.000 employees	Head of Facility Management	X	X
3	Real estate investment	200 employees	Sustainability Manager	X	
4	Legal tech software	8 employees	Technical Director		X
5	Real estate investment	200 employees	Asset Manager Sustainability	X	
6	Research	3.150 employees	PhD Candidate		X
7	Knowledge platform	12 employees	Manager Business Development	X	
8	Consultancy	250 employees	Senior Consultant		X
9	Consultancy	6.000 employees	Consultant		X
10	Consultancy	100 employees	Consultant	X	
			SUM	**6**	**5**

Experts active as consultants provided a wide range of expertise, depending on their respective fields. Three experts work as consultant were included initially, two on *health* and one on *environmental sustainability*.

The expert active in real estate development is primarily involved in the construction phase of the building. Even though their presence in the operational phase of the building is limited, their executive power during construction is high, which makes their expertise highly valuable for this research. Some developers implement software products in their assets and provide building management services via a platform after construction. The expert included a focus on *environmental sustainability*, primarily.

Corporate real estate managers are essential to consider in this research since they represent the building's user, who is one of the most important stakeholders during an office's operational phase. The user will experience the design elements within the building, affecting them. The expert included is facility manager at a large insurance company, focusing on *environmental sustainability* and *health*.

Asset and portfolio management is relevant during the operational phase of the building. Experts within this field often represent the owner of the building and have the executive power to invest in buildings during the operational phase, benefitting the office's *environmental sustainability* and *health*. Two experts from a real estate investment firm are included: an asset manager and a sustainability manager. Both were expected to provide an *environmentally sustainable* view.

The research expert, PhD candidate, provided state-of-the-art insights into implementing *environmental sustainability* and *health* in the context of office buildings. The academic expertise determines the knowledge of the different layers.

Two other types of experts were also included. One expert is a technical director who focuses on the legal part of WELL and CSRD, which made them sufficiently qualified to discuss *environmental sustainability* and *health*. The other expert is a Manager of Business Development for a smart workplace platform and was expected to be sufficiently qualified to discuss *environmental sustainability* and *health* as well.

Concluding, the mix of expertise and sectors is broad. It focuses primarily on the operational phase but does include the developer, they are fairly relevant during the construction phase of a building, creating a solid foundation for the interview and its results. The selection of experts has been primarily focused on the sector. Researching *environmental sustainability* and *health* does not require great proficiency due to its fairly new relevance. Hence, this thesis did not select experts based on years of experience.

3.3 Data analysis

The analysis of the interview results was two-layered. The relations identified and marked in the PowerPoint slides were used as a starting point for the analysis. Additionally, the interviews were transcribed and coded to identify the reason behind a trade-off or synergy. In total, ten interviews of 60 minutes were transcribed using SonixAI, resulting in approximately 25 pages per interview, 250 pages in total. A snipped of one interview has been presented in Appendix C-IV.

3.4 Conclusion

Several relations were identified by this thesis. A synergy may be a positive or a negative synergy; the first represents a design element with a positive influence on *environmental sustainability* and *health*. The latter represents the opposite, a design element with a negative influence on *environmental sustainability* and *health*. A trade-off can be an *environmental* trade-off that negatively influences *environmental sustainability* while positively influencing *health*. Or a trade-off can be a *health* trade-off, negatively influencing *health* while positively influencing *environmental sustainability*.

‘Chapter 4: Results’ will discuss the design elements using the shearing layer concept as structure. Each element will be introduced by discussing the main effect of the element, a trade-off or synergy, and accompanied by a brief explanation if needed. A table will follow, shown in Figure 17. The table contains the explicit, positive and negative, influences of the design element on *environmental sustainability* and *health*. This Figure shows the expert stating the effect of a design element. Several effects are possible, as shown in the legend. (+) indicates a positive influence, and (-) indicates a negative influence. The table also shows the total number of experts considering a relationship between environmental sustainability and health for the applicable design element. And a summation of the individual effects on either concept. The final row of the table shows the ‘most-mentioned relation’, the relationship with the most agreement among experts: the primary relationship. The ‘most-mentioned relation’. Additionally, secondary and tertiary relationships exist; these relations are mentioned less often than the primary. The relevance of the difference between them becomes apparent in the final section of the results chapter..

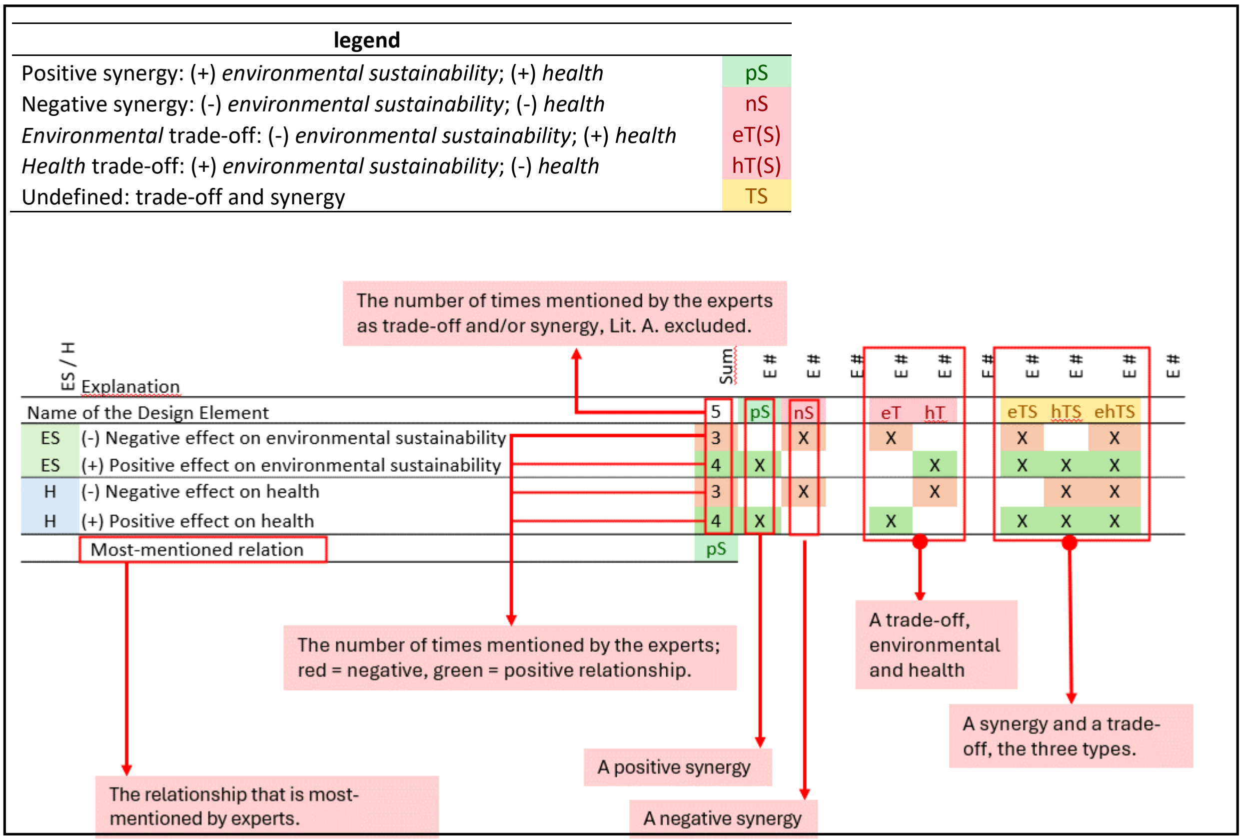

Figure 17; Explanation of the tables in the results chapter.

Below the Table the discussion of the influence of design elements will be discussed, starting with the negative effects and followed by the positive effects. Finalised with a comparison of the interview results to literature.

4. Results

This chapter will present and discuss the result of this thesis. First the selected expert sample will be discussed, followed by the interview results and preliminary conclusions. *Brandt's Shearing Layers* will be used to segment this chapter. Each section, will start with an overview of the relevant design elements in the Layer affecting *environmental sustainability* and *health*. The design elements are not limited to the predefined elements from the literature review as the experts were provided room to add additional elements. Each design element will be discussed individually, using a Table to provide an overview of the mentioned benefits for *environmental sustainability* or *health*. This has been shown in Figure 17 on page 4. First an overview will be provided on the number of times it is marked as a synergy or a trade-off by experts. After the discussion of the results, a comparison to the literature review will be made for additional discussion of findings. The final section will provide an overview of the most-mentioned trade-offs and synergies, and briefly conclude on the most-relevant individual design elements

4.1 Sample match

Table 7 shows the actual focus of experts, which is based on self-assessment. Based on the sample selection it was expected that six experts focus on *environmental sustainability* (ES) and four experts on *health* (H). The actual focus among experts has turned out broader; nine experts identify themselves as experienced in *environmental sustainability* and seven in *health*. The years of experience on *environmental sustainability* range between 4 and 17 years and for *health* range between 3 and 20 years. On average, the experts in the sample have, respectively, 9,2 and 7,4 year experience in their work field. The sample leans slightly towards *environmental sustainability*, however, due to double proficiency this is compensated.

Table 7; Sample match with the prospected sample diversification.

	Prospected focus		Years of experience		Actual focus	
Expert	ES	H	ES	H	ES	H
ID 1	X		5	-	X	
ID 2	X		15	20	X	X
ID 3	X		4	-	X	
ID 4		X	5	5	X	X
ID 5	X		17	-	X	
ID 6		X	5	10	X	X
ID 7	X		10	3	X	X
ID 8		X	15	6	X	X
ID 9		X	-	7		X
ID 10	X		7	7	X	X
SUM	**6**	**4**			**9**	**7**
MEAN			**9,2**	**7,4**		

4.2 Site

This section will discuss the elements linked to the site layer of an office building. Table 8 shows an overview of the design elements considered relevant by experts regarding *environmental sustainability* and *health*.

Biophilic design; green elements were considered by ten experts, as well as blue element (two experts), open pavement (one expert) and outdoor meeting space (two experts). For transportation amenities experts considered bike parking (ten experts), bike sharing (two experts), car parking (five experts) and electric charging amenities (six experts) relevant.

Table 8; List of design elements influencing environmental sustainability and health.

	Design element	# Experts
Site		
	Biophilic design	
	Green elements	10
	Open pavement*	1
	Blue elements*	2
	Outdoor meeting space*	2
	Transportation amenities	
	Bike parking	10
	Bike-sharing amenities	2
	Car parking	5
	Electric car charging amenities	6

* Additional design element mentioned by one or multiple experts during the interviews.

The following section will make use of abbreviations. The legend is presented below:

legend	
Positive synergy: (+) *environmental sustainability*; (+) *health*	pS
Negative synergy: (-) *environmental sustainability*; (-) *health*	nS
Environmental trade-off: (-) *environmental sustainability*; (+) *health*	eT(S)
Health trade-off: (+) *environmental sustainability*; (-) *health*	hT(S)
Undefined: trade-off and synergy	TS

4.2a Site: Biophilic design

Outdoor green elements

All experts considered a synergetic relation between *environmental sustainability* and *health* through outdoor green elements, as shown in Table 9, emphasising a strong agreement among experts. Three experts mentioned a potential negative influence on *environmental benefit* and one expert considered a potential negative influence on *health* as well. However, they dismissed that the magnitude of the drawbacks outweighs the benefits; thus outdoor green elements might be a (positive) synergy, as indicated in the bottom row of Table 9.

Table 9; The benefits of green elements of environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Outdoor green elements		10	pS	eTS	pS	pS	eTS	pS	pS	pS	nS	pS
ES	(-) Maintenance activities emit GHG	2		X			X					
ES	(-) Maintenance uses pesticides	1									X	
ES	(+) Reduced cooling needs for the building	4	X			X	X			X		
ES	(+) Biodiversity-enhancing	3			X		X				X	
ES	(+) Undefined positive influence	2							X			X
ES	(+) Connection to surrounding green structure	2		X				X				
ES	(+) Filtration of the air	2	X					X				
ES	(+) Water retention; climate adaption	3					X	X			X	
H	(-) The use of pesticides	1									X	
H	(+) View on green (visually pleasing)	5	X	X	X	X				X		
H	(+) Access to green	4				X	X		X	X		
H	(+) Filters outdoor air	2	X					X				
H	(+) Undefined positive influence	2									X	X
	Most-mentioned relation	pS										

Experts mentioned the biodiversity-enhancing qualities of greenery and their potential to connect an office with its surrounding green structure as beneficial for *environmental sustainability*. Additionally, potential cooling effects might reduce an office building's energy consumption. Lastly, local air filtration by greenery and climate adaption by retaining water both positively influence an office's *environmental benefits*.

Greenery on the Site might have a positive influence on the *health support* of an office. A view of greenery is considered positive since it is "visually pleasing" and benefits *mental health*. Besides that, access to the greenery promotes physical activity and is calming, and by implementing walking paths or routing facilities, accessibility is increased. Experts found the benefits of air filtration, limiting the level of GHG concentration, relevant to *health* as well; they marked it as beneficial for *environmental sustainability* and *health*. A potential drawback of greenery is its maintenance requirement; the use of pesticides might have a negative influence on *health*. Consequently, *environmental sustainability* might be negatively influenced as well through reduced biodiversity. This implies that 'low maintenance' green elements can act as a resource for *environmental sustainability* and *health* by limiting the need for harmful pesticides.

The results from the literature study on *environmental sustainability* and *health* match the statements of experts. Both mentioned the connection of an office with surrounding greenery (Kempeneer et al., 2021), biodiversity-enhancing qualities (Chwieduk, 2003; Wen et al., 2020; Zimmermann et al., 2019; Zuo & Zhao, 2014), potential cooling effects (Si et al., 2016; Wijesooriya & Brambilla, 2021), water-retaining characteristics of greenery (Calcagni & Calenzo, 2023; Rodrigues et al., 2023; Zuo & Zhao, 2014) as beneficial for *environmental sustainability*. Greenery also benefits *health* by providing access and views (Clements-Croome, 2018; Gilchrist et al., 2015; Sadick & Kamardeen, 2020). However, the literature does not include the influence of maintenance on *environmental sustainability* and *health.*

Open Pavement
One expert considered the addition of an open pavement on-site a synergy. It provides water drainage, which could make the Site more climate-adaptive. It can also make the Site *health*ier by providing a view of greenery. The literature study does not consider this design element.

Blue elements
Experts considered blue elements relevant for *environmental sustainability* and *health* since greenery diversification strengthens the influence of outdoor green elements. Blue has 'better' cooling capabilities and might function as a buffer space for water, respectively providing additional energy and climate adaptation benefits. Cooling capabilities might also benefit *health* by reducing local heat stress. In conclusion, two experts considered blue elements a synergy. Besides that, the literature does not consider this design element.

Outdoor Meeting Space
Experts highlighted outdoor meetings as beneficial for *environmental sustainability* and *health*, making them a potential synergy. Outdoor meetings may reduce the building's energy consumption by reducing the demand for indoor meeting space. They might also benefit physical *health* through the provision of (free) fresh outdoor air and greater travel distance between meetings. The literature study does not consider this design element.

4.2b Site: Transportation Amenities

Transportation amenities are considered together since their interrelation is strong. All experts marked bike parking as a synergy. A limited number of experts thought that bike-sharing influences both *environmental sustainability* and *health*. Car use is promoted by providing car parking, which predominantly causes a trade-off between *environmental sustainability* and *health*. Lastly, electric car charging could benefit *environmental sustainability* by reducing the negative influence of cars. However, it seems that active transportation methods are better at benefitting both *environmental sustainability* and *health*.

Table 10; The benefits of transportation amenities for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Transportation amenities												
Bike parking		10	pS	pS	pS	pS	pS	pS	pS	pS	pS	pS
ES	(+) Reduced emissions (on-site)	10	X	X	X	X	X	X	X	X	X	X
H	(+) Physical activity of employees	10	X	X	X	X	X	X	X	X	X	X
H	(+) Reduced emissions (on-site)	9	X	X	X	X		X	X	X	X	X
H	(+) Experience no traffic jams, less frustration	1		X								
H	(+) Providing choice	1					X					
	Most-mentioned relation	pS										
Bike-sharing amenities		2		pS								pS
ES	(+) Active travel to local meetings	2		X								X
ES	(+) General positive influence on sustainability	1	X									
H	(+) Active travel to local meetings	2		X								X
	Most-mentioned relation	pS										
Car parking		5	nS	nS	nS	nS		nS				
ES	(-) Promotes car use, GHG emissions	5	X	X	X	X		X				
H	(-) Promotes car use, contributes to bad OAQ	4		X	X	X		X				
H	(-) Promotes car use, physical inactivity	3	X	X							X	
H	(-) Parking garage	1					X					
	Most-mentioned relation	nS										
Electric car charging amenities		6	TS	TS		pS		pS	pS		pS	pS
ES	(-) Increased energy demand	1					X					
ES	(0) Influence depending on the energy source	4		X		X			X		X	
ES	(+) General positive influence on sustainability	6	X	X	X	X	X				X	
ES	(+) Reduced emissions (on-site)	7	X	X		X		X	X		X	X
ES	(+) Provides the opportunity add sharing cars	1										X
H	(-) Promotes car use, physical inactivity	3	X	X							X	
H	(+) Reduced emissions (on-site)	7	X	X		X		X	X		X	X
	Most-mentioned relation	pS										

Bike Parking

Bike use reduces GHG emissions, benefiting *environmental sustainability*, and increases physical activity, benefiting *physical* and *mental health*, compared to car use. Reduced emissions on-site also benefit local air pollution and thus *physical health*. All experts marked bike parking as beneficial for *environmental sustainability* and *health*, thus creating a synergetic relationship.

Bike-sharing Amenities

Bike-sharing amenities, in addition to bike parking, are considered beneficial for *environmental sustainability* and *health* since they strengthen the effects of bike parking. They were highlighted as a synergy since they provide the opportunity to travel to meetings in the local area using active transportation.

Car parking

Car parking is considered a negative synergy since it negatively influences *environmental sustainability* and *health*. Car parking promotes the use of cars, which emits GHG and negatively affects physical activity. Besides that, increased local GHG emissions on-site reduces local outdoor air quality (OAQ) and negatively influence physical *health*, especially if car parking is underground. Underground car parking may retain harmful emissions, affecting *health*. On the other hand, cars provide a feeling of safety, causing relaxation and thus benefitting *mental health*.

Electric Car Charging Amenities
The provision of car charging amenities might make car use more *environmentally sustainable*. However, experts found the relationship with *health* challenging to define. Therefore, the effects of car parking on *health* have been reused. By doing this, most experts defined electric car charging amenities as a synergy, even though car use remains a drawback for *physical health*. Reducing GHG emissions on and off-site benefits *environmental sustainability* and *health*. Lastly, it should be noted that the benefits of charging amenities depend on its energy source.

Literature
As both stated by experts and literature, indirect location-depending CO_2 emissions due to transportation can be decreased by using active transportation instead of passive transportation (Gallo & Marinelli, 2020; Park et al., 2024; Wen et al., 2020) or by electrifying the car fleet (Gallo & Marinelli, 2020). The literature study considers shared biking amenities beneficial for reducing the perceived proximity to public transportation (Gallo & Marinelli, 2020). However, experts did not support this since the link may be too farfetched.

4.3 Skin

The following section will discuss the Skin Layer and provide an overview of the design elements relevant to *environmental sustainability* and *health*. This includes greenery, air ventilation systems, windows, and a double-skin façade. Ten experts considered greenery on the façade. Besides that, eight experts considered windows as a relevant base scenario, and several experts mentioned types of energy-efficient windows. Openable windows (nine experts), window orientation (two experts) and static sunlight shading (ten experts) are also discussed. Lastly, a double-skin façade (five experts) is discussed as well.

Table 11; List of design elements influencing environmental sustainability and health.

		Design element	# Experts
Skin			
	Biophilic design		
		Green roof or façade	10
	Air ventilation system		
		Building structure: Open	9
		Openable windows	9
		Openable roof*	1
		Building structure: Closed	8
	Windows		
		Windows	8
		Micro shading *	1
		Solar panel glazing*	2
		Sunlight coating*	2
		Window orientation	4
		Static sunlight shading	10
	General		
		Double skin façade	5

* Additional design element mentioned by one or multiple experts during the interviews.

The following section will make use of abbreviations. The legend is presented below:

legend	
Positive synergy: (+) *environmental sustainability*; (+) *health*	pS
Negative synergy: (-) *environmental sustainability*; (-) *health*	nS
Environmental trade-off: (-) *environmental sustainability*; (+) *health*	eT(S)
Health trade-off: (+) *environmental sustainability*; (-) *health*	hT(S)
Undefined: trade-off and synergy	TS

4.3a Skin: Biophilic Design

Green roof and façade

The benefits of greenery on the building's skin are comparable to those on its site, see Table 11 and Table 12. All experts considered it to be a positive synergy due to its benefits for *environmental sustainability* and *health*.

Table 12; The benefit of green facade & roof for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Green façade & roof		10	pS	pS	pS	pS	pS	pS	pS	pS	pS	pS
ES	(+) Cooling effect on building	6	X			X	X		X		X	X
ES	(+) Comparable benefits of greenery on site	4					X	X	X	X	X	
ES	(+) Biodiversity enhancing	3		X			X		X			
ES	(+) Water storage capabilities	3				X	X				X	
ES	(+) Cooling effect on surroundings	1	X									
ES	(+) Undefined positive influence on *sustainability*	1			X							
H	(+) Green is visually pleasing	5	X	X	X	X				X		
H	(+) Green reduces outdoor air pollution	3	X	X							X	
H	(+) Comparable benefits of greenery on site	3					X	X	X		X	
H	(+) Acoustical qualities	1									X	
H	(+) Undefined positive influence on *health*	1										X
	Most-mentioned relation	pS										

Additional benefits of greenery on the façade compared to greenery on the site include its cooling effect, which positively influences *environmental sustainability* even more due to its location on the façade. In addition, greenery on the façade might have acoustical qualities.

The literature review supports the benefits of a green façade for the building's energy use, thus, *environmental sustainability* (Wang et al., 2024; Wijesooriya & Brambilla, 2021) and *health* (Kropman et al., 2023). Hence, scholars also conclude that the green façade or roof is a synergy.

4.3b Skin: Air Ventilation

The Skin allows for air ventilation, which can be done through an open or closed building structure. The building Structure can be defined as two different types: closed and open. The influence of an open building structure on an office's *environmental sustainability* and *health support* is generally negative, see Table 13. An open building structure providing openable windows is a drawback for *environmental sustainability*, according to eight experts, causing an *environmental* trade-off. A closed building structure is considered an *environmental* trade-off as well. Experts consistently agreed on the negative influence on *health*, but agreement on the influence on *environmental sustainability* was lacking. Open and closed situations represent extremes and are not ideal, as discussed in the literature review and supported by experts.

Table 13; The benefit of an open and closed building structure for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Building structure: Open												
Openable windows		9	eT		eT	eT	eTS	eTS	nS	nS	eTS	nS
ES	(-) The HVAC system is not able to respond	7	X			X	X	X	X		X	X
ES	(-) Temperature differences	4	X		X					X	X	
ES	(-) Polluted air	3	X							X	X	
ES	(+) Opportunity to lose gained (solar) heat	3					X	X			X	
H	(-) Outdoor air pollution enters the building	5		X					X	X	X	X
H	(-) Unstable situation	2									X	X
H	(+) Allows for control, benefitting *mental* health	7	X	X	X	X				X	X	X
H	(+) Allows 'fresh' outdoor air to enter	4					X	X		X	X	
H	(+) If combined with sensors	2							X	X		
	Most-mentioned relation	eT										
Building structure: Closed		8	nS		nS	hT	hT	nS		hT	nS	hT
ES	(-) Increased need for ventilation	4	X		X			X			X	
ES	(+/-) Depending on the system's 'smartness'	1							X			
ES	(+) Energy efficient	5			X	X	X			X		X
H	(-) Does not allow for 'fresh' air	5	X		X	X	X	X				
H	(-) Does not allow for control for the employee	3				X					X	X
H	(-) Undefined negative influence on health	1								X		
H	(+/-) Influence depending on the location	2							X		X	
	Most-mentioned relation	nS AND hT										

Open Building Structure: Openable Windows

Openable windows are part of an open building structure. The main negative contributor of openable windows to an office's *environmental sustainability* is that the HVAC system cannot respond to disturbed indoor air, causing temperature differences and/or polluted air from the outside. The latter two contribute negatively to the *health support* of the building as well. Experts mentioned that openable windows also provide environmental benefits by allowing the loss of gained (solar) heat in the summer, reducing the energy demand for cooling. Besides that, the main reason openable windows might be implemented is to provide control, allowing employees the feeling of 'fresh' air. However, this effect might only be psychological since the intake of uncontrolled outdoor air is not beneficial for *physical health*. Experts proposed that openable windows might be combined with sensors to diminish this drawback for *environmental sustainability* and *health*.

The literature study states that openable windows might act as a source of natural ventilation (Felius et al., 2020), can provide control (Kropman et al., 2023), and the intake of outdoor air might negatively influence *physical health* (Kumar et al., 2023). Scholars and experts disagree on the potential for openable windows as a source of natural ventilation. Experts explicitly stated that uncontrolled outdoor air intake negatively influences *environmental sustainability* and *health*. Causing openable windows to be a negative synergy or a *health* trade-off.

Open Building Structure: Openable roof & Midnight cooling
Experts mentioned that implementing an openable roof can be more effective in preventing overheating than openable windows because of its ability to lose gained solar heat. *Midnight cooling* was mentioned as a method in combination with an openable roof. It is energy-efficient to provide cooling outside office hours to save energy the first few hours of the workday. Depending on the building's location, *health* might be negatively influenced. The literature study does not consider this design element.

Closed Building Structure
It seems logical to argue that the benefits of a closed ventilation structure on *environmental sustainability* and *health* are the opposite of those of an open structure. However, this is not the case; most effects are comparable. A closed building structure also experiences polluted indoor air due to human activities, demanding increased ventilation and increasing energy demand. On the other hand, a closed building structure is controlled more easily, causing it to be more energy-efficient. This is rather counterproductive, and the net energy gain remains unclear. In addition, polluted indoor air is a drawback to *health*. Causing a closed building structure to be considered a *health* trade-off or even a negative synergy by experts.

According to scholars, a closed building structure is a *health* trade-off due to its limited intake of fresh outdoor air while being energy-efficient (Ghaffarianhoseini et al., 2018). This increases the need for ventilation, as argued by experts. In addition, the literature study also discusses the lack of control in a closed building structure.

4.3c Skin: Windows

Eight experts thought that a trade-off occurs due to window size, while four experts thought it could be a synergy. General agreement is noticeable on the *health* benefits of windows. However, a slight variation between experts is noticeable considering *environmental sustainability*. Thus, windows are predominantly an *environmental* trade-off.

Table 14; The benefit of traditional windows for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Windows		8	eT		eTS	eTS	eTS		eT	eT	eTS	eT
ES	(-) Heat gain	9	X		X	X	X	X	X	X	X	X
ES	(-) Less energy efficient than a closed wall	2				X			X			
ES	(+) Less energy use due to more natural light	4			X	X	X				X	
H	(+) Daylight is good for the *health* of people	7	X	X		X	X		X	X	X	
H	(+) View to the outside	5	X		X	X	X					X
H	Biorhythm	2	X								X	
H	Circadian effects	1	X									
	Most-mentioned relation	eT										

Experts agreed on the negative influence of window size on *environmental sustainability*. Solar heat gain due to windows causes greater cooling needs, thus increasing energy demand. Two experts explicitly compared a window to a wall and mentioned the influence based on this: walls are much better at insulation than windows. On the other hand, *environmental benefits may* be positively influenced by windows allowing for natural light to enter the building, reducing the need for artificial lighting, thus an office's energy demand.

Natural light is also a resource for *health*. It might contribute to human biorhythm and have positive circadian effects. Besides that, a view to the outside (on green) is beneficial as well.

The literature study states that windows are an environmental trade-off as well. Its heat gain (Chwieduk, 2003; Hashempour et al., 2020) allows daylight to enter the building and provides a view to the outside (Kropman et al., 2023).

Energy-efficient Windows

This section considers a variety of energy-efficient windows and uses the traditional design element discussed in the section above as a reference. Experts proposed three types: micro shading within windows, solar panel glazing, and sunlight coating. However, they might benefit *environmental sustainability* at the cost of *health*, causing it to be a *health* trade-off.

Table 15; The benefit of energy-efficient Windows for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Energy-efficient windows												
	Micro shading within windows	1	hT									
ES	(+) Influences the solar gains	1	X									
H	(-) Prevents views to the outside	1	X									
	Solar panel (vertical)	2							hT	hT		
ES	(+) Energy generation	2							X	X		
H	(-) Lower window coverage	2							X	X		
	Sunlight coating	2					hT					pS
ES	(+) influences solar gains	2					X					X
H	(-) Obstructs view to the outside	1					X					
H	(+) Influences solar gains	1										X
	Most-mentioned relation	hT										

Micro shading glazing benefits the environment by preventing solar gains and reducing the need for cooling. Preventing solar gains also reduces the view to the outside, causing a *health* trade-off.

Solar panel glazing allows PV panels to be placed on the façade; energy generation benefits *environmental sustainability*. Placing PV panels on the façade will reduce the potential window coverage, limiting natural light indoors. Vertical solar panels might be a *health* trade-off.

Lastly, sunlight coating on windows might be a synergy since it reduces solar gains, benefiting *environmental sustainability* and *health*. On the other hand, by adding a film to the glass, the outside world might feel “less real”.

The literature study did not provide examples as has been done by the experts, but it does mention comparable results: the window is energy-efficient, benefiting both *environmental sustainability* and *health* (Chwieduk, 2003; Hashempour et al., 2020).

Window Orientation

Window Orientation is a multi-interpretable design element; its effectiveness depends on the orientation of the windows. Experts discussed multiple orientation possibilities and their influence on *environmental sustainability* and *health*. The orientation possibilities are in the vertical plane: north, south, south/west, and in the horizontal plane: roof glazing. Even though *environmental sustainability* and *health* might experience benefits, window orientation is predominantly an environmental trade-off.

Table 16; The benefit of window orientation for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Window orientation		8	eTS		eTS	eTS	eTS	eTS		eTS	eTS	eTS
ES	(+/-) Affecting the heat gain of the building	9	X		X	X	X	X	X	X	X	X
H	(+/-) Benefit depends on their positioning	5			X	X	X	X		X		
	Vertical Plane: North	3	pS								pS	pS
ES	(+) Limited solar gains	4	X				X				X	X
ES	(+) Big windows	1					X					
ES	(+) More natural lighting while less heat gain	1									X	
H	(+) On the North limit glare	1										X
H	(+) On the North provide natural lighting	2	X								X	
	Vertical Plane: South	3	eT								eT	eT
ES	(-) High heat gain	3	X								X	X
ES	(+) Small windows	1					X					
H	(+) Natural lighting	3	X								X	X
	Horizontal Plane: Roof	1					eTS					
ES	(-) Solar gains	1					X					
ES	(+) Low need for artificial light	1					X					
H	(+) Natural light	1					X					
	Most-mentioned relation	?										

Vertical Plane: North

Windows on the North experience more indirect light, thus limiting solar gains and providing high-quality natural lighting, which is beneficial for the building's energy use. Besides that, due to indirect sunlight, less glare is experienced, limiting irritation among employees, and the light is experienced as "more comfortable," both benefiting *health*. Window orientation on the North might be a synergy.

Vertical Plane: South

Windows orientated to the South experience a great amount of daylight. However, windows on the North experience the opposite effect: greater heat gain while providing more natural lighting. Windows on the South might be an environmental trade-off.

Horizontal Plane: Roof Glazing & Openable Roof

Roof glazing provides more natural light penetration, reducing an office's heat gain and need for artificial lighting. It also provides *environmental* and *health* benefits and drawbacks. Hence, depending on the implementation, roof glazing might be a trade-off or a synergy.

Literature

Scholars argue that window orientation can effectively influence *health* (Clements-Croome, 2018) and *environmental sustainability* (Calcagni & Calenzo, 2023). However, the literature study lacks evidence on how this works, and few experts provide insights into the effectiveness of window orientation.

Static Sunlight Shading

One of the most controversial design elements is static sunlight shading. It has been marked as important for *environmental sustainability* and *health* by all experts, showing a strong sense of impact among experts. They agreed on the benefits of *environmental sustainability*, while disagreeing on the influence on *health*. Five experts marked it as a trade-off, while five others marked it as a synergy, as shown in Table 17.

Table 17; The benefit of static sunlight shading for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Static sunlight shading		10	hT	hT	hT	pS	pS	hT	hT	pS	pS	pS
ES	(+) Prevents solar gains	6	X	X				X	X		X	X
ES	(+) Prevents heat gain in the summer, and allows for it in the winter	3			X	X	X					
ES	(+) Undefined positive influence on sustainability	2					X			X		
H	(-) Obstructs light to penetrate the building	2		X	X							
H	(-) Obstructs views to the outside	2	X		X							
H	(-) Undefined negative influence	2						X	X			
H	(+) Allows for view to the outside while shading the sun	3				X	X					X
H	(+) Less experience from solar heat	1									X	
H	(+) Undefined positive inlfuence on *health*	2					X			X		
	Most-mentioned relation	hT	AND	pS								

Static sunlight shading prevents solar gains and reduces the building's energy needs. Besides that, different benefits may be experienced during the seasons, such as preventing heat gain in the Summer and allowing it in the Winter, potentially causing optimum energy efficiency in all seasons.

The obstruction of light reduces heat gain and limits light penetration into the building, negatively influencing *health*. It also permanently obstructs the view to the outside for a great part, reducing the view to green or imposing a feeling of being "locked up." The static character may benefit *health* by allowing a view of the outside while shading the sun.

Scholars agree with experts on *environmental sustainability*'s benefits (Hashempour et al., 2020). They also argue that it benefits *health* by preventing solar gains (Calcagni & Calenzo, 2023) and glare (Kropman et al., 2023). However, reducing the view to green or imposing a feeling of being "locked up" is not mentioned by scholars.

4.3d Skin: Double Skin Façade

Experts considered a double skin façade a trade-off and a synergy. *Environmental sustainability* is positively influenced, while *health* may experience a negative influence. Even though it is most-mentioned as a positive synergy, the *health* trade-off should not be neglected.

Table 18; The benefit of double skin façade on environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Double skin façade		5			pS	hT	hT			pS		pS
ES	(+) Isolation values	7			X	X	X		X	X	X	X
ES	(+) Heating in winter and cooling in summer	1		X								
H	(-) Decreased view to the outside	3	X			X	X					
H	(-) Decreased natural light penetration	2	X				X					
H	(+) Improved IAQ	1										X
H	(+) Improved sound insulation	3	X		X					X		
	Most-mentioned relation	pS										

A double skin's isolation value may be better than traditional insulation. It acts as a "buffer area," ensuring a reduced influence from outdoor conditions on the IAQ and reducing an office's energy demand. Both benefit *environmental sustainability* and *health*. To create a buffer area, the façade is thicker than a regular wall. This may decrease the view to the outside and cause lower light penetration, which might negatively influence *health*.

The literature study concluded the same as experts did: a double-skin façade creates synergy and may even be better than traditional insulation (Calcagni & Calenzo, 2023). However, the literature review does not include the negative effects on *health*, especially the reduced view of the outside or limited light penetration, which might negatively influence employees.

4.4 Services

The Service Layer includes heating, ventilation and cooling equipment. HVAC systems were considered traditional method by all experts and were found relevant for *environmental sustainability* and *health*, benefitting *health* at the cost of the environment. Hybrid ventilation systems, radiant heating, and locally controllable thermal systems could benefit *environmental sustainability* compared to the traditional method. Besides that, this layer includes lighting systems; traditional lighting is considered a traditional method. All experts thought a relationship exists between *environmental sustainability* and *health* through benefitting *health* at the cost of the environment. Smart Lighting, locally controllable lighting, and dynamic sunlight shading might benefit *environmental sustainability* and/or *health* and are discussed in relation to the traditional design element. Thus, this layer includes two 'traditional' design elements, an HVAC system and a traditional lighting system, and several 'upgrades'. The influence of the 'upgrade' depends on its relation to the traditional method.

Table 19; List of design elements influencing environmental sustainability and health.

		Design element	# Experts
Services			
	Heating, Ventilation & Cooling		
		HVAC system	10
		Hybrid ventilation system	4
		Radiant heating	8
		Locally controllable thermal system	8
	Lighting system		
		Traditional artificial lighting	10
		Smart lighting	10
		Locally controllable lighting system*	1
		Dynamic sunlight shading	9
	General		
		IEQ management system	10

* Additional design element mentioned by one or multiple experts during the interviews.

The following section will make use of abbreviations. The legend is presented below:

legend	
Positive synergy: (+) *environmental sustainability*; (+) *health*	pS
Negative synergy: (-) *environmental sustainability*; (-) *health*	nS
Environmental trade-off: (-) *environmental sustainability*; (+) *health*	eT(S)
Health trade-off: (+) *environmental sustainability*; (-) *health*	hT(S)
Undefined: trade-off and synergy	TS

4.4a Services: Heating, Ventilation & Cooling

HVAC system

All experts considered an HVAC system a trade-off. As mentioned in the introduction, it benefits *health* at the cost of *environmental sustainability*; making it an *environmental* trade-off.

Table 20; The benefit of an HVAC System for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
HVAC system		10	eT	eT	eT	eTS	eT	eT	eT	eT	eT	eT
ES	(-) Its energy use	7		X	X	X	X			X	X	X
ES	(-) Ventilation to meet IAQ standards	3	X				X			X		
ES	(-) If the system runs inefficient	2						X	X			
ES	(-) Ignorant to the outdoor climate	1						X				
ES	(+) If the system is calculated for or responsive to the location	1				X						
H	(-) If the system runs inefficient	1							X			
H	(+) Experienced as comfortable	8		X	X	X	X		X	X	X	X
H	(+) Manages the moist levels of the air	2						X				X
H	(+) If the system is calculated for or responsive to the location	1				X						
H	(+) Manages the ventilation rate	1	X									
	Most-mentioned relation	eT										

The influence of an HVAC system on *environmental sustainability* is solely energy-related. An HVAC system uses energy to maintain the IAQ, causing a strong relationship between *environmental sustainability* and *health*. This might be directly through ventilation rates or an inefficient system or indirectly through the type of building structure; an open building structure allows outdoor air to enter the building uncontrolled, and the system needs to work harder to compensate. A closed building structure may ignore the local environment by “fighting the environment”. However, older systems might be more ignorant than modern HVAC systems; the latter may be calculated and responsive to the local climate. Benefitting *environmental sustainability* and *health*.

Maintaining the IAQ is the primary goal of an HVAC system, as mentioned in the literature and confirmed by experts. By doing this, the system uses energy (Calcagni & Calenzo, 2023; Ghaffarianhoseini et al., 2018). Experts and scholars both marked this design element as an *environmental* trade-off. However, the responsiveness of an HVAC system, as discussed by experts, is not mentioned in the literature study. This might positively influence the experience of the HVAC system for both *environmental sustainability* and *health*.

Hybrid ventilation system

A hybrid ventilation system works with an open building structure and an HVAC system. By providing the best of both worlds, this system might be a synergy.

Table 21; The benefit of a hybrid ventilation system on environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Hybrid ventilation system		4				eT		pS		pS	pS	
ES	(-) Additional heating needs	2			X	X						
ES	(-) If OAQ is low, more filtration needed	2		X		X						
ES	(+) Undefined positive influence on *environment*	3						X		X	X	
ES	(+/-) Benefit depends on the HVAC’s software	3	X				X		X			
H	(+/-) Benefit depends on the local OAQ	1		X								
H	(+) Undefined positive influence on *health*	5				X	X	X		X	X	
H	(+) If monitored well	1							X			
H	(+) If control for the employee is implemented	1	X									
	Most-mentioned relation	pS										

The benefits of hybrid ventilation are comparable to those of an open building structure, as can be seen in Table 21. Due to the intake of outdoor air, additional heating and filtration may be required to limit environmental drawbacks. However, it provides employees with control over the indoor environment, which benefits *mental health*.

The literature study is generally more positive about a hybrid system. Scholars propose this system due to its benefits in using outdoor airflow, temperature, and 'fresh' air to their advantage, increasing an HVAC system's efficiency (Chenari et al., 2016). Experts were more conservative towards its benefits due to additional heating and air filtration demand from the in-take outdoor air. This highlights that the literature and experts argue in opposite directions.

Radiant heating

Experts considered radiant heating a synergy. Radiant heating can be implemented as floor heating or as UV panels in the ceiling, benefitting *environmental sustainability* and *health*.

Table 22; The benefit of radiant heating for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Radiant heating		8		pS	pS	pS	pS		pS	pS	pS	hT
ES	(+) Better than conventional heating systems	5		X		X			X	X	X	
ES	(+) Combined with low energy heating system	4			X		X			X		X
ES	(+) Potential for heating specific areas	2				X			X			
ES	(+) Undefined positive influence on sustainability	2						X			X	
ES	(+) Implemented in an open floorplan	1							X			
H	(-) Responds relatively slow	1										X
H	(+) Experienced as comfortable by people	8		X	X	X	X	X	X	X	X	
H	(+) Potential for heating specific areas, providing control	2				X			X			
	Most-mentioned relation	pS										

Radiant heating can be considered an effective alternative to conventional heating due to better energy efficiency and since it is experienced more comfortably by employees. Combining radiant (floor) heating with a low-energy heating system can reduce an office's energy demand even more. Radiant heating also provides the potential to heat specific areas and can thus be implemented in an open floorplan, benefitting *environmental sustainability* and *health*. The only potential drawback might be the response rate of radiant heating, which is relatively slow and might influence *mental health* negatively.

The literature study states that a radiant heating system can also be considered a synergy due to its energy efficiency and comfortability (Chwieduk, 2003). Scholars do not consider the lack of control mentioned by one of the experts.

Locally controllable thermal system

A locally controllable thermal system is a controversial design element; experts did not agree on the benefits of *environmental sustainability*, while they agreed on its benefits for *health*. Five experts considered an environmental trade-off, and four considered it to be a positive synergy.

Table 23; The benefit of locally controllable thermal system for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Locally controllable thermal system		8	eTS		eT	eT	pS	eT	pS	pS	hT	
ES	(-) Cooling and heating simultaneously, if the system is not well monitored	3	X		X	X						X
ES	(-) Undefined negative influence on sustainability	1						X				
ES	(+) The potential of heating specific areas	4					X		X	X	X	
ES	(+) Combined with a low-temperature system	1	X									
H	(-) Hard to understand; mismanagement	1									X	
H	(+) Control for the employee	6	X	X	X		X		X	X		
H	(+) Allows for gender differences	2				X		X				
	Most-mentioned relation	eT										

Mismanagement of local controllable thermal systems is the main contributor to reduced *environmental sustainability* and *health*. The system may heat and cool simultaneously due to bad IAQ monitoring, which causes unreasonably high energy demand and an uncomfortable environment. However, the potential of heating specific areas and the combination with a low-energy system benefits *environmental sustainability* and *health* positively. Additionally, dummy control may also be effective, providing no actual control.

The division among experts could be expected from the literature study. Scholars consider the potential of a locally controllable thermal system for *health* (Kekäläinen et al., 2010; Kropman et al., 2023) and *environmental sustainability* (Felius et al., 2020) for the same reasons. However, scholars also acknowledge that the system might be mismanaged, which can diminish the *environmental* benefit (Felius et al., 2020). During implementation, this design element should be carefully considered.

4.4b Services: Lighting System

Traditional artificial lighting

Experts argued that traditional artificial lighting is an environmental trade-off, due its energy demand to create a comfortable IEQ.

Table 24; The benefit of traditional artificial lighting for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Traditional artificial lighting		10	eT	nS	eT	eT	eT	eT	eT	nS	eT	eT
ES	(-) Energy use	10	X	X	X	X	X	X	X	X	X	X
ES	(-) More lux equals higher energy use	3		X			X			X		
H	(-) Artificial lighting is experienced negatively compared to natural lighting	2		X						X		
H	(+) Experienced as comfortable	7	X		X	X	X	X	X		X	X
	Most-mentioned relation	eT										

Environmental sustainability is influenced by the energy use of traditional artificial lighting to create a comfortable workplace, and experts argued that more lux increases the energy demand. Besides that, a greater intensity is more benefits *health*.

The literature states that it is also an environmental trade-off (Colenberg et al., 2021; Hashempour et al., 2020). Two experts implicitly argued that excluding this design element by marking it as a negative synergy is not an option due to the *health* benefits of lighting in general.

Smart lighting

Smart lighting can be implemented as an extension of artificial lighting; it ensures that the lighting systems are managed automatically and can control the colour and intensity of lighting to mimic the outdoor lighting qualities. Experts considered this design element a positive synergy, while some highlight the negative influence of *environmental sustainability* or *health* as well.

Table 25; The benefit of smart lighting for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Smart lighting		10	eT	pS	pS	pS	pS	eT	pS	pS	eTS	pS
ES	(-) Daylight-mimicking systems use more energy	2	X								X	
ES	(-) More energy use due to mismanagement	1						X			X	
ES	(+) Occupancy rate dependent	4			X				X	X		X
ES	(+) Lighting is only turned on when daylight is not sufficient	4		X	X	X					X	
ES	(+) Undefined positive influence on *sustainability*	1					X					
H	(+) Provide control	3	X			X		X				
H	(+) Daylight dependent	8	X	X		X		X	X	X	X	X
H	(+) Undefined positive influence on *health*	3			X		X	X				
	Most-mentioned relation	pS										

Environmental sustainability might be negatively influenced because daylight-mimicking systems use more energy. If smart lighting is implemented, employees experience a lack of control, negatively influencing *health*. However, the benefits of smart lighting systems might outweigh this. They are caused by the system adapting the lighting to the occupancy rate of the building or by turning off artificial lighting if outdoor natural light is sufficient. Both reduce an office's energy demand. Since the system is daylight-dependent, it also benefits *health*; employees will experience natural light more intensely.

The literature study presents smart lighting as a solution to traditional artificial lighting; smart indicates that it benefits *environmental sustainability* and *health* by reducing energy demand and enhancing *health* (Hashempour et al., 2020). Experts presented certain drawbacks, such as its lack of control, which scholars discuss only limitedly. However, experts agreed with the literature on the effectiveness of smart lighting systems.

Locally controllable lighting system

Experts also mentioned a locally controllable lighting system, which has comparable benefits to a locally controllable thermal system. Mismanagement might cause an environmental drawback, while control might benefit *health*. Hence, a locally controllable lighting system could be an *environmental* trade-off.

Dynamic sunlight shading

Dynamic sunlight shading has the same function as static sunlight shading; two experts thought that dynamic shading to be better than static shading due to its difference in functionality. Experts considered dynamic sunlight shading a *health* trade-off due to its lack of control. Only three experts thought dynamic shading to be a synergy by mentioning the same benefits as static sunlight shading.

Table 26; The benefit of dynamic sunlight shading for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Dynamic sunlight shading		9	hT	hT	hTS	hTS	pS		pS	hTS	pS	hT
ES	(+) Reduces solar gains	9	X	X	X	X	X		X	X	X	X
H	(-) If no control; experienced as annoying	3	X	X	X							
H	(-) Limits views to the outside	3				X				X		X
H	(-) Locked-up feeling	2			X					X		
H	(-) Limits natural daylight	1								X		
H	(+) IAQ is consistent	3			X	X					X	
H	(+) Limits glare	2					X			X		
H	(+) Undefined positive influence on *health*	1							X			
	Most-mentioned relation	hT										

Most experts thought that dynamic sunlight shading benefits *environmental sustainability* by limiting solar gains. *Health* may experience negative influence if the dynamic shading provides no control. It might also limit the views to the outside if the shading is active, which imposes a locked-up feeling and limits natural light. On the other hand, dynamic shading controls the IAQ by making it more consistent and limiting glare, benefiting *health*. Hence, if control is provided, dynamic shading might be a synergy instead of *a health* trade-off.

The literature study concludes only *environmental* and *health* benefits for dynamic shading systems. Scholars mention that it effectively reduces solar gains (Calcagni & Calenzo, 2023), ensures a consistent IAQ, and limits glare (Kropman et al., 2023). Due to its dynamic character, it provides more control to the user than static shading (Kropman et al., 2023). Hence, this makes it a synergy, according to the literature. Experts argued that limited control over the system is the main drawback to *health*. If control is provided, dynamic shading becomes a synergy instead of *a health* trade-off.

4.5 Space Plan

Most experts identified a relationship between *environmental sustainability* and *health* for amenities such as showers, changing rooms, a gym and a canteen. The layout and design of an office were discussed with the experts using three types: an open floorplan, an ABW office, and a private office plan. As shown in Table 27, multiple experts considered the different layouts relevant to *environmental sustainability* and *health*. In addition to the design elements from the literature review, experts added multiple elements to the layout and design of the office, as indicated by '*'.

Table 27; List of design elements influencing environmental sustainability and health.

Design element	# Experts
Space Plan	
Amenities	
Showers & changing rooms	9
Gym	7
Canteen	9
Layout & design	
Open floorplan	6
ABW offices	6
Alcoves and flexible workplaces*	1
Private offices	8
Staircase design	9
Walking route to meeting*	2
Water tap*	1
Colour use	4

* Additional design element mentioned by one or multiple experts during the interviews.

The following section will make use of abbreviations. The legend is presented below:

legend	
Positive synergy: (+) *environmental sustainability*; (+) *health*	pS
Negative synergy: (-) *environmental sustainability*; (-) *health*	nS
Environmental trade-off: (-) *environmental sustainability*; (+) *health*	eT(S)
Health trade-off: (+) *environmental sustainability*; (-) *health*	hT(S)
Undefined: trade-off and synergy	TS

4.5a Space Plan: Amenities

Showers and Changing Rooms

All experts considered a synergetic relationship, making it a relevant design element contributing to *environmental sustainability* and *health*. Potential negative influences might involve water use, causing drawbacks to *environmental sustainability*. The net benefit of showers remains unclear. However, it is most likely to cause a positive synergy.

Table 28; The benefit of showers & changing rooms for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Showers & changing rooms		10	pS	eTS	eTS	eTS	pS	eTS	pS	pS	pS	pS
ES	(+) Stimulates active transportation	10	X	X	X	X	X	X	X	X	X	X
X	(-) Water use	4		X	X	X		X				
X	(+) Stimulates active transportation	10	X	X	X	X	X	X	X	X	X	X
X	(+) Stimulates (leisure) workouts	4			X		X				X	X
H	(+) Provides a place to freshen up	1										X
	Most-mentioned relation	pS										

Showers and changing rooms can stimulate active transportation, which benefits *environmental sustainability* and *health*. Its water use might be an environmental drawback; however, as mentioned in the introduction, it is unclear whether it outweighs the benefits. In addition to active work travel, employees may also engage in leisure workouts and jogging during the lunch break, which benefits their *health*. Lastly, the possibility to freshen up during work hours increases employees' hygiene and mental *health*, as mentioned as well.

The positive and negative benefits of showers and changing rooms are comparable with the findings in the literature review; scholars mention that they stimulate active transportation, benefiting the *environment* (Wen et al., 2020) and *health* (Zhu et al., 2020). However, showers and changing rooms use water (Calcagni & Calenzo, 2023), which may negatively influence the environment.

Gym

Six experts considered this design element as an *environmental* trade-off, while only two thought a gym experiences to be a synergy. The negative influence is caused by its energy use.

Table 29; The benefit of a gym for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Gym		8	eT	eT	eT			pS		eT	eT	eT
ES	(-) Uses a little bit of energy	6	X	X	X					X	X	X
ES	(+) Capture electricity	1						X				
H	(+) Undefined positive influence on *health*	6	X		X	X		X	X	X		
H	(+) Physical activity improves *physical health*	3		X							X	X
H	(+) Experienced as 'comfortable to have'	1		X								
H	(+) Physical activity improves *mental health*	1							X			
	Most-mentioned relation	eT										

The influence of the gym on energy use is often described as “just a little bit” or “marginal,” while six experts mentioned it, which indicates that it might be more than marginal. A gym may also be able to capture energy produced by gym equipment. The *health* benefits of a gym are achieved through physical activity. And by providing the choice to exercise at work, the gym benefits employees’ *mental health*.

The literature does not agree with the drawbacks mentioned by experts. Experts did not mention the increased energy demand from implementing a gym since no literature exists on its environmental benefits. Scholars research a gym for its *physical* and *mental health* benefits, comparable to the benefits mentioned by experts. In addition, the literature also considers the positive social benefits of the gym through team spirit (Zhu et al., 2020), which was not mentioned by experts.

Canteen

Most experts considered a canteen beneficial for *environmental sustainability* and *health*, while some (three experts) also highlighted its drawbacks for *environmental sustainability*. Experts agreed on the positive influence of a canteen on *health* since all ten experts mentioned at least one benefit.

Table 30; The benefit of a canteen for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Canteen		9	eTS	eTS	pS	pS	eTS	pS	pS	eT	eT	
ES	(-) High energy demand	2	X				X			X		
ES	(-) Overproduction of food	1									X	
ES	(-) Uses more water	1		X								
ES	(+) Potential to serve sustainable meals	6		X	X	X	X	X	X			
ES	(+) Reduces plastic waste	2	X						X			
ES	(+) Controls food waste	1		X								
H	(+) Potential for *healthy* food provision	9	X	X	X	X	X	X	X	X		X
H	(+) Social interaction	2						X			X	
	Most-mentioned relation	eT										

A negative influence on *environmental sustainability* might be caused by its energy demand, overproduction of food, or water use. The *environmental* benefits might be caused by serving sustainable meals, reducing plastic waste due to the economy of scale, and controlling food waste by cameras scanning kitchen waste. The latter can be combined with a smart procurement system, adjusting new deliveries to the actual demand. *Health* is benefitted by the possibility of *healthy* food provision and social interaction among coworkers during lunch breaks.

Experts provided more nuisance concerning the benefits of *environmental sustainability* than the literature study does. Scholars do not mention plastic waste management, energy demand, and water demand for a canteen. On the other hand, experts did not mention the potential of trip combination (Khavarian-Garmsir et al., 2023). The benefits of a canteen on *health* match the ones concluded from the literature (Corvo et al., 2020). Hence, a canteen might be an environmental trade-off.

4.5b Space Plan: Layout & Design

Open Floorplan

An open floorplan is solely identified as a negative synergy. Multiple drawbacks for both *environmental sustainability* and *health* are mentioned.

Table 31; The benefit of an open floorplan for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Open floorplan		6	nS	nS		nS			hT		hT	nS
ES	(-) HVAC may cool and heat simultaneously	2				X						X
ES	(-) Undefined negative benefit	2				X						X
ES	(-) If the temperature is adaptable	1	X									
ES	(-) IAQ of the office area needs to be controlled as one	1		X								
ES	(+) Greater adaptability	1		X								
ES	(+) Higher capacity	1									X	
ES	(+) More sustainable than private offices	1										X
H	(-) Annoyance due to noise disturbance	5		X			X			X	X	X
H	(-) Undefined negative (mental) *health* benefit	4	X		X			X	X			
H	(-) Does not allow for individual control	3				X	X			X		
H	(-) No privacy	1					X					
H	(-) Annoyance due to visual disturbance	1									X	
H	(+/-) infleunce depends on the person	1	X									
H	(+) *Social health* benefit	1	X									
	Most-mentioned relation	nS										

In an open floorplan the HVAC may cool and heat simultaneously, negatively influencing *environmental sustainability*. This effect might be strengthened if the HVAC system is not smart, or adaptable. Besides that, in an open floorplan the IAQ needs to be controlled for the entire office, even though the office is not fully occupied.

Health is primarily negatively influenced by annoyance due to noise or visual disturbance, lack of individual control, and/or lack of privacy. The *health* benefits also depend on the type of person, but they are primarily negative. However, an open floorplan can facilitate social interactions, benefitting *social health*. The latter might not compensate for the previously mentioned drawbacks. Hence, an open floorplan might be a negative synergy, and exclusion could be the best solution.

ABW Offices

Experts often mention this layout type combining the benefits of an open floorplan and a private office. Six experts identified a synergetic relationship, while two also mentioned potential drawbacks for *health*.

Table 32; The benefit of an activity-based workplace for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
ABW offices		6		pS		hTS	pS	hTS	pS	pS		
ES	(+) HVAC and lighting based on occupancy	4				X	X		X	X		
ES	(+) Undefined positive influences on sustainability	2		X				X				
	More sustainable than private offices	1										X
H	(-) HVAC and lighting based on occupancy	1				X						
H	(-) Does not allow for gender differences	1						X				
H	(+/-) Influence depends on the quality of execution	1										X
H	(+) Fit for purpose	3						X	X		X	
H	(+) Undefined positive influence on *health*	3		X	X		X					
H	(+) Control of IEQ based on task and personal preferences	2				X			X			
	Most-mentioned relation	pS										

The main benefit of an ABW is reduced energy demand since its heating and lighting system is occupancy-based, which benefits *environmental sustainability*. However, *health* may be influenced negatively since the automated HVAC and lighting systems cause annoyance among employees. An ABW allows for gender differences since it is “fit for task.”

Private Offices

Experts considered private offices as an environmental trade-off. Drawbacks are found within both the *environmental* and *health* domain. It seems that optimizing both is challenging.

Table 33; The benefit of private offices for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Private offices			nS	nS		eT		eTS	pS	pS	nS	eT
ES	(-) Uses more space, has a relatively high energy demand	6	X	X		X		X			X	X
ES	(+) More controlled energy use	5		X				X	X	X	X	
ES	(+) If linked to the occupancy rate	1									X	
H	(-) Loneliness	2	X	X								
H	(-) Low casual meeting possibilities	2		X							X	
H	(-) Low information provision from colleagues	1	X									
H	(-) Low visual contact	1		X								
H	(+/-) May be experienced as positive, may be experienced as negative	1			X							
H	(+) Potential for control	7	X			X	X		X	X	X	X
H	(+) If flexible use is possible	1						X				
H	(+) Noise reduction	1	X									
H	(+) Undefined positive influence on *health*	1					X					
	Most-mentioned relation	eT										

The main negative contributor to *environmental sustainability* is the additional energy use of private offices. However, private offices can also offer benefits, including the potential for more controlled energy use due to space segmentation, which could be linked to the occupancy rate.

Health is negatively influenced by private offices, which may impose loneliness due to the low possibility of casual meetings, low information provision, and low visual contact. Private offices benefit *health* through the potential for control over the workplace, visually and thermally, and by noise reduction.

The office types in the literature
Minimal academic literature on the *environmental* performance of office types is available. The experts often struggled to identify the *environmental* benefits as well. *Health* benefits are easier to identify for experts and literature: physical, social (Colenberg et al., 2023; Haapakangas et al., 2018) and mental (Kropman et al., 2023). Most environmental benefits are energy-related; experts stated that an open floorplan uses more energy than a private office since the office cannot be segmented. However, scholars mention the potential of an open floorplan of deep light penetration, benefitting *environmental sustainability*. Even though the actual environmental benefits remain unclear, experts and scholars agree on the *health* benefits of an ABW office.

Staircase Design
Experts unanimously agreed on the benefits of an attractive staircase design: rerouting employees to the stairs reduces an office's energy use and increases employee physical activity.

Table 34; The benefit of a staircase design for environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Staircase design		9	pS	pS	pS	pS	pS	pS		pS	pS	pS
ES	(+) Less energy use due to less elevator use	9	X	X	X	X	X	X		X	X	X
H	(+) Physical activity	9	X	X	X	X	X	X		X	X	X
	Most-mentioned relation	pS										

The effectiveness of a staircase design in benefitting the *environment* and *health* was mentioned by experts and is supported by literature as well (Michalchuk et al., 2022; Zhu et al., 2020).

Walking Route (to meeting), Water Tap & Colour Use
Walking routes to meetings can decrease the use of indoor space, thus reducing energy use. It also benefits *physical health*, ultimately resulting in a synergy.

A water tap may be placed in a prominent location in the office. This could reduce the use of single-use plastic bottles while promoting hydration. It would benefit the *environment, sustainability*, and *health*, causing a synergy.

Light colours may reduce the energy needs of indoor lighting due to light reflection. Colours can also contribute to people's *health*. This is comparable with the benefits found in literature (Calcagni & Calenzo, 2023; Hafez et al., 2023).

4.6 Stuff

The last layer includes relatively small design elements in the office. It will focus on indoor biophilic design and green and blue elements. Besides that, HVAC filters are part of an HVAC system and deserve a separate discussion; ten experts have considered it relevant for *environmental sustainability* and *health*. One expert added ventilators as a beneficial design element for the IAQ. Desk lamps are mentioned by seven experts as relevant. Colour use will not be discussed in this section since its benefits are comparable to the ones mentioned in the previous section.

Table 35; List of design elements influencing environmental sustainability and health.

Design element	# Experts
Stuff	
Biophilic design	
Green elements	10
Blue elements*	1
Heating, Ventilation & Cooling	
HVAC filters	9
Ventilators*	1
Lighting system	
Desk lamp	7
Layout & design	
Colour use	2

* Additional design element mentioned by one or multiple experts during the interviews.

The following section will make use of abbreviations. The legend is presented below:

legend	
Positive synergy: (+) *environmental sustainability*; (+) *health*	pS
Negative synergy: (-) *environmental sustainability*; (-) *health*	nS
Environmental trade-off: (-) *environmental sustainability*; (+) *health*	eT(S)
Health trade-off: (+) *environmental sustainability*; (-) *health*	hT(S)
Undefined: trade-off and synergy	TS

4.6a Stuff: Biophilic Design

Green Elements

All experts considered indoor green elements a synergy, while seven experts also consider it an environmental trade-off under specific conditions. *Environmental sustainability* mainly experiences a negative influence, while *health* mainly experiences benefits.

Table 36; The benefit of green elements on environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Indoor green elements		10	eTS	eTS	eTS	hTS	eTS	pS	pS	pS	eTS	eTS
ES	(-) Maintenance	4			X		X				X	X
ES	(-) Water use	2	X	X								
ES	(-) Embodied carbon of materials needed to maintain the plants	1	X									
ES	(-) Energy use increases due 'grow' lamps	1		X								
ES	(-) High amount of floorspace needed	1	X									
ES	(+) Benefits the IAQ	8	X	X	X	X		X	X	X		X
ES	(+) Undefined positive influence on *sustainability*	2						X			X	
H	(-) May cause an allergic reaction	1				X						
H	(+) *Mental health* benefits	7	X	X		X	X	X	X			X
H	(+) Benefits the IAQ	4	X		X	X			X			
H	(+) Diffuses sound	1								X		
H	(+) Undefined positive infleunce on *health*	1									X	
	Most-mentioned relation	eTS										

Indoor greenery can not be watered in a natural manner and thus may increase a building's water demand. Besides, indoor greenery may be supported by so-called 'grow'-lamps, causing additional energy consumption. On the other hand, greenery can positively influence the IAQ, benefitting the *environment*. However, floorspace equals energy use, and the total floorspace required to achieve environmental benefits might not compensate. Besides that, increased IAQ benefits *health* as well, as well as a view of greenery.

The literature review stated that indoor green elements can be considered a synergy, contributing to *environmental sustainability* (Calcagni & Calenzo, 2023) and *health* (Colenberg et al., 2023; Kim & de Dear, 2013; Smith & Pitt, 2009). However, experts also considered the negative influence of green elements on *environmental sustainability* considerable, but scholars do not discuss this. Hence, indoor green elements might cause an environmental trade-off.

Blue Elements
Experts mentioned indoor blue elements as an additional benefit for *health*. It may benefit employees' *health* due to visual and sound benefits, especially when the sound of moving water can be calming. The water use of blue elements may also be relevant. It might be an *environmental* trade-off like indoor green elements are as well.

4.6b Stuff: Heating, Ventilation & Cooling

HVAC Filters
Five experts considered HVAC filters a synergy, and four considered it a trade-off. The negative influence is solely on the environment; the energy demand may increase due to increased pressure. On the other hand, *Health* benefits are caused by clean indoor air. Even though the energy demand may increase, most experts argue it causes a synergy.

Table 37; The benefits of HVAC filters on environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
HVAC filters		9	pS		pS	eT	eT	eT	pS	pS	pS	eT
ES	(-) Increased pressure if quality increases	1				X	X	X				X
ES	(+) Efficient systems	5	X		X				X	X	X	
H	(+) Clean indoor air	9	X		X	X	X	X	X	X	X	X
	Most-mentioned relation	pS										

Scholars also mention increased IAQ, which results in a more energy-efficient system and *healthy* employees (Calcagni & Calenzo, 2023; Si et al., 2016). Scholars do not find increased pressure relevant.

Ventilators
One expert considered ventilators as an important contributor to the cooling of an office. However, the use of additional energy, compared to a traditional HVAC system, results in an *environmental* trade-off.

4.6c Stuff: Lighting System

Desk Lamp

Seven experts considered desk lamps a trade-off. However, four experts also acknowledge that a desk lamp can be a synergy if implemented with a low-energy lighting system.

Table 38 The benefits of desk lamps on environmental sustainability and health as defined by the experts.

		Sum	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
Desk lamp		7	eT	eTS	eTS		eTS		eTS		eT	eT
ES	(-) Energy use	8	X	X	X		X	X	X		X	X
ES	(+) If implemented with low-energy lighting	4		X			X		X	X		
H	(+) Undefined positive influence	4					X		X		X	X
H	(+) Providing control, benefitting mental *health*	3		X	X						X	
H	(+) Musculoskeletal benefits	2	X			X						
	Most-mentioned relation	eT										

The negative contributor of a desk lamp to the environment is its energy use. A desk lamp can be combined with a low-intensity lighting system, reducing an office's energy demand. Splitting the required 500 lux between the fixed ceiling lighting and desk lamps might save energy if employees do not turn on the desk lamps. *Health* benefits are achieved through increased control over lighting conditions and better seating posture due to well-lit desks. This might be beneficial for *mental health* and *physical health*.

The literature review argues that desk lamps are an environmental trade-off by providing the same arguments as the experts (Colenberg et al., 2021; Kropman et al., 2023).

4.7 Results: An Overview

The final section of the results presents a combined analysis of the previously discussed design elements. Placing the opinion of experts on individual elements into context for the layer, other design elements, and literature. The section starts by presenting an overview of the most-mentioned relations per layer; this shows the general influence of an individual layer on *environmental sustainability* and/or *health*. After this, the most-mentioned trade-offs and synergies are be discussed and compared to the literature. Finally, implementing individual elements and their influence on their effectiveness will be discussed. This is be done by considering and presenting external effects and effects of comparable elements on the effectiveness of a design elements, influencing their benefits and drawbacks.

Shearing layers

An overview of the number of synergies and trade-offs by layer has been presented in Table 39. This table shows almost all design elements per layer as synergy or trade-offs. Two design elements are categorized as synergy and trade-off by the same number of experts and are shown in a separate table, Table 40. Table 39 shows that only the Site and Space Plan are dominated by synergies, while other layers experience predominantly trade-offs*; it* seems that the Site is an 'easy-to-hit' target if one aims to increase the *environmental sustainability* and *health* of an office simultaneously. Service and Stuff experience a greater difficulty since most design elements in this layer are an environmental trade-off, causing a drawback for the environment by benefitting *health*. The number of total environmental trade-offs (14) is relatively high, showing a strong dependency on environmental resources to provide a *health*-supporting office. The total number of synergies (22) is slightly higher than the number of trade-offs (18), suggesting that benefits for environment *sustainability* and *health* are more *dominant* than the drawbacks *of design elements on both*.

Table 39; The number of design elements identified as synergy or trade-off by layer.

Layer	Design elements	Synergies		Trade-offs		
		Positive	Negative	Total	Environmental	*Health*
Site	8	**7 (88%)**	1 (12%)			
Skin*	14	5 (36%)		**6 (43%)**	4	2
Structure						
Service	8	3 (38%)		**5 (63%)**	4	1
Space plan	10	**6 (60%)**	1 (10%)	3 (30%)	2	1
Stuff	5	1 (20%)		**4 (80%)**	4	
Total	45	**22 (49%)**	2 (4%)	18 (44%)	14	4

*Incomplete due to undefined relations; see Table 41

Table 40; Undefined relations for design elements.

Undefined relation	Layer	# Experts	Type of relation 1	Type of relation 2
Static sunlight shading	Skin	5	*Health* trade-off	Synergy
Building structure: Closed	Skin	4	Negative synergy	*Health* trade-off

As shown in Table 39, Table 40 remains incomplete. Two design elements of the skin layer are marked by the same number of experts as synergy and as a (*health*) trade-off, suggesting that they are the most controversial design elements in this thesis.

The literature study argues that static sunlight shading benefits *health* and *environmental sustainability*. It is a tool to minimize the *environmental* and *health* drawbacks of a building by limiting solar gains (Calcagni & Calenzo, 2023; Hashempour et al., 2020) and solar glare (Kropman et al., 2023). Experts agreed with these findings but added that static sunlight shading might be negative for *health*; it may create a locked-up feeling and limit the view to the outside due to its fixed design. A potential solution to this might be dynamic shading, which provides control for the employee over the amount of shading.

The literature review argues that a closed building structure is a trade-off due to reduced IAQ (Ghaffarianhoseini et al., 2018) while providing an energy-efficient design (Chenari et al., 2016; Felius et al., 2020). Experts also argued this and mentioned that no system is completely closed; this system might allow fresh outdoor air to enter after it is filtered. The *health support* of the system is better than natural ventilation, as experts and literature state.

Trade-offs & Synergies

The following section discusses the most remarkable results: trade-offs, as shown in Table 41, and synergies, as shown in Table 42. The section primarily focuses on the design elements that are not aligned with the literature.

Most-mentioned trade-offs

Table 43 shows the most-mentioned trade-offs; it should be noted that they are often marked as synergy as well. Experts marked the same design element differently (eight design elements), as shown in the 'second relation'- and 'third relation'-columns. These columns show the number of experts mentioning an alternative relationship than the primary relationship; the most-mentioned relationship. Alternatively, one expert marked the same design element differently depending on external factors (seven design elements), indicated by the star ('*'). Only windows are solely an environmental trade-off; the other 11 design elements experience differences in opinions. This section will discuss the other design elements.

Table 44 shows that the Service Layer is the most discussed layer in the trade-off relation (4 design elements by 27 experts). Besides, the Skin layer is identified as the layer with the most trade-offs (3 design elements by 20 experts). This means that experts were more confident about the trade-offs in the Service layer (6,75 experts per design element) than in the Skin layer (6,67 experts per design element). The design elements in the Service layer are more agreement, while in the Skin layer, more complex design elements seem to be located. Potentially due to the 'active' character of the design elements in the Service layer, it contains more design elements which use energy to maintain the *health* of occupants.

Trade-offs are predominantly thermal and lighting qualities; active and passive strategies are identified. The indoor thermal environment is influenced actively by the HVAC systems and controllable systems or passively by windows, their orientation and sunlight shading. Active strategies are often mentioned as trade-offs due to their energy use, which is an obvious environmental drawback. Passive strategies do not use energy to influence the IEQ but may indirectly influence an office's energy use. Experts found it easier to identify direct energy use over indirect energy use.

Table 41; The most-mentioned trade-offs, as well as second and third relation.

Trade-offs			Layer	# Experts	Alignment with literature	Second relation	# Experts	Third relation	# Experts
1	ES	HVAC system	Service	9	Aligned	N. synergy	1		
2	ES	Traditional artificial lighting	Service	8	Aligned	N. synergy	2		
3	ES	Windows	Skin	8	Aligned				
4	ES	Window orientation*	Skin	8	Partly aligned				
5	ES	Desk lamp*	Stuff	7	Aligned				
6	ES	Indoor green elements*	Stuff	6	Not aligned	Synergy	3	N. synergy	1
7	ES	Gym	Space plan	6	Not aligned	Synergy	1		
8	H	Dynamic sunlight shading	Service	6	Not aligned	Synergy	3		
9	ES	Openable windows*	Skin	5	Not aligned	N. synergy	4		
10	ES	Canteen*	Space plan	5	Not aligned	Synergy	4		
11	ES	Locally controllable thermal system*	Service	4	Not aligned	Synergy	3	H trade-off	1
12	ES	Private offices*	Space plan	3	Aligned	Synergy	2	N. synergy	1

* design elements considered as trade-off and synergy simultaneously, see Table 43

As mentioned, windows are the only design element solely marked as an environmental trade-off; this is aligned with the literature. Windows are essential in a building and provide natural lighting and a view to the outside, benefitting *health*. However, they cause energy leakage, influencing *environmental sustainability* (Chwieduk, 2003; Hafez et al., 2023; Hashempour et al., 2020).

HVAC systems and traditional lighting are environmental trade-offs as defined by experts and literature; they experience (high) energy demand to maintain the comfort levels of employees (Calcagni & Calenzo, 2023; Hashempour et al., 2020). Some negative influences on *health* have been mentioned in relation to an HVAC system and traditional lighting due to the (potential) inefficient use of the system. Hence, some experts considered these systems to be a negative synergy. However, the systems are too vital for *health* to exclude from the office design.

Window orientation and desk lamps are considered an environmental trade-off due to their energy demand. However, one could benefit *environmental sustainability* depending on its orientation. Windows orientated to the North experience a low solar gain while providing a view to the outside. Desk lamps implemented together with a low-energy lighting system could positively influence a building's energy expenditure.

Green elements occur in Tables 41 and 42; indoor greenery is considered a trade-off, while outdoor greenery is considered a synergy. If greenery is placed indoors, environmental benefits like biodiversity-enhancing qualities disappear, and the element will only use environmental resources. Experts and literature limitedly acknowledge this. The effectiveness of indoor green elements seems to depend on external factors, for example by 'grow-lamps' evidently causes indoor green elements to be an *environmental* trade-off.

A gym and canteen are identified by this thesis as *environmental* trade-offs due to their energy use, while the aim is to create more physical activity among employees. The literature study argued that combining work-related trips could benefit the *environment*. However, this is limitedly supported by this thesis. A canteen may experience an environmental trade-off, since it is essential for *health*, providing a place to eat and creating social connections. Its energy use may cause environmental drawbacks, while it may have the potential to create environmental benefits as well. It can provide sustainable meals, less plastic waste and control over food waste by scanning the trash and adjusting the procurement of new supplies accordingly. The literature study is not aligned with this potential and only argued that a canteen may cause trip combination. This thesis did not find the potential for trip combination for both the gym and canteen.

Dynamic sunlight shading is the only design element marked as a *health* trade-off, primarily caused by the lack of control of automated systems to limit solar gains. Scholars do not consider this; they consider dynamic shading an example of adaptive design that allows for control (Kropman et al., 2023). This design element seems to be an example of a mismatch between theory and practice. Why or how this works remains unclear.

Experts identified openable windows as an environmental trade-off since they allow polluted and warm/cold air to enter the building, increasing the energy demand. However, the literature states that they can be used to reduce energy demand by utilizing natural air pressure differences (Felius et al., 2020). A discrepancy is visible between theoretical and practical implementation. Especially if *health* is considered, scholars argue that openable windows allow 'fresh' outdoor air to enter the building (Calcagni & Calenzo, 2023). However, experts emphasize that it depends on the building's location and its local air pollution.

Private offices are considered negative for *environmental sustainability* due to the inefficient use of space. However, private offices are better segmented than open floorplans, allowing for segmented heating and lighting and creating energy benefits.

Lastly, locally controllable thermal systems seem to come with the price of additional energy demand. On the other hand, it also has the potential to decrease the energy expenditure of an office through workplace segmentation. The design of the office is relevant for its benefits.

Most-mentioned synergies

Table 44 shows the most-mentioned synergies. Different experts marked the same design element differently (nine design elements), as shown in the 'second relation'- and 'third relation'-columns. These columns also show the design elements that have been marked by the same expert differently depending on the method of external factors (six design elements), indicated by the star ("*").

The Site layer is in the top agreement of experts; 28 experts mentioned 4 design elements as synergy. Besides that, the Space Plan layer is also at the top; 26 experts mentioned 5 design elements as synergy. The Site layer contains the most synergies, while the Space Plan layer has more agreement among experts on individual design elements (Space Plan: 7 experts per design element; and Site: 5,2 experts per design element). The Space Plan layer seems to be more top-of-mind among experts, since the most experts argued on the design elements in this layer. Its potential may cause this; not all office buildings have a site for potential design elements. Buildings in inner-city locations often directly border public spaces.

Transportation amenities (bike and car parking, charging amenities and showers) were considered a synergy by the most (26) of the experts. Biophilia design elements (green roof or façade, outdoor green elements) are the second most-mentioned synergy (17 experts). Both types are often located on the site of an office, but also in the space plan.

Table 42; The most mentioned (positive and negative) synergies, and their second or third relation.

Synergy			Layer	# Experts	Alignment with literature	Second relation	# Experts	Third relation	# Experts
1	+	Bike parking	Site	10	Aligned				
2	+	Green roof or façade	Skin	10	Aligned				
3	+	Staircase design	Space plan	9	Aligned				
5	+	Outdoor green elements	Site	7	Aligned	ES trade-off*	2	N. synergy*	1
6	+	Radiant/Floor heating	Service	7	Aligned	H trade-off	1		
7	+	Electric car charging amenities	Site	6	Not aligned				
8	+	Smart lighting	Service	6	Aligned	N. synergy*	2	ES AND H trade-off	1+1
9	+	Showers and changing rooms	Space plan	5	Aligned	ES trade-off*	4		
10	+	Filters of HVAC System	Stuff	5	Aligned	ES trade-off	4		
11	-	Car parking	Site	5 (100%)	Aligned				
12	+	ABW offices	Space plan	4	Aligned	H trade-off*	2		
13	+	Colour use	Space plan	4	Aligned				
14	-	Open floorplan	Space plan	4	Aligned	H trade-off	2		

* design elements considered as trade-off and synergy simultaneously, see Table 43

Bike parking is a synergy due to its positive influence on GHG emissions and *physical health* by reducing car use. The relation is supported by scholars as well (Wen et al., 2020; Zhu et al., 2020).

Green façades are synergistic as well due to their cooling qualities for the building, reducing energy demand and benefitting *environmental sustainability*. Additionally, they provide a view of nature, which benefits *mental health*. These benefits are supported by literature as well (Kropman et al., 2023; Zimmermann et al., 2019)

Outdoor green elements provide biodiversity-enhancing qualities, benefitting *environmental sustainability*. They benefit *health* by providing a view of and access to nature; this is supported by literature as well (Kropman et al., 2023; Zimmermann et al., 2019).

Radiant heating is often compared to conventional heating by HVAC systems; the energy-efficiency and comfort are higher in comparison. Benefitting *environmental sustainability* and *health*, thus a synergy. On the other hand, radiant heating is slower in response, which provides a low potential for control, causing a *health* trade-off. The effectiveness of radiant heating in comparison to HVAC systems is supported by literature (Chwieduk, 2003; Norton et al., 2021).

The experts indicated that electrical car charging amenities might be a synergy since emissions are eliminated, causing environmental and *health* benefits. However, this is not aligned with the literature since EVs emit more fine dust (Gallo & Marinelli, 2020). Besides, car use negatively influences *physical health*, which may be more harmful than increased physical *health* due to reduced on-site emissions. The benefits remain unclear since the magnitude of the different effects is unknown.

Smart lighting is a synergy since it depends on the occupancy rate and natural light provision, which is beneficial for *environmental sustainability* and *health* (Hashempour et al., 2020). Thus, smart lighting is primarily a synergy. However, experts mentioned that smart lighting may also experience *health* drawbacks due to its automated character, which limits control. Potentially causing a *health* trade-off, additional guidance during implementation may be required.

Showers and changing rooms may benefit the environment due to increased bike use and, thus, reduced car use. These benefits are also supported by literature (Gallo & Marinelli, 2020; Park et al., 2024; Wen et al., 2020). On the other hand, the literature study also states that water use is an environmental drawback (Wen et al., 2020); in comparison to the benefits, the net result remains unclear. Table 44 shows that several experts considered it both a trade-off and a synergy due to this issue.

Car parking and open floorplan are both considered negative synergies. If applied at the office, *environmental sustainability* and *health* are negatively influenced. Exclusion of car parking promotes bike use and potentially public transport, which is beneficial for the energy demand of a building and the *health* of employees. However, the exclusion of car parking affects the functioning of and office and might not be viable.

An open floorplan demands heating and lighting for the total office space, and occupancy-based heating and lighting can not be implemented, ultimately negatively influencing the energy demand. A segmented workplace design benefits *environmental sustainability* due to the potential for occupancy-based heating and lighting. Besides that, *health* benefits also came forward from the reduced noise and visual disturbance and increased potential for control and privacy. Hence, it seems that considering a different layout than an open floorplan could result in a synergy for *environmental sustainability* and *health*.

Double relation by one expert: External factors & Availability of comparable design elements

The effectiveness of design elements is influenced by 1) external factors, the design element's drawbacks may become synergies. And 2) the availability of comparable design elements; for example, an element may has a negative influence if considered independently, while in comparison to a similar design element its influence is positive.

External factors

Table 45 shows the design elements an expert considers as a trade-off and synergy simultaneously. Since negative effects often outweigh the positive, the design element is considered a trade-off in the previous Tables (41 and 42). This section will provide a view of the benefits or drawbacks depending on external factors.

Table 43; Number of experts arguing environmental and health drawbacks as well as environmental and health benefits.

Design element	**# Expert**
Window orientation	8
Indoor green elements	7
Windows	4
Desk lamp	4
Openable windows	3
Dynamic sunlight shading	3
Canteen	3
Private offices	2
Roof glazing	1
HVAC system	1
Locally controllable thermal system	1
Water tap*	1
Showers and changing rooms	4
Outdoor green elements	3
Smart lighting	2
ABW offices	2

The effectiveness of green elements, indoor and outdoor, depends on the external situation. Table 41 shows that seven experts consider indoor green elements a trade-off; in combination with Table 43, it can be concluded that all seven experts simultaneously considered it a synergy as well. Experts highlight that the benefits of air filtration per plant might be negligible, and without any environmental benefits if placed indoors, the design element seems to be a trade-off. The literature considers the air filtration capabilities not negligible and mainly focuses on the benefits of indoor greenery (Calcagni & Calenzo, 2023; Norton et al., 2021). Experts and scholars seem reluctant to acknowledge the environmental drawbacks of indoor greenery.

Openable windows are proposed by scholars since they provide natural ventilation, allowing for *environmental* and *health* benefits (Kim et al., 2011; Smith & Pitt, 2011), while negative effects are limitedly highlighted by scholars (Al Horr et al., 2016; Calcagni & Calenzo, 2023). This thesis shows that the effectiveness depends on the building's location and indoor function. As experts mentioned, natural ventilation is possible in a residential dwelling; however, HVAC is essential in an office. Besides that, opening a window will negatively influence IAQ if the local air pollution is high. Openable windows, hybrid ventilation and natural ventilation, should be researched extensively before implementation.

Sunlight shading seems to be a rather controversial design element. Static and dynamic sunlight shading are considered a *health* trade-off by this thesis, while the literature states that it benefits *environmental sustainability* (Hashempour et al., 2020; J. T. Kim & Yu, 2018) and *health* in offices (Kropman et al., 2023; van Duijnhoven et al., 2019). This thesis found that static sunlight shading minimizes solar gain and glare; however, it limits the view to the outside. Benefitting the *environment* at the cost of *health*. Dynamic sunlight shading might be a solution that provides control (Kropman et al., 2023). However, experts explicitly state that dynamic sunlight shading lacks the potential for control since it is connected to an automated building management system. Improvement in this system might cause dynamic sunlight shading to become a synergy since the literature seems to show that it has the potential.

A canteen might benefit *environmental sustainability* in addition to its *health* benefits. This solely depends on its external situation. It has the potential for sustainable food provision, procurement and waste management. If this potential is not used, this study concludes that a canteen is a trade-off for the environment.

Availability of comparable design elements

The influence of a design element on *environmental sustainability* or *health* may vary depending on the situation which it is compared to. This section sheds light on the relations between design elements which are influencing the benefits of design elements on the background, as will be discussed in the following section. Table 44 shows the design elements which are discussed by experts in relation to a 'base' scenario.

Table 44; Compareable design elements tot their base situation.

Essential and improvement	T/S
Car parking	eT
Electrical car charging	S
Bike parking	S
Bike sharing amenities	S
Showers and changing rooms	S
Windows (/ roof glazing*)	eT
Micro shading within windows*	hT
Solar panel glazing*	hT
Window sunlight coating*	hT
HVAC system	eT
Radiant heating	S
Natural ventilation (openable windows)	nS
Filters in HVAC system	S
Ventilators*	eT
Artificial lighting	eT
Smart lighting	S
Open floorplan	hT
Private offices	eT
ABW offices	S

*additional design element

Transportation amenities

The benefits of electrical charging amenities, bike parking, sharing amenities and showers and changing rooms are discussed by experts in relation to car parking. Travel to work is often done by car, so most offices facilitate car parking. In addition to car parking an office can facilitate electrical charging amenities, this reduces the influence on the environment while preserving the *mental health* benefits. Hence, creating a synergy in comparison to car parking; bike use can be promoted by bike parking, sharing amenities, and showers and changing rooms. This thesis found that these three amenities work together in creating a synergy in comparison to an office providing car parking only.

Glazing

Windows are essential in the façade, and scholars propose 'energy-efficient windows' (Chwieduk, 2003; Hafez et al., 2023; Hashempour et al., 2020). Experts proposed multiple types of energy-efficient windows; micro-glazing, solar panel glazing, and sunlight coating. However, the effects are counteractive; positive for the environment and negative for employee *health*. This is caused by the reduced view to the outside and light penetration by energy-efficient windows. If energy-efficient windows are used instead of traditional windows the negative effects might migrate from an *environmental* to *health*.

Heating, Ventilation & Cooling

An HVAC system can become more energy-efficient and *healthy* if supported by or replaced with radiant heating, since radiant heating has *health* benefits and environmental benefits compared to an HVAC system. Employees experience radiant heating as more comfortable, besides that, it is more energy-efficient as well. The relevance of comparing design elements becomes apparent when considering radiant heating, since on its own it might still be an environmental trade-off due to its energy use.

Besides that, a benefit may be achieved by high-quality filters in an HVAC system. Additionally, the literature study proposes openable windows as an energy-efficient alternative to traditional HVAC systems (Calcagni & Calenzo, 2023), experts argue that this is often not the case due to the lacking ability of an HVAC system to respond. The environment and *health* of employees will be likely influences negatively in comparison the traditional HVAC systems.

Lighting

Artificial lighting and smart lighting experience the same relationship as HVAC systems and radiant heating. Smart lighting is a more energy efficient method of lighting the indoor environment, while it does use energy still. In comparison to traditional lighting, smart lighting is a synergy.

Office Layout

Three types of layout are considered in this thesis. An open, private (closed) and ABW layout. Both open and closed layouts are considered a trade-off by this thesis. Interestingly, an open layout influences *health* negatively, while a closed layout influences *environmental sustainability* negatively. A proposed solution may be an ABW office layout, this study showed multiple reasons for a synergetic relationship.

Conclusion

On a concluding note, the influence of design elements on environmental sustainability and/or health depends for the greatest part on external factors or the availability of comparable design elements.

This thesis proposes a 'trade-off' checklist, Appendix E Figure 23, to ensure completeness. A list with 'yes' and 'no' questions seeks a design element's potential (within scope) to be a trade-off. Vice versa, this means that if a design element does not match the checklist, it has the potential to be a synergy. The questions in the checklist are based on the responses from experts as shown in the tables; "The benefit of [design element] for environmental sustainability and health as defined by the experts" in Chapter 4, pages 45 to 69.

For only several design elements, this thesis found agreement among experts: HVAC systems, traditional artificial lighting, and windows are environmental trade-offs. Besides that, bike parking, outdoor green elements (greenery on the site and/or on the skin), and an attractive staircase design benefit environmental sustainability and health. Hence, they are defined as a synergy. Other design elements can not be defined due to the influence of other factors on their effectiveness.

5. Discussion & Conclusion

This research aimed to identify trade-offs and synergies between office building design elements that create an *environmentally sustainable* and those that create a *healthy* office building. Limited research is present at this intersection of *health* and *environmental sustainability* offered by office design elements. However, increased interest is noticeable in both *environmental sustainability* and *health* driven by policies on ESG, for example, GHG emissions and energy expenditure in the operational phase (UN, 2015) and costs associated with *health* in the workplace (Kelloway et al., 2023; WHO, 2018).

In this thesis, building design elements relevant to *environmental sustainability* and *health* have been first studied separately. Brand's (1994) shearing layer concept has been used to structure these elements. This framework guided the interview sessions with experts and made it possible to discuss the design elements efficiently. The experts have been selected based on their expertise (environment, *health* or both) and sector and function to diversify among experts. Ten experts on *environmental sustainability* and/or *health* provided professional opinions on the benefits of design elements, often fuelling the conversation with additional design elements. The following sections will answer the research (sub)question(s), discuss the implications for theory and practice and finish with the study's limitations. The results of the study may help workplace designers, policymakers and investors to make decisions regarding *environmental sustainability* and *health* in office buildings.

5.1 Answer to the Research Question

The main research question of this study is: ***(1)*** *'What are the trade-offs and/or synergies between office building design elements that create a healthy and those that create an environmentally sustainable building?'* Several sub-questions have been defined to guide the research question, which will be discussed in the following paragraphs.

Environmental sustainability

The first sub-research question is ***(1a)*** 'What defines an *environmentally sustainable* office building?'. An office building influences the environment in a multifaceted manner, focusing on the efficient use of resources—energy, water, and waste—and its impact on local biodiversity and the urban environment. A critical aspect of resource management is its energy expenditure, which contributes to greenhouse gas (GHG) emissions, negatively affecting the environment. Key components influencing a building's energy use include thermal, air, and lighting systems. Energy-efficient buildings reduce GHG emissions and lower operational costs, making 'sustainability' economically attractive.

Effective resource management extends to water and waste. Efficient water use is vital for quality of life. At the same time, thoughtful waste management can enhance recycling efforts, aligning with broader sustainability goals, such as the Dutch government's ambition for a circular economy by 2050.

Due to their dense nature, urban environments often pose challenges to biodiversity. However, by designing buildings that connect with local urban and green structures, their negative impacts can be minimized. Integrating greenery into building designs can serve as a "stepping stone" for local ecosystems, helping to reduce habitat fragmentation and support biodiversity.

The integration with the urban environment may also benefit employees' transportation behaviour by providing amenities that promote active transportation, limiting indirect (local) emissions.

Health

The second research question states **(1b)** '*What defines a healthy office building?'*. This thesis defines *health* by following the definition of the WHO (2010): *'A state of complete physical, mental and social well-being, and not merely the absence of disease'*.

The *health* dimensions (physical, mental, and social) are interconnected; for instance, physical illness can lead to mental *health* issues such as stress or depression. Factors influencing *health* in office environments include indoor air quality, thermal comfort, lighting, noise levels, office layout, and biophilic design elements. To foster a positive social climate and encourage interaction, specific design elements—such as furniture arrangement, layout, and greenery—are essential. Lastly, since effective office design goes beyond merely addressing diseases; it utilizes design elements as resources to promote overall *health*, and it should be recognized that individuals can experience varying levels of *health* regardless of the presence of disease.

Types of relation

The third research question: **(1c)** '*What are the potential trade-offs between a healthy office building and an environmentally sustainable office building?'* and the fourth research question **(1d)** '*What are the potential synergies between a healthy office building and an environmentally sustainable office building?*' sub research questions are respectively seeking the potential trade-offs and synergies in an office building design. The answers are found by combining the results from the literature review and the interviews with experts. Multiple types of relations emerged: an environmental trade-off, a *health* trade-off, a positive synergy, and a negative synergy. An environmental trade-off indicates a design element that negatively influences *environmental sustainability* while positively influencing *health*. A *health* trade-off indicates the opposite: negatively influencing *health* and positively influencing *environmental sustainability*. A positive synergy shows that the design element positively influences *environmental sustainability* and *health*. While a negative synergy shows that the design element influences both *environmental sustainability* and *health* negatively, this indicates that excluding the design elements is a positive synergy. The final results are two-layered: ranking the most-mentioned trade-offs and synergies and providing nuances by secondary effects. The ranking shows the most relevant design elements, while the second and third relations show nuances.

Trade-offs

Trade-offs are predominantly located in the skin and service layers of an office and are mainly concerned with the thermal and lighting quality, both for active and passive strategies. They are primarily negative for *the environment* and beneficial for *health*. Only one *health* trade-off is mentioned in this research: dynamic sunlight shading. Other *health* trade-offs exist as secondary or tertiary relations, but are overruled by negative effects for *environmental sustainability*, making them an environmental trade-off or a negative synergy in this thesis. Other trade-offs may have the potential to be synergies, depending on external factors, as experts argue. This limits the number of clearly defined trade-offs; this thesis found agreement among experts that HVAC systems, traditional artificial lighting, and windows are environmental trade-offs; this answers research question **(1c)**. This thesis identified 12 primary trade-offs, 11 *environmental* and one *health* trade-offs. This shows the ambiguous effect of design elements on the environment or *health* since only three design elements could be defined as solely a trade-off. Additionally, it shows that experts are willing to make a trade-off to facilitate a *healthy* office building at the cost of the environment, and not vice versa.

Environmental trade-offs may be caused by the influence of the design element on the building's energy demand, as a direct (HVAC systems) or indirect effect (openable windows). Creating a comfortable indoor space to maintain or increase occupants' *health* inherently influences an office's energy expenditure. HVAC systems, traditional lighting, and desk lamps directly influence the energy expenditure of a building by benefitting IEQ to maintain occupants' *health*. Passive strategies can also be identified as *environmental* trade-offs due to their indirect effect on an office's energy expenditure, such as windows, window orientation, indoor green elements, and openable windows. For example, the latter influences *the mental health* of occupants by allowing for control over the workplace while disrupting the IAQ since they allow untreated air (polluted, cold or warm) to enter the building. In conclusion, office buildings inherently influence the environment by their existence. To limit the influence, this study identified synergies which can be implemented instead of in addition to the discussed environmental trade-offs.

Health trade-offs may stem from interventions aiming to benefit the *environment*. *Health* is negatively influenced by, amongst others, a closed building structure, which manages the IAQ energy-efficiently. Besides that, the sun's shade is energy-efficient but limits the view to the outside. Moreover, limiting control over IAQ in an open floorplan favours the building's energy-efficiency. These three benefit *environmental sustainability* at the cost of *health*, which seems to occur more often among 'energy-efficient' interventions.

Synergies

Lastly, a synergy may emerge if the design element positively contributes to the environment and *health* of employees; bike parking, outdoor green elements (greenery on site and/or on skin), and attractive staircase design only benefit *environmental sustainability* and *health*. Hence, they are defined as a synergy, answering the research question **(1d)**. Generally, synergies are located on the site or in the space plan of an office. Design elements causing a positive synergy are often not essential for an office. Transportation amenities such as bike parking, car charging amenities, outdoor green elements, attractive staircase design, radiant heating, smart lighting, showers, and ABW offices benefit *environmental sustainability* and *health*, while they can be excluded, and a functional office still exists.

The negative synergies identified by this study are car parking and an open floorplan; it seems that excluding these elements promotes *environmental sustainability* and *health*. However, they are essential for the functioning of an office. If no car parking is present, most building occupants will depend on public car parking, which might not fit a company's policy. Moreover, some are more likely to travel by public or active transport to work if 'bike use promoting facilities' are solely present, like bike parking and showers. Open floorplans provide economic benefits due to their efficient use of space. However, they use more energy than segmented floorplans and cause disturbance due to noise, visual disturbance and bad odours. These drawbacks might outweigh the economic benefit, challenging change in office layout.

Double relation

Trade-offs are predominantly thermal and lighting; active and passive strategies are identified. Avoiding energy use by implementing passive strategies that have counteractive effects and indirectly increase an office's energy expenditure. However, several design elements identified as synergy in this thesis may offer a solution for the identified trade-offs. However, energy-efficient design elements tend to create drawbacks for *health*. Thus, one should carefully consider the full scope of effects before implementation. Synergies may be reached by focussing on the site and space plan and are primarily caused by active and green design strategies (transportation and greenery).

5.2 Implications for theory

This research contributes to the scarce literature on the intersection of *environmental sustainability* and *healthy* design elements in an office building design.

A limited number of relations are aligned with the findings in the literature, showing that the practical world of corporate real estate professionals and scholars only share a small part of knowledge and actions accordingly. This study mostly shows the complexity of the relationship between *environmentally sustainable* and *healthy* office space. About 22 of the total 45 design elements are not aligned with literature, meaning that a discrepancy came forward between the academic and practical world.

Inconsistent results with literature

Green elements

Translating the effects of outdoor green elements to indoor green elements is difficult for scholars and experts. This thesis showed that indoor green elements are a drawback for *environmental sustainability* due to the energy demand from ‘grow-lamps’, water demand, and limited air filtration. These drawbacks are not present if located outside; outdoor green elements even enhance biodiversity. Scholars present that IAQ benefits from indoor green elements by filtering the air and maintaining comfortable thermal conditions (Calcagni & Calenzo, 2023; Norton et al., 2021). However, experts argue that a great number of plants are required to make a noticeable difference. Moreover, too many plants cause chaos and diminish *the mental health* benefits of an office, as supported by literature (Smith & Pitt, 2009) and experts. Indoor green elements will likely remain a trade-off, either *environmental* or *health*. A reason why the drawbacks of indoor green might be overlooked might originate from the natural character of green. Externalities influence the effectiveness of green by placing natural elements in an unnatural environment (an office). Additional artificial implementations are needed to utilize its benefits.

Transportation amenities

Scholars argued that bike-sharing reduces the perceived proximity to public transportation (Gallo & Marinelli, 2020). However, the experts in this thesis do not support this; an environmental benefit is only obtained if employees switch travel patterns, which is extremely challenging. Shared bikes might be beneficial for travel to meetings during business hours, providing an *environmental* and *health* benefit.

Ventilation

This thesis found that passive ventilation is not a resource for *health* in office buildings for different reasons, as argued by experts. Several scholars considered it to be a resource (Chenari et al., 2016; Dimitroulopoulou et al., 2023; Zhang & Srinivasan, 2020), although some did not as well (Al Horr et al., 2016; Calcagni & Calenzo, 2023). The reasons include (1) the IAQ depends on the local outdoor air pollution and temperature; (2) displacement of air is often not strong enough to ventilate an office building.

(1) Local outdoor air quality (OAQ)

Some scholars argue that the influence of OAQ is relevant when implementing passive ventilation since the outdoor air might not be better than the indoor air (Kumar et al., 2023). However, other scholars propose a hybrid ventilation system as a resource for the *environment* and *health* (Chenari et al., 2016; Dimitroulopoulou et al., 2023; Zhang & Srinivasan, 2020). This thesis showed that it might be the case if the local air is not polluted. Several experts argue for the benefits of fresh air. However, they also mention that filtration is required to benefit *health* due to the polluted air in the Netherlands.

(2) Displacement of air

A constant airflow is required to maintain *health* (Al Horr et al., 2016; Calcagni & Calenzo, 2023), and some scholars argued that passive ventilation might be able to do this (Chenari et al., 2016). This thesis found that passive ventilation systems like openable windows or hybrid ventilation are not able to maintain a constant displacement of air in an office building. Residential dwellings might rely on passive ventilation. However, office buildings are often too large (Al Horr et al., 2016).

(3) Solution; Closed building structure with high-quality HVAC system

The literature study showed that a closed building structure is a drawback for *environmental sustainability* and *health (*Chenari et al., 2016; Felius et al., 2020*)*. Experts only partly agreed with this, stating that sealed-off buildings may experience *health* drawbacks and *environmental* benefits. However, modern HVAC systems maintain IAQ in an environmentally friendly and *healthy* manner. Combined with a sealed-off building, an ideal situation can be created where the indoor climate is controlled to achieve optimum *health*. If openable windows or other types of passive ventilation are implemented, the indoor environment might be disturbed. The HVAC system needs to use energy to compensate, causing an environmental drawback.

Control over IEQ

Scholars argue that providing control is essential to creating *health* benefits (Kropman et al., 2023), which this thesis also supports. However, the design elements proposed by scholars are not echoed by experts as controllable design elements. For example, dynamic sunlight shading and smart lighting systems are presented as controllable, which is refuted by experts. Both design elements are connected to a building management system that automatically adjusts the lighting according to the assumed needs and wishes of the occupant or to prevent unnecessary energy use. Often, the systems provide too little control, creating annoyance among employees. Hence, this thesis found that dynamic sunlight shading and smart lighting are not viable solutions if one wants to provide control.

Office layout

Private offices create a place where employees can work in solitude, so scholars argue it is a drawback for *social health* (Colenberg et al., 2021). In practice, experts have mentioned that private offices may be a drawback to *environmental sustainability* and a resource for *health*. A private office for one person uses more space than an open floorplan for dozens; more space equals more energy use. Even though energy use may be more controlled, benefitting *environmental sustainability*, this thesis found that it is unlikely to outweigh the *environmental* drawbacks. Additionally, these experts mentioned found negative effects on *social health* as well, which the mental *health* benefits may outright through the potential for control.

Trip combination

Scholars argued that by providing several amenities at the office, employees would combine their work travel with travel to the amenities (Khavarian-Garmsir et al., 2023). Two common design elements have been selected to research the potential of trip combination: a gym and a canteen. It was found that trip combination is not at the top of mind among experts. Even if the impact exists, it is likely to outweigh the additional environmental impact of providing amenities at the office. Besides that, both the gym and canteen are not researched in the *environmentally sustainable* literature, solely by *health*-related literature.

Gaps in literature

Office layout

The *environmental* benefits of an open floorplan and private offices remain scarce in the literature, as both layout types are primarily researched by scholars focussing on *health*. This might be because the difference between the office types for *environmental sustainability* is challenging to define.

Energy-efficiency

Energy-efficient windows have been included in this research as an improvement to the *environmental* drawbacks of traditional windows. However, all proposed window types experience *health* drawbacks, and moving the problem to another field is not solving it. Besides that, dynamic shading and a closed building structure are also energy-efficient design elements and negatively influence *health*. Literature often only mentions energy-efficiency as beneficial for the *environment* and does not include its influence on *health*. This thesis showed that it is relevant to consider the *health* effects as well since they are often negative.

5.3 Implications for practice

This research aimed to guide corporate real estate, asset managers and policymakers in designing or facilitating an *environmentally sustainable* and *healthy* office building.

Building layers

It seems that the site of a building is an easy-to-hit target if one would like to increase *environmental sustainability* and *health*. Table 39 on page 71 shows that most design elements in this layer experience a synergetic relationship. Transportation amenities and greenery on site are synergetic and should be implemented if possible. Besides that, workplace and asset managers should focus on limiting the dependency on car use since it is a drawback for *environmental sustainability* and *health*. Investing in offices at an intercity location might contribute to this and entice employees to travel by public transport. However, the provision of greenery on site is challenging at these locations. A location at the edge of the city could provide the potential for more greenery but might be at the cost of providing sustainable and *healthy* transportation.

Table 41 on page 72 shows that the building's skin and services layers experience more complex mechanisms due to the high energy expenditure to support users' *health*. A great number of trade-offs are noticeable in these layers. Most trade-offs are aligned with literature, while some are not. Design elements that have the potential to provide control of indoor air temperature should be a focus for the asset or workplace manager, especially since, in practice, these design elements often do not live up to their promises. Renovation of the HVAC system, lighting and windows has the greatest potential of benefitting both *environmental sustainability* and *health*.

The Space Plan Layer might also be relevant for workplace managers to consider. Especially the layout of an office has potential *health* benefits. Implementing ABW offices seems to accommodate the three different types of *health* and *environmental sustainability*. However, as mentioned in the previous section, limited research is available on the *environmental sustainability* of office layouts. The Stuff layer is more difficult since the benefits of the design elements depend on external factors; for example, green elements and desk lamps are trade-offs due to their energy use. This could be reduced if green elements are placed at a well-lit location, reducing the need for so-called grow-lamps. Moreover, if desk lamps are implemented with a low-energy lighting system, it could also be synergetic. Consulting experts is advised before implementing synergetic design elements in the Space Plan and Stuff Layer of the building.

Availability of comparable design elements

Several synergies may be used to limit the drawbacks of trade-offs, as discussed in Table 44 on page 77. This Table shows that car parking is related to electrical charging amenities, bike parking, bike-sharing, and showers. Implementing one or all of these design elements may reduce employee car use. Electrifying the car fleet by providing electrical charging amenities is especially beneficial for *environmental sustainability*. Implementing showers strongly relates to bike parking; it allows employees to travel a greater distance to work.

Besides, an HVAC system might be implemented with a radiant heating system; this thesis found it more energy-efficient and comfortable. In addition, an HVAC system may be equipment with air filters; this thesis also considers them beneficial due to their energy and *health* benefits. Lastly, artificial lighting may be replaced by smart lighting. If the service layer is renovated, one could focus on implementing radiant heating or a modern HVAC system with high-quality filters.

Trade-off checklist

A trade-off checklist, Appendix E; Figure 23, allows the reader to test design elements that are not included in this thesis but within scope. This checklist can (1) identify potential synergies, (2) locate potential negative effects of a design element, and (3) select the best-suited option if multiple comparably functioning design elements are a possibility. It will be discussed in more detail in the following section on limitations.

Policy measures

The policy implications could concern 'low-maintenance' design elements, which can influence the environment positively due to the reduced indirect negative influence. Several experts discussed this, and policy measures may reduce these effects.

5.4 Limitations & suggestions for future research

The quality of the literature review is a limiting factor

Limitation

The number and types of design elements identified by the researcher in the literature review are crucial for the quality of the interview results. The thesis seeks design elements that are relevant to *environmental sustainability* and *health*. Thus, the completeness of the listed design elements is important. The number of design elements found in the literature was extensive and covered (almost) all possible types of design elements. Nonetheless, multiple limitations emerged during the interviews: 1) the list of design elements was too extensive, and the experts felt rushed and overwhelmed by the amount of information, reducing the interview quality. Consequently, 2) gaps may be overlooked due to the apparent completeness of the listed design elements for experts, reducing the quality of the interview results. Lastly, 3) the extensive list of design elements may have limited experts to think outside the box.

Research suggestion

The final research results seem relevant since a great part of them match the data from the literature review. To prioritize the expert's focus, the scope of the research could be limited. The research could focus on only one or a few building layers. This provides the opportunity to increase the quality of the subject researched.

Interview method might be a limiting factor

Limitation

The interview method may experience certain biases, misinterpretation, misunderstanding, and personal bias. This has been tried to limit by creating slides to guide the research direction without guiding too much, as shown in Appendix C. However, this may impose a great influence on the attitude, views and perspective of the interviewer, as well as the tendency to seek answers expected from the literature review (Alshenqeeti, 2014).

The sample of the experts is a limiting factor

Limitation

The final sample is subject to the agenda of the experts; the researcher aimed for an even representation of experts on *environmental sustainability* and experts on *health*. The final sample is slightly tilted to the *environmental sustainability* spectrum.

Besides that, the sample size may be limiting for the final results since the true influence of several elements remains uncertain. Table 42 on page 74 shows several trade-offs rated as a synergy by only one expert (4 out of 12 design elements), which reduces the likelihood of the trade-off since a benefit may still exist. The same is visible in Table 43 on page 76, showing the synergies identified; it shows three design elements where one expert argues it may be a trade-off. A greater sample would reduce the relevance of a small difference. The small difference may also be resolved by additional contact moments with experts.

Lastly, the sample of experts is solely made of experts working in the Netherlands, which could create biased results. One should be cautious when applying the results to an international context. A bias may be noticeable while discussing 'indoor green elements'; the negative influence on *environmental sustainability* is accepted by all experts and diminished in relation to its assumed benefit for *health*. The opinion may not match the international consensus.

Research suggestion

The sample may be increased for future research, or additional contact moments with the experts may be arranged. Both methods allow the researcher to target the ambiguous character of some design elements explicitly, increasing the quality of the final results.

The knowledge of the expert is a limiting factor

Limitation

Multiple factors caused by the expert's knowledge can limit the results of this study; the following section will name a few (potential) limiting factors. (1) Experts found it difficult to compare two concepts simultaneously: Environment and *health*. The researcher had to steer the conversation regularly during the interview to create sufficient results. (2) Conflicting opinions and arguments became visible while discussing comparable design elements with the same expert, diminishing the quality of the response by the expert. As discussed, Table 42 on page 74 shows 17 design elements with inconclusive argumentation from experts. (3) Experts are not always complete in their answers. Often, the most obvious answers are not given. 'increased water use' as a negative effect on the environment was often not mentioned in relation to showers and a canteen by experts; one would expect that it would be mentioned. (4) Experts found it rather easy to start the interview by repeating what was put forward by the researcher at the start of the interview. Influencing the effectiveness and quality of the interview. (5) Expert knowledge is created based on the geographical location of an expert. This has already been mentioned in the previous limitation, but it can also be a limitation concerning an expert's knowledge. (6) The selection of the experts was based on their primary focus: *environmental sustainability* or *health*. However, this research subject focuses on the relationship between both. The double proficiency provided more possibilities during the interview; experts can provide knowledge on both fields and their relation. The interview results are expected to be richer since the knowledge is present in both fields.

The listed design elements are likely to be and remain incomplete

Limitation

During the interviews, new design elements emerged, showing that the list of literature-based design elements is incomplete. This research challenges the reader to identify more design elements by providing a trade-off checklist. Following the same flow of this research, one could be able to identify the influence based on similar design elements in this study.

Suggestion: Trade-off checklist

To fill the gaps in the results, a checklist, Figure 23, has been developed to include design elements excluded from the list of design elements based on literature and interviews. The questions are based on the main takeaways from the results of the interviews.

The checklist knows two approaches; if one individual design element has to be checked, plan (1) should be followed: the checklist is filled out until a negative effect ("Yes") is marked. If one would like to compare interchangeable elements, plan (2) should be chosen: the checklist is completed for each element, and the one with the lowest number of negative effects ("Yes") is the best element to implement.

The checklist starts with *health* since multiple experts mentioned that a building should be designed from a *health* perspective. The questions match the interview results and the structure as shown in Figure 23 . After the *health* section is completed, the checklist continues with questions related to *environmental sustainability*. A great proportion of the questions related to the energy expenditure of the building, sub-questions help determine its applicability, showing the dependency of a building on energy once again.

The checklist provides the opportunity for workplace managers to gain insight into the influence of design elements on either *health* or *environmental sustainability*. The checklist can identify potential synergies; if no question is answered with "Yes", the design element might be a synergy, assuming it has benefits. The checklist can also be used to locate potential negative influences of a design element; if one or few negative results from the checklist, the office manager may decide to compensate or accept the trade-off.

The magnitude of typical benefits is not taken into account

Limitation

While considering the results of this study, the magnitude of the influence of design elements on *environmental sustainability* and *health* is not considered; this creates difficulty comparing design elements; this has been solved by assuming a drawback weight greater than the benefit. At an individual level, it creates difficulty if a trade-off exists; its benefits may outweigh its drawbacks, this may cause design elements to be labelled as trade-offs, while the benefits are much greater than the drawbacks, making it worth implementing the design element.

Suggestion: Trade-off checklist

The two plans of action in the trade-off checklist allow the user to sum up the drawbacks and make an informed decision on the full picture. If comparing alternatives, i.e. HVAC system to radiant heating, one could decide to replace the "Yes" with a magnitude, providing the opportunity to value benefits and drawbacks.

The research's scope is a limiting factor

Limitations

The list of design elements researched by this thesis remains incomplete due to the thesis' focus on the exploitation phase rather than the construction phase.

Besides that, the full scope of the *health* benefits remains incomplete due to the focus on physical elements in the workplace while neglecting their impact on behaviour.

Research suggestion

This research excludes material use for new constructions and renovations; thus, this study ignores the actual effectiveness of design elements with a high embodied carbon footprint and a low influence (environmental/*health*). For example, a 'double skin façade' has a high carbon footprint, as mentioned by multiple experts, due to the application of a second façade. This study identified a double skin façade as a synergy due to its energy efficiency in the operational phase of the building. The actual benefit may be limited due to the embodied carbon. Researching or including the construction phase of an office would present a more complete image of the effectiveness of design elements.

This research excludes behaviour and policy measures since it only focuses on physical design elements. Experts mentioned the impact of behaviour on the effectiveness of design elements. 'Control' has been considered within the scope of this research due to its correlation to *mental health*, while one could argue it is out of scope, due to its behavioural aspect. Experts consider mismanagement due to behaviour as a significant contributor to an office's energy use. If behaviour had been included, the results of this study would probably have differed from the actual results. Researching the influence of behaviour on the *environmental sustainability* or *health support* of design elements is highly valuable.

General research suggestion

A case study can be initiated to research the influence of the most-mentioned trade-offs and synergies. This would provide the opportunity to 1) research the true influence of the trade-offs and synergies as answered to RC (1c) and (1d) (HVAC systems, traditional artificial lighting, windows, and desk lamps are environmental trade-offs. Bike parking, green roof or facades, and staircase design are positive synergies. Moreover, car parking is a negative synergy). Besides that, 2) a case study provides the opportunity to control for external factors influencing the results.

5.5 Final Thoughts

Only a limited number of trade-offs and synergies could be identified. The greatest part of the design elements were identified as trade-off and synergy simultaneously by the same experts or different experts. Showing the complexity of *environmental sustainability* and *health* and their combination. The limitations and suggestions for future research are only a small part of the research needed to create robust conclusions on the relationship between *environmental sustainability* and *health*. An office building has the potential to be a resource for the environment and employee's *health*.

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Appendices

A. The literature review on *environmentally sustainable* building elements

Appendix A shows the most relevant sources in the literature study on *environmental sustainable* building elements.

Table 45; Literature review on environmentally sustainable building elements.

			Calcagni & Calenzo, 2023	Chenari et al., 2016	Chwieduk, 2003	Dimitroulopoulou et al., 2023	Felius et al., 2019	Gallo & Marinelli, 2020	Hafez, et al., 2023	Hashempour et al., 2020	Khavarian-Garmsir et al., 2023	Kim et al., 2018	Kumar et al., 2023	Meena et al., 2022	Norton et al., 2021	Park et al., 2024	Si et al., 2016	Wen et al., 2020	Wijesooriya & Brambilla, 2021	Zhang & Srinivasan, 2020
Resource management: Energy use & efficiency		General energy efficiency measures	X	X	X	X	X		X	X		X	X	X	X	X	X	X		X
	Air	HVAC system	X	X	X	X	X		X	X		X	X	X	X	X	X	X		X
		Air source management											X							X
		Hybrid ventilation systems		X		X														X
		IAQ monitor system (Air quality sensors)		X		X	X		X			X				X	X	X		X
		Passive ventilation	X	X		X	X		X			X	X	X	X					
		Openable windows					X		X			X	X							
		Inner courtyard / atrium	X	X		X						X								
	Thermal	Thermal conditions	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	
		Small' energy consumers			X										X					
		HVAC system	X	X	X	X	X		X	X		X	X	X	X	X	X	X		
		Separate thermostats										X								
		Radiant flooring			X										X					
		Building envelope (closed/open)				X	X													
		Building's skin:	X	X	X	X	X		X	X		X		X			X	X		
		Insulation			X		X		X	X		X					X			
		Energy-efficient windows			X		X		X	X		X					X			
		Climate façade / Double skin façade	X	X								X								

		Sunlight shading	X				X		X	X		X								
		Window orientation	X				X		X			X								
	Lighting	Smart / energy-efficient lighting systems		X	X	X	X		X	X		X		X	X		X	X		
		Daylight	X	X			X		X	X		X		X	X		X	X		
		Sunlight shading	X						X	X		X								
		Window orientation	X									X								
		Colour use and layout							X											
		Climate façade / Double skin façade		X																
		Inner courtyard / atrium	X	X																
	Renewables	Energy generation on-site		X	X		X		X	X						X	X	X		
		Storage or trading of renewable energy			X		X		X							X				
	Software	IAQ management system					X		X							X	X	X		X
		Digital Twin Model														X				X
Resource management: Water, waste & material	Water	Water consumption	X		X				X					X		X	X	X		
		Rainwater harvesting	X															X		
	Waste	Waste consumption	X		X				X					X	X	X	X	X		
		Waste sorting & recycling			X									X	X	X	X	X		
	Materials	Adaptable building design			X									X						
		Recycled/reuseable material							X					X			X	X		
		Non-toxic / natural materials			X									X			X	X		
Biophilia	Indoor	Indoor biophilic design	X												X				X	
	Outdoor	Outdoor biophilic design	X						X							X		X		
		Biodiversity-enhancing greenery			X													X		
		Green roofing/façade															X		X	
Transportation & Amenities	Transportation	Active transportation facilities:						X			X					X		X		
		Bike parking														X		X		
		Electric charging facilities																		
		Showers & changing rooms																X		
		Public transportation:						X			X							X		
		Bikesharing						X												
		Passive transportation:						X												
		Electric charging facilities						X												
	Amenities	Lacking amenities in the surroundings									X									
		Flooding prevention	X													X				

B. The literature review on *healthy* building elements

Appendix B shows the most relevant sources in the literature study on *healthy* building elements.

Table 46; Literature review on healthy building elements.

			Al Horr et al., 2016	Chatterjee et al., 2020	Clements-Croome, 2018	Colenberg et al., 2021	van Duijnhoven et al., 2017	Ghaffarianhoseini et al., 2018	Heerwagen, 2000	Kropman et al., 2023	Kumar et al., 2023	Lottrup et al., 2012	Magalhães Rios et al., 2009	Park et al., 2024	Raw, 1998	Sugiyama et al., 2021	Zhu et al., 2019
Indoor Air Quality & Climate	General	IAQ monitor system (sensors & software)	X		X			X	X		X			X	X		
		Air source management						X	X		X				X		
	Thermal	Temperature (20 to 24 °C)	X		X			X	X	X	X		X	X	X		
		HVAC & Insulation	X		X			X	X	X				X	X		
		(Openable) Windows	X		X												
		Sunlight shading			X			X									
	Humidity	RH of 40 to 60%	X		X			X	X	X	X		X		X		
		HVAC	X		X			X						X	X		
	Ventilation	Natural ventilation	X		X			X		X	X		X	X	X		
		Closed building envelope						X		X	X		X		X		
		Openable windows			X			X		X	X		X		X		
		Ventilation rate (8 to 25 L/s per person)	X		X			X	X	X	X		X				
		Air filtration (HVAC)	X		X			X	X	X	X		X	X	X		
		Cleaning of HVAC						X	X	X	X		X		X		
		High emittance office equipment			X			X	X	X	X		X		X		
	Personal control		X		X				X	X					X		
		Locally controlled thermal system (thermostat	X					X		X							
		Openable windows			X			X		X			X				
Lighting		Appropriate condition	X		X	X	X	X	X	X							

		Blue-enriched light (CCT 17.000K)			X	X	X	X		X							
		Illumance (1.000-1.200 lx)?			X	X	X	X		X							
		Smart lighting (occupancy based)	X														
		Daylight exposure			X	X	X		X	X							
		Windows (vertical and horizontal plane)	X		X												
		Office colour & layout			X			X									
		Sunlight shading	X		X		X	X		X							
	Personal control	e.g. desk lamps				X				X							
Acoustics		Sound absorbing material	X		X	X		X		X				X			
		External façade insulation	X														
		Internal insulation	X														
	Personal control	e.g. level adaptive noise barriers	X		X					X							
Office Layout & Design	Type of layout		X		X	X		X	X	X					X	X	X
		Open floorplan: spatial openess	X		X	X		X	X	X					X	X	X
		Cellular offices: small clustered rooms (2-4 people)	X			X				X						X	
		Private offices	X							X							
		Activity Based Working				X				X						X	X
	Type of workstation				X	X		X								X	X
		Dedicated or flexible seating						X								X	
		Active workplace station (Sit-stand desk / bike desk)			X	X											X
		Adjustable chairs			X	X											
	Design	Material use	X						X								
		Colour use	X														
		Staircase			X												X
		Indoor biophilia	X			X		X	X	X	X	X		X			
Location & Amenities	Outdoor biophilia	Acces to nature				X		X	X	X		X		X			
		View on nature	X		X	X		X		X		X					
	Transportation	Passive transportation facilities	X	X													X
		Active transportation facilities:	X	X	X									X			X

	Bike parking			X												X
	Showers / changing rooms			X												X
	Public transportation facilities:	X	X													X
Amenities	Lacking amenities in the surroundings	X														X

C. Interview Process

C-I. Interview framework

The following framework has been used to effectively conduct interviews on the relationship between *environmentally sustainable* design elements and *healthy* design elements in offices.

#	Design element	Sub design element	Trade off	Synergy	Sustainability	*Health*
Site (5 minutes) Timestamp: 0.10						
	> 300 years • The area on which the building is built. Fit of the building with its surroundings.					
	Biophilic design					
1		Outdoor green elements	○	○		
	Transportation amenities					
2		(Electric) bike-sharing amenities	○	○		
3		Bike parking	○	○		
4		Electric car charging amenities	○	○		
Skin (10 minutes) Timestamp: 0.15						
	20-50 years • The exterior surface of the building. Protects the users of the building from external factors.					
	Biophilic design (2,5 min.)					
5		Green roof or façade	○	○		
	Air ventilation system (2,5 min.)					
		Building structure: Open	○	○		
6		Openable windows	○	○		
7		Building structure: Closed	○	○		
	Windows (2,5 min.)					
8		Energy-efficient windows	○	○		
9		Window orientation	○	○		
10		Fixed sunlight shading	○	○		
	General (2,5 min.)					
11		Double skin façade	○	○		
Structure (5 minutes) Timestamp: 0.25						
	50-300 years The load-bearing elements in a building.					
Services (10 minutes) Timestamp: 0.30						
	10-20 years • The building services: mechanical installations, plumbing, lighting. Supports/maintains the Indoor Environmental Quality (IEQ).					

	Heating, Ventilation & Cooling (3 min.)			
12		HVAC system	○	○
13		Hybrid ventilation system	○	○
14		Radiant heating	○	○
15		Locally controllable thermal system	○	○
	Lighting system (3 min.)			
16		Artificial lighting	○	○
17		Smart lighting	○	○
18		Dynamic sunlight shading	○	○

Space plan (10 minutes) Timestamp: 0.40

3-10 years

- E.g. the partition walls, ceilings, floors, and doors.

  Interacts with other layers as well, used to optimize a building.

	Amenities (5 min.)			
19		Showers and changing rooms	○	○
20		Gym	○	○
21		Canteen	○	○
	Layout & design (5 min.)			
22		Open floorplan	○	○
23		ABW offices	○	○
24		Private offices	○	○
25		Staircase design	○	○
26		Colour use	○	○

Stuff (5 minutes) Timestamp: 0.50

< 3 year

- Chairs and desks, but also phones.

  Greatest ‘turnaround’ of materials.

	Biophilic design			
27		Indoor green elements	○	○
	Heating, Ventilation & Cooling			
28		HVAC filters	○	○
	Lighting system			
29		Desk lamp	○	○

Wrap-up (timestamp: 0.55)

C-II. PowerPoint slides of interviews; Skin layer

The following slides where used to guide experts through the interviews. This appendix shows the slides of the Skin layer. The content is based on the interview framework presented in Appendix C-I. The sequence of the layers is the same as shown below. Therefore, only one layer is shown. The slides show the results after an interview, Figure 21 is filled in with the opinion of the expert by "X".

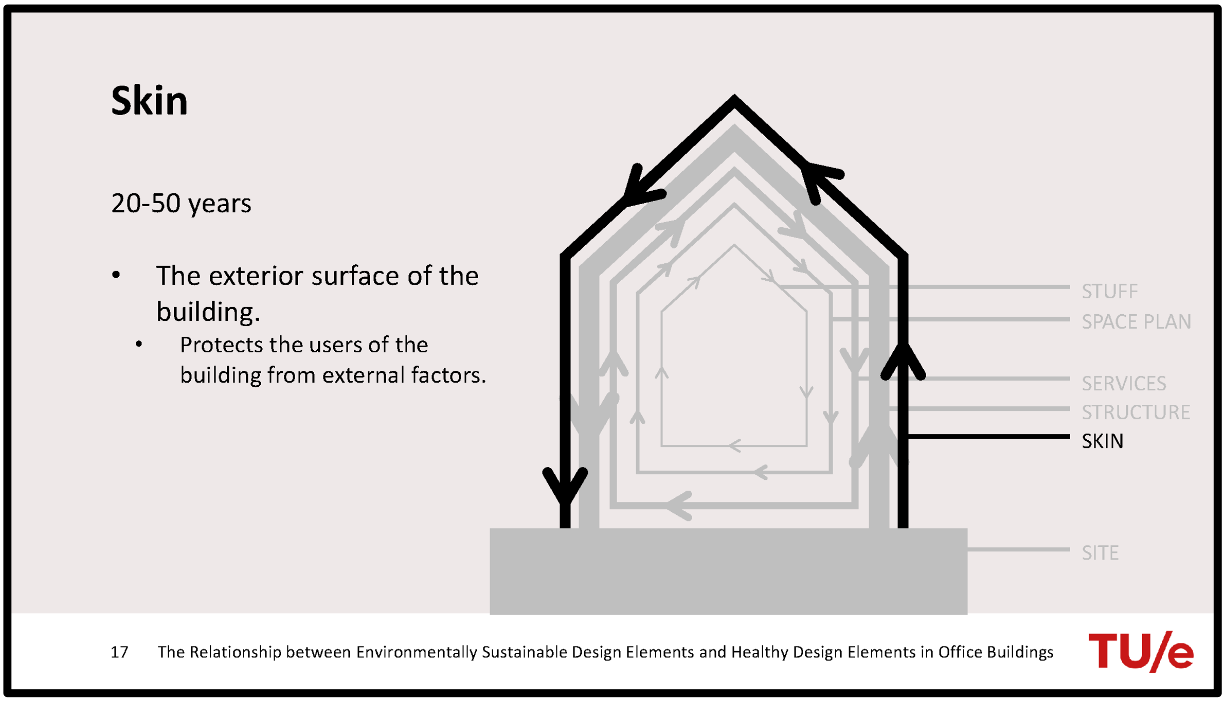

Figure 19; Slide 1 of the Skin layer during the interviews.

Skin: **What design elements experience a trade-off or synergy, considering sustainability and health?**

Biophilic design	T	S	*Windows*	T	S
Air ventilation possibilities	T	S			
			General	T	S

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Figure 18; Slide 2 of the Skin layer during the interviews.

Skin: What design elements experience a trade-off or synergy, considering sustainability and health?

Biophilic design	T	S	*Windows*	T	S
Green roof or façade		X	Energy-efficient windows		X
Air ventilation possibilities	T	S	Window orientation		X
Building structure: Open Openable windows		X	Fixed sunlight shading	X	
Building structure: Closed Mechanical ventilation	X				
			General	T	S
			Double skin façade		

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Figure 21; Slide 3 of the Skin layer during the interviews.

Skin: Do you have any additions?

Biophilic design	*Windows*
Green roof or façade	Energy-efficient windows
Air ventilation possibilities	Window orientation
Building structure: Open Openable windows	Fixed sunlight shading
Building structure: Closed Mechanical ventilation	
	General
	Double skin façade
	Insulation

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Figure 20; Slide 4 of the Skin layer during the interviews.

C-III. Framework after interview; Skin layer

During the interviews the interviewer also writes down notes and influences which are not written down in the PowerPoint, see Figure 22.

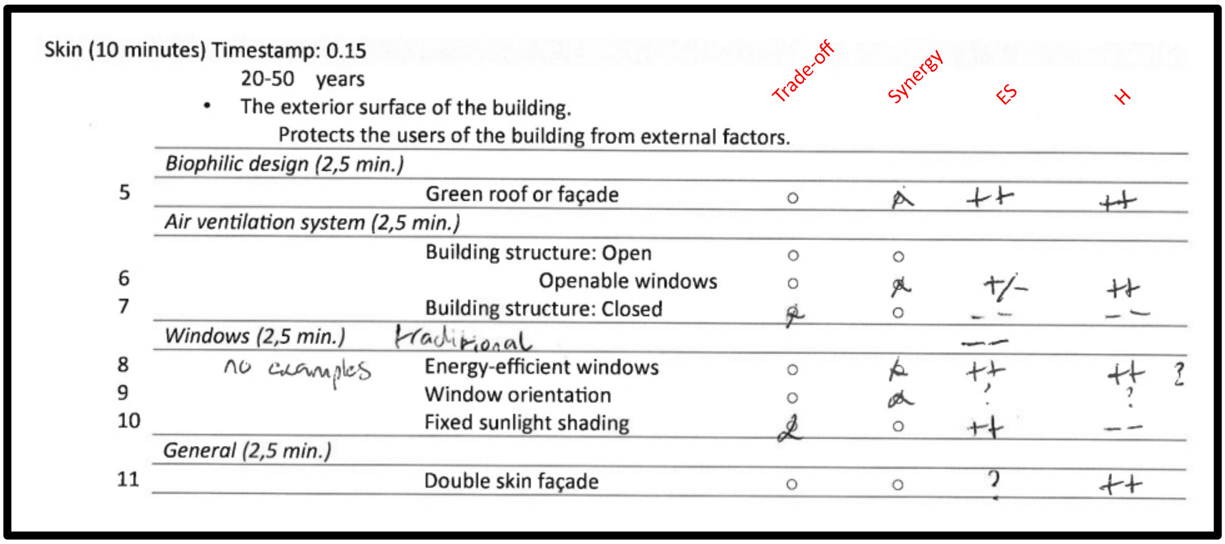

Figure 22; Snip of the scrap notes during the interviews; Skin.

C-IV. Transcribed interview; Skin layer (Expert ID6)

The following appendix shows a section of an interview of Expert ID6, the section is the Skin layer.

2. Skin

[00:25:35] **Wiebe van Spronsen:** Okay. Clear. Let's move on to the Skin layer. So the exterior surface of the building I would like to ask the big question again; 'what design elements do you think experience a trade-off and or synergy considering sustainability and *health*?'. And I have defined some categories. Biophilic design, again, air ventilation possibilities. We discussed that already a bit. Windows as well. And some more general things. Maybe I can just show them on the slide. And we can just walk them through.

[00:26:21] **Expert ID6:** Yeah, I think that's better.

[00:26:23] **Wiebe van Spronsen:** I'll mark the green roof and facade as well as the synergy since they have the same effect. Do you think there are more sustainability benefits from a green roof than there are from biophilic design outside on the site?

[00:26:42] **Expert ID6:** Can you say that again?

[00:26:48] **Wiebe van Spronsen:** Just in general, what are the sustainability benefits from a green roof or a green facade?

[00:26:57] **Expert ID6:** Well plants they produce oxygen. I think we lean a little bit too heavily on them for that. You know, there's too many offices that put a couple of plants in the office and they go; 'oh, it's producing oxygen for these 200 people'. So from a *health* perspective and from a sustainability perspective, oxygen is great. I think that's that that takes both.

[00:27:30] **Wiebe van Spronsen:** We discussed air source management already and an open building structure with natural ventilation. What do you think of a closed building structure? What are the effects on sustainability and *health*?

[00:27:45] **Expert ID6:** I think you have to really make sure that you're getting it right. I did a interview with a TV station one time where we actually measured the oxygen there, and they had they had retrofitted an old building and did a closed window system, and the air quality was absolutely awful, and people were getting sick. People had you know, nose bleeds and dry eyes and nausea and all of this. They were basically experiencing some level of, you know lack of oxygen or even some kind of toxins or air poisoning.

[00:28:28] **Wiebe van Spronsen:** Okay.

[00:28:28] **Expert ID6:** I think if you're not measuring it, you have to be extremely careful with your *health* levels. And then you have to make sure that the right people are monitoring it. I worked at a company where I worked with a company that should have known better, but they were having trouble with their humidifier. So we push in air, But we also need to push in humidity, otherwise it'll be very dry air, which spreads diseases extremely quickly and has other negative *health* benefits. And they had been off for five years and they said; 'oh, but there's no problem.' You know, dry air doesn't do anything. Wet air, you know, has mould and does all of this. And they said the dryer's extremely bad and you can feel it. So you have to have the right people and an open system, or at least a partially open system has a little bit more room for error. And so I think monitoring air quality, because we know how bad it's been in the past is extremely important/tangent.

[00:29:40] **Wiebe van Spronsen:** So you say that having an indoor environmental quality management system is really important?

[00:29:47] **Expert ID6:** Yeah. But it can also be important when having an open building structure.

[00:29:56] **Wiebe van Spronsen:** Well let's move on to the windows. Windows in general are of course not good for the sustainability, but implementing energy-efficient windows can maybe take away that negative benefit.

[00:30:13] **Expert ID6:** Yep.

[00:30:14] **Wiebe van Spronsen:** Okay. We discussed openable windows already and window orientation, which I picked up as synergies. But if I'm wrong, you should correct me.

[00:30:24] **Expert ID6:** No, I totally agree. There's also a lot of studies on the mental *health* benefits of windows that open at least partly.

[00:30:32] **Wiebe van Spronsen:** Yeah, yeah. Do you think there is a negative effect on the sustainability when opening windows?

[00:30:37] **Expert ID6:** Yeah, that's what they've shown. It's very hard to control temperatures and run the HVAC, which will run more when people can open windows.

[00:30:50] **Wiebe van Spronsen:** Okay. So there is a trade off as well in it?

[00:30:53] **Expert ID6:** Yeah. But I think it's about just learning how to design better as well.

[00:30:59] **Wiebe van Spronsen:** Okay. And what do you think of fixed sun lighting? We have dynamic sun lighting and fixed sun lighting.

[00:31:11] **Expert ID6:** In terms of? What do you mean by that exactly?

[00:31:16] **Wiebe van Spronsen:** Well-fixed elements on the facade, which cannot be changed, they are there from the construction on and they, of course, shade the sunlight but cannot be changed as dynamic shading can.

[00:31:34] **Expert ID6:** Yeah. I think that's also an area that we haven't mastered yet. So I think there's a lot of room for improvement with using sunlight to control temperature, so you don't have to run your HVAC while also keeping people comfortable.

[00:31:53] **Wiebe van Spronsen:** Okay, so right now it is a trade-off. But in the future when managed well it can be a synergy?

[00:31:59] **Expert ID6:** Yeah, I think so.

[00:32:01] **Wiebe van Spronsen:** Okay. And what do you think of a double skin facade as an effect on the *health*?

[00:32:10] **Expert ID6:** I do not know. I'm familiar with it. But I don't know about *health*.

[00:32:19] **Wiebe van Spronsen:** Okay. I'll leave it open. And insulation in general?

[00:32:28] **Expert ID6:** Yeah, that can obviously be sustainable a huge benefit because you don't have to change temperatures as much and you can keep a more consistent temperature. This can also lead to better comfort for individuals, because you don't have the fluctuating temperature changes of trying to always reach that ideal temperature.

[00:32:54] **Wiebe van Spronsen:** Can it have more positive effects on *health* only then the comfort on a temperature?

[00:33:01] **Expert ID6:** It depends on what kind of insulation you're talking about, I guess. But I can't think of anything right now.

[00:33:11] **Wiebe van Spronsen:** Okay. Where do you think the biggest trade off lies? From the the elements on the slide.

[00:33:26] **Expert ID6:** I would say the operable windows and energy efficient windows is the biggest thing where people are trying to decide what to do now.

D. *Environmental Sustainable* and *Healthy* Design Elements

This appendix shows the final table with the relationship mentioned by experts for all the considered design elements in this thesis.

Table 47: Relationships of the design elments per layer for the ten experts.

	Design element	Summation	# Trade-offs	# Negative Synergy	# Environmental Trade-offs	# *Health* Trade-offs	# Positive synergies	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10
Site																	
	Biophilic design																
1	Outdoor green elements	**10**	3	1	2	0	**7**	pS	eTS	pS	pS	eTS	pS	pS	pS	nS	pS
2	Outdoor blue elements*	**2**	0	0	0	0	2			pS		pS					
3	Open pavement*	**1**	0	0	0	0	1										pS
4	Outdoor meeting space*	**2**	0	0	0	0	2	pS						pS			
	Transportation amenities																
5	Bike parking	**10**	0	0	0	0	**10**	pS	pS	pS	pS	pS	pS	pS	pS	pS	pS
6	Bike-sharing amenities	**2**	0	0	0	0	2		pS								pS
7	Car parking	**5**	5	5	0	0	0	nS	nS	nS	nS		nS				
8	Electric car charging amenities	**6**	0	0	0	0	**6**	pS	pS		pS		pS			pS	pS
Skin																	
	Biophilic design																
9	Green roof or façade	**10**	0	0	0	0	**10**	pS	pS	pS	pS	pS	pS	pS	pS	pS	pS
	Air ventilation system																
	Building structure: Open																
10	Openable windows	**9**	9	4	5	0	0	eT		eT	eT	eTS	eTS	nS	nS	nS	nS
11	Building structure: Closed	**8**	8	4	0	4	0	nS		nS	hT	hT	nS		hT	nS	hT
12	Midnight Cooling*	**0**	0	0	0	0	0	T									
	Windows																
13	Windows	**8**	8	0	8	0	0	eT		eTS	eTS	eTS		eT	eT	eTS	eT
14	Microshading within windows*	**1**	1	0	0	1	0	hT									
15	Solar panel glazing*	**2**	2	0	0	2	0							hT	hT		
16	Window sunlight coating*	**2**	1	0	0	1	1					hT					pS
17	Openable roof*	**1**	0	0	0	0	1					pS					
18	Roof glazing*	**1**	1	0	1	0	0					eTS					
19	Window orientation	**8**	8	0	8	0	0	eTS		eTS	eTS	eTS	eTS		eTS	eTS	eTS
20	Static sunlight shading	**10**	5	0	0	5	5	hT	hT	hT	pS	pS	hT	hT	pS	pS	pS
Services																	
	Heating, Ventilation & Cooling																
21	HVAC system	**10**	10	1	9	0	0	eT	eT	eT	eTS	eT	eT	nS	eT	eT	eT

22	Hybrid ventilation system	**4**	1	0	1	0	3				eT		pS		pS	pS	
23	Radiant heating	**8**	1	0	0	1	7		pS	pS	pS	pS		pS	pS	pS	hT
24	Locally controllable thermal system	**8**	5	0	4	1	3	eTS		eT	eT	pS	eT	pS	pS	hT	
Lighting system																	
25	Traditional artificial lighting	**10**	10	2	8	0	0	eT	nS	eT	eT	eT	eT	eT	nS	eT	eT
26	Smart lighting	**10**	4	2	1	1	6	nS	pS	pS	hTS	pS	nS	pS	pS	eTS	pS
27	Locally controllable lighting system*	**1**	1	0	1	0	0									eT	
28	Dynamic sunlight shading	**9**	6	0	0	6	3	hT	hT	hTS	hTS	pS		pS	hTS	pS	hT
Space Plan																	
Amenities																	
29	Showers and changing rooms	**9**	4	0	4	0	5		eTS	eTS	eTS	pS	eTS	pS	pS	pS	pS
30	Gym	**7**	6	0	6	0	1	eT	eT	eT			pS		eT	eT	eT
31	Canteen	**9**	5	0	5	0	4	eTS	eTS	pS	pS	eTS	pS	pS	eT	eT	
Layout & design																	
32	Open floorplan	**6**	6	4	0	2	0	nS	nS		nS			hT		hT	nS
33	ABW offices	**6**	2	0	0	2	4		pS		hTS	pS	hTS	pS	pS		
34	Private offices	**7**	5	1	3	1	2		hT		eT		eTS	pS	pS	nS	eT
35	Staircase design	**9**	0	0	0	0	9	pS	pS	pS	pS	pS	pS		pS	pS	pS
36	Walking route to meeting*	**2**	0	0	0	0	2	pS						pS			
37	Water tap*	**1**	1	0	0	1	0	hTS									
38	Colour use	**4**	0	0	0	0	4		pS		pS	pS			pS		
Stuff																	
Biophilic design																	
39	Indoor green elements	**10**	7	1	6	0	3	eTS	eTS	eTS	nS	eTS	pS	pS	pS	eTS	eTS
40	Indoor blue elements*	**1**	1	0	1	0	0				eT						
Heating, Ventilation & Cooling																	
41	Filters of HVAC System	**9**	4	0	4	0	5	pS		pS	eT	eT	eT	pS	pS	pS	eT
42	Ventilators*	**1**	1	0	1	0	0				eT						
Lighting system																	
43	Desk lamp	**7**	7	0	7	0	0	eT	eTS	eTS		eTS		eTS		eT	eT

E. Trade-off checklist

This appendix shows the checklist created by combining the responses form experts during the interviews. Following the checklist may result in a better insight in individual design elements.

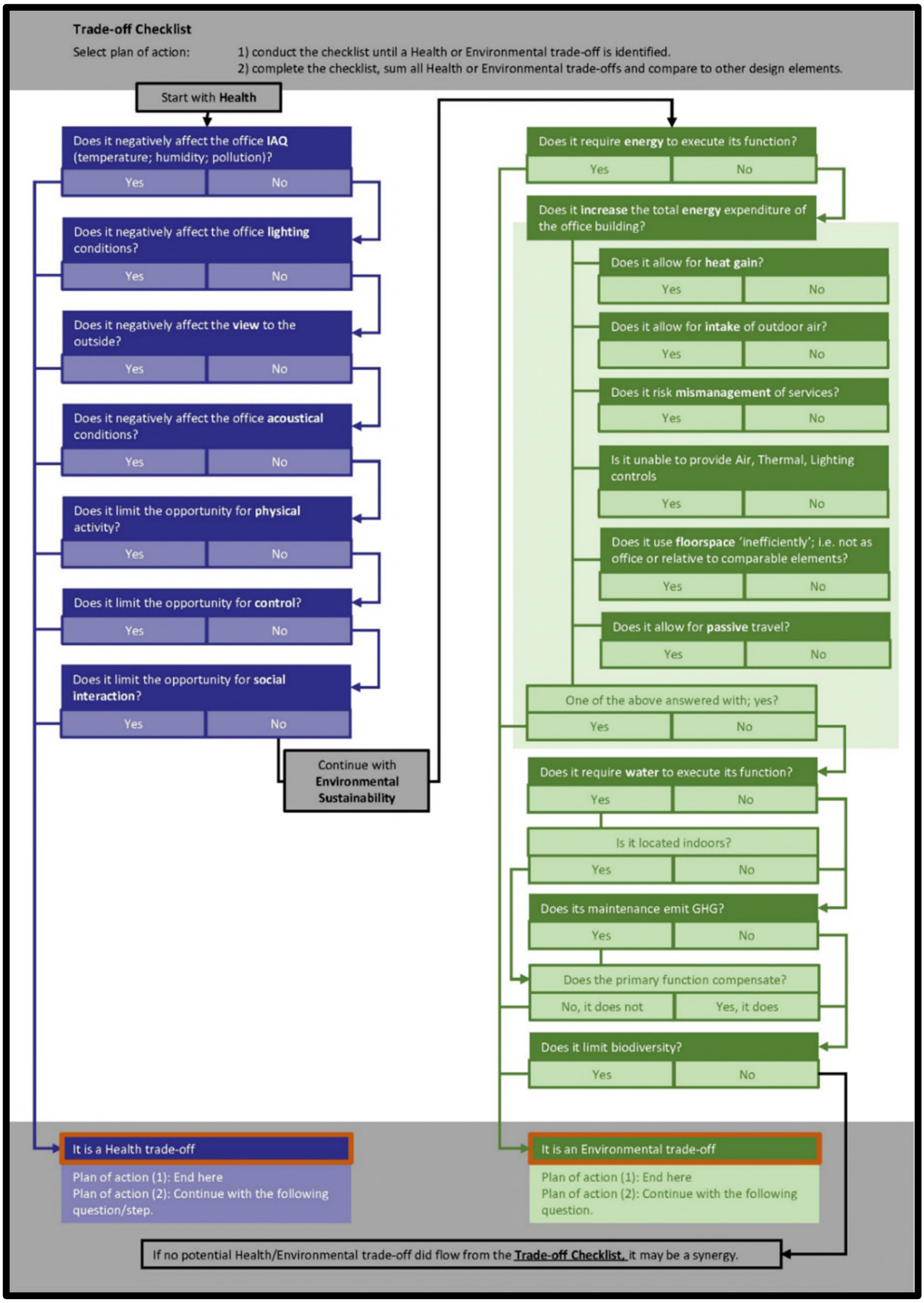

Figure 23; Trade-off checklist.