rijksuniversiteit groningen

Bachelor’s thesis

Harmonizing urban form and function

Exploring the synergy of green space, densification, and urban heat reduction in post-war neighbourhoods

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Abstract

The Netherlands is currently experiencing a growing housing shortage, and it is projected that approximately one million new homes will need to be developed in the coming years to address this challenge. Many urban areas are adopting densification as a strategic approach to accommodate the increasing demand for housing due to its potential positive impacts on economic, environmental, and social sustainability objectives. Post-war neighborhoods, characterized by low density and significant green spaces, are being identified as suitable areas for densification efforts. It is crucial to recognize that while densification offers a solution to the housing shortage, it may also introduce difficulties such as the reduction of green spaces and the exacerbation of the urban heat island (UHI) effect, potentially leading to heightened energy consumption, increased air pollution, and associated health implications. Therefore, this research aims to illustrate how densification of a post-war neighborhood can reduce the UHI effect by optimizing urban form and integrating urban green spaces. To do so, this report addresses the following research question: "How can the densification of post-war neighborhoods be strategically designed to reduce the urban heat island effect through optimized building morphology and the integration of urban green spaces?’’

This research is structured using the design thinking methodology, as it combines literature-driven insights with iterative prototyping, leading to more practical solutions that are adaptable to real-world complexities. Through a literature review, five indicators that influence the intensity of the UHI effect are identified. Subsequently, the literature is used to understand how building morphology and urban green spaces can leverage these five indicators to reduce the UHI effect, resulting in a set of design principles. This information is then used as input for the design process. A selected section of the post-war Vinkhuizen neighborhood in Groningen serves as a case study to apply the design principles. The findings indicate it appears that the UHI effect in post-war neighborhoods can be mitigated by using high albedo materials or coatings, integrating vegetation on building surfaces, and casting shadows on roads through building morphology or trees. Additionally, adjusting building orientation in the green borders of the neighborhood seems to contribute to lowering temperatures within the buildings and in public spaces. However, it appears to be not possible to formulate one specific strategy as the results show that the interaction between different components is crucial and various design principles can conflict with each other in practical application. This leads to the conclusion that there is no definitive answer to the main question. Both building morphology and urban green spaces have components that can theoretically contribute to reduction of the UHI effect in post-war neighborhoods, but the context of the location determines whether a particular adjustment can lower the UHI effect and there will always be concession to be made.

Key words: Densification, urban green space, Urban Heat Island (UHI) effect, post-war neighborhoods

1 Introduction

1.1 Background

The densification of urban areas has emerged as a sustainable urban development strategy to counter the increasing housing shortage and meet the future demand in the Netherlands. Capital Value (2024) has reported that the Netherlands is facing a housing shortage of 390,000 dwellings that is projected to increase to 450,000 by 2027 if no action is taken. To tackle this critical issue, the ministry of interior and kingdom relations (2022) has announced that the 12 provinces have agreed to construct 900,000 new dwellings by 2030. Research by Claassens, Koomen, and Rouwendal (2020) reveals that a significant number of municipalities in urban areas across the Netherlands are inclined towards densification rather than spatial expansion as the preferred approach to accommodate the influx of new housing units. According to Bibri, Krogstie, and Kärrholm (2020), this aligns with the principle of the compact city paradigm. This concept is actively advocated by both global and local policies for their beneficial impacts on economic, environmental, and social sustainability goals.

Post-war neighbourhoods which are situated on the fringes of existing urban areas, are characterised by low density and ample green spaces, making them an attractive location for adding dwellings while preserving quality of life. According to a report by van Beckhoven, Bolt and van Kempen (2005), the post-war neighbourhoods were built in the 1950s, '60s and '70s, based on idealistic, modernist urban development plans. In addition, van der Cammen and de Klerk (2006) as well as de Hoop (2009) have stated that these neighbourhoods were designed to address two major challenges: providing high-quality dwellings to solve the post-war housing shortages and improving liveability in the neighbourhood. Deelstra's (2022) research highlights that the challenges faced in constructing post-war neighborhoods to tackle housing shortages and improve the living conditions have resulted in a design featuring relatively low density and ample green spaces. Presenting a prime opportunity for densification.

Nevertheless, negative effects of densification are increasingly evident. One issue identified is the lack of urban green space in densified urban areas and the removal of green space when densifying city areas (Haaland and van den Bosch, 2015). In their research Lee et al. (2015) emphasize that urban green spaces offer a multitude of benefits that advocate for their preservation and expansion. These spaces play a crucial role in mitigating urban heat, reducing greenhouse gas emissions, and managing stormwater. Additionally, Fuller & Gaston (2009) showed that urban green spaces contribute to physical and mental well-being, social cohesion, ecosystem services, and biodiversity conservation.

An additional negative effect of densification in urban areas is the potential to exacerbate the urban heat island (UHI) effect. According to Kuang et al. (2014) the UHI effect can increase because of the concentration of buildings and impervious surfaces, which absorb and retain heat, leading to elevated temperatures in densely populated areas. Lee et al. (2015) reported that the consequences of the UHI effect include higher energy consumption for cooling, elevated air pollution levels, compromised human health due to heat-related illnesses, and increased greenhouse gas emissions. Additionally, Wang et al. (2017) mentions that UHI's can also disrupt ecosystems, alter weather patterns, and intensify urban heat stress, particularly impacting vulnerable populations in cities.

The tension between prioritizing compact city approaches and valuing open structures for resilience underscores the societal significance of this research. Densification and climate resilience are key discussions in urban politics, aiming for sustainability. Reckien et al. (2018) highlighted that compact cities target reducing emissions and traffic, while resilient cities focus on adapting to environmental changes. Balancing these approaches requires nuanced land-use planning, highlighting the societal importance of this research.

In addition to its societal importance, this research addresses a critical gap in the academic discourse by examining the dynamics of UHI and densification in post-war neighbourhoods. The ongoing academic discourse on compact versus resilient cities has been highlighted since 2005 with Neuman's "compact city paradox." While numerous studies have explored UHI and waterlogging, they often focus on urban areas, overlooking post-war neighbourhoods on urban fringes. This study aims to fill this gap by examining densification in Dutch post-war neighbourhoods to mitigate UHI effects.

1.2 research problem

This research aims to illustrate how densification of a post-war neighborhood can reduce the UHI effect by optimizing urban form and integrating urban green spaces. To do so, this report addresses the following research question:

"How can the densification of post-war neighbourhoods be strategically designed to reduce the urban heat island effect through optimized building morphology and the integration of urban green spaces?’’

To answer this research question, the following sub-questions were developed:

1. What are the spatial characteristics of a post war neighborhood in the Netherlands?
2. In what ways can the process of densification affect the key characteristics of a buildings morphology that influence the UHI effect?
3. What types of urban green spaces are most effective in reducing the UHI effect?
4. How can an existing post-war neighborhood be redesigned to incorporate optimized building morphology and urban green spaces to reduce the UHI effect?

1.3 Thesis structure

This bachelor thesis is structured into several sections, each guided by the sub-questions to address the main research question. Initially, the theoretical framework is explored, in which the most important concepts are explained, followed by the visualisation of the conceptual model. Subsequently, the methodology is explained, detailing the rationale behind the chosen research methods, data collection procedures, and justification for the selected case. In the results section, the various sub-questions are addressed. Finally, the conclusions section addresses the main research question, followed by a discussion of the limitations of this research and recommendations for future studies.

2 Theoretical framework

2.1 Concepts

Post-war neighbourhood design

According to Braae et al. (2021) and Bouziotas et al. (2019), post-war neighborhoods in the Netherlands were designed based on a cluster of values aimed at creating inclusive and sustainable living environments. These values include providing housing for all, promoting a healthy and equitable city, fostering strong communities, ensuring equitable access to nature, and creating a nurturing environment for children. De Hoop et al. (2009) highlights two core concepts underlying the design of these neighborhoods. The first is the organic residential area, characterized by strategically located amenities for residents of all ages and connections to the city's green infrastructure (Van Rossum and Schilt, 2002). The second concept is the neighborhood concept (wijkgedachte), defining the neighborhood as a segment of the city residents oversee and engage with, centered around essential facilities within a distinct boundary (De Hoop et al., 2009).

To integrate these concepts into the urban fabric of post-war neighbourhoods, a set of design principles was implemented. De Hoop et al. (2009) emphasize the structured layout of these neighborhoods, characterized by distinct green and road networks. The road layout follows a grid pattern with main roads, commercial streets, local roads, and residential streets designed according to traffic needs. The green network includes interconnected parks and park strips that connect the neighborhood with urban and rural surroundings, serving as pathways to parks and amenities. Surrounding the neighborhood are high-rise buildings and green borders, emphasizing its distinct identity and serving as landmarks. Additionally, Lörzing (2008) mentions the stamp structure used to aid residents' orientation within their immediate environment. These stamped areas include a mix of low-rise and mid-rise buildings to accommodate residents at different stages of life, often featuring a central communal courtyard with seating and recreational areas.

Urban heat island effect

According to O'Malley et al. (2014), the Urban Heat Island (UHI) effect refers to significant temperature variances between urban and adjacent rural areas. The UHI effect consists of two main components: surface and atmospheric UHI's. According to Tang (2022) surface UHI's are most prominent during daytime and are observed at ground level and on building surfaces. In contrast, Kuang et al. (2014) and Mohamed (2024) highlight that atmospheric UHI's are characterized by heightened atmospheric temperatures, with a notable increase in intensity during night-time. "UHI intensity," calculated as urban air temperature minus rural air temperature, quantifies the UHI effect across different cities (Pacheco-Torgal, 2020). Nevertheless, the UHI effect is also often associated with the concept of Outdoor Thermal Comfort (OTC). According to Thorsson et al. (2010) OTC refers to the subjective perception of thermal conditions experienced in outdoor spaces. Studies by Zhang et al. (2020) and Ishak et al. (2023), among others, have consistently shown the significance of air temperature in determining individuals overall thermal sensation, with high temperatures notably affecting human comfort and safety.

Research by Prayudha et al. (2022) and Tahooni and Kakroodi (2019) highlights that albedo significantly influences the surface temperature of urban areas. Albedo denotes the capacity of a surface to reflect light, expressed as a percentage. Taha (2017) demonstrated through a literature review that numerous studies have indicated that increasing urban albedo can effectively mitigate the UHI effect. In addition, Wahba et al. (2019) emphasise the role of evapotranspiration in influencing the UHI effect, which includes both evaporation and transpiration processes from vegetation. Research by Qiu et al. (2013) demonstrated that evapotranspiration can lower atmospheric temperatures by 0.5 to 4.0°C through the release of moisture into the atmosphere. Furthermore, Huang et al. (2020) and Sen and Roesler (2020) have shown that higher wind speeds can help reduce surface temperatures and improve thermal comfort by enhancing the dispersion of heat. Another factor that influences OTC and the UHI effect is shading (Middel et al., 2014) (Park, Guldmann and Liu, 2021). Yin et al. (2019) found that shading significantly affects the thermal sensation of pedestrians during the daytime, particularly around noon when the sun is at its peak.

Finally human activities such as modes of transportation and energy use can increase or decrease the thermal temperature. Research conducted by Rizvi et al. (2023) demonstrated that internal combustion engine vehicles have an efficiency ranging from 16 to 20 percent. Nearly all of the remaining energy contained in the fuel is converted into heat, thereby exacerbating the magnitude of the UHI effect. Additionally, several studies have linked increased electricity use for air conditioning to outdoor temperatures, highlighting that the use of air conditioning can increase the street-level temperature with 0.5 to 2°C (de Munck et al., 2012) (Lundgren and Kjellstrom, 2013). Figure 1 provides a comprehensive overview of the various factors influencing both the UHI effect and OTC.

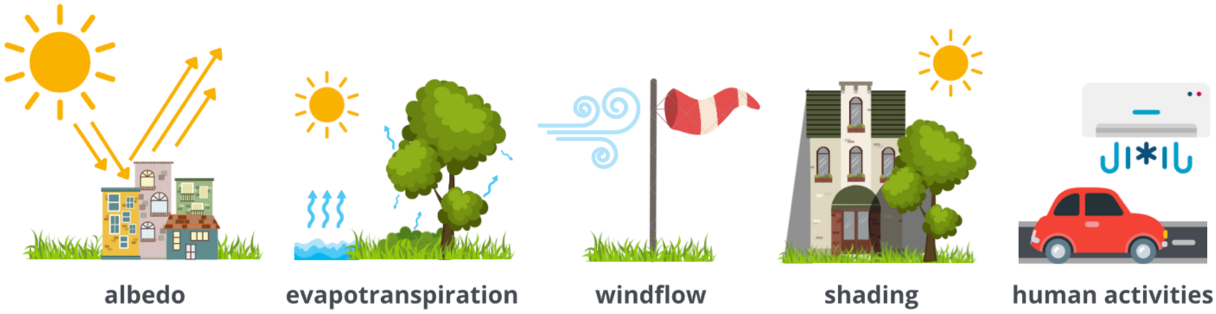

Figure 1 factors that influence OTC and the UHI (own work, 2024)

Utilizing densification strategies to reduce the UHI effect

According to Broitman and Koomen (2015) the concept of densification involves the strategic increase in population or building density within existing urban areas. Ferrante, Fotopoulou, and Mazzoli (2020) highlight the importance of densification strategies in addressing contemporary urban challenges like population growth, climate change, and environmental degradation. In their publication, Brunner and Cozens (2013) discuss how densification strategies can entail the expansion of existing structures by adding one or two additional stories to existing buildings or the construction of new buildings on previously undeveloped land, a practice commonly referred to as infill development. In addition, Jenks, Williams and Burton (2000) suggest that densification can be accomplished by repurposing built-up areas that previously served different functions or by replacing low-density buildings with high-rise constructions.

Urban geometry significantly influences the UHI effect. Research by Bayoumi (2018) and Nasrollahi et al. (2020) shows that buildings with reduced heights and increased spacing between them can facilitate natural ventilation and passive cooling, increasing the thermal comfort levels. Furthermore, research conducted by Nasir et al. (2017) found that buildings positioned to minimize direct sun exposure during peak hours can reduce heat absorption and lower overall temperatures in urban areas.

Utilizing urban green space to reduce the UHI effect

According to Taylor and Hochuli (2017) as well as Lee, Jordan and Horsley (2015) the definition of urban green space is subjective and vary widely, but it broadly encompasses publicly accessible areas with natural vegetation, such as grass, plants, or trees. In the context of the UHI effect, Amani-Beni et al. (2019) and Bao et al. (2016) refer to urban green space as vegetated areas within urban environments that counteract the UHI effect by providing cooling effects, promoting evapotranspiration and enhancing air quality. Hafsi et al. (2022) further notes that water bodies and features such as ponds and fountains, while not always explicitly classified as urban green spaces, can significantly enhance the urban microclimate by reducing temperatures and contributing to the overall cooling effect.

Research conducted by Nasrollahi et al. (2020) and Pradipta (2018) shows that the most affective heat-mitigation strategy for improving thermal comfort was found to be the presence of vegetation and particularly trees, due to their shading and evaporative cooling properties. Price et al. (2015) mentions green roofs, vertical greenery systems, and green walls as examples of how vegetation can be integrated into urban design to enhance cooling. Gillner et al. (2015) estimated that tree-shaded streets could decrease air temperatures by 0.9 to 2.6 degrees Celsius. According to Shashua-Bar et al. (2012) the primary advantage of tree-provided shade lies in enhancing local thermal comfort during daylight hours. Research by Föllmi et al. (2023) shows that the maximum daytime surface temperatures for blue and green roofs are on average 2 tot 3 °C lower than for gravel roofs. In addition, Tseng et al. (2022) emphasise that dwellings with a blue or green roof are less sensitive to outside air temperature changes as daily temperature fluctuations were systematically lower compared to conventional roofs for both warm and cold periods.

Additionally, research has shown that incorporating water bodies, such as ponds and fountains, can have a cooling effect on urban environments. For instance, a study conducted by Robitu et al. (2006) demonstrated that a small pond could reduce temperatures by approximately 1°C at a distance of 30 meters. Additionally, Farnham et al. (2015) showed that the combination of water mist and fans has been found to be highly efficient in rapidly decreasing skin temperatures. Moreover, research by Zhou et al. (2011) emphasizes that the presence of water bodies, such as fountains, can enhance thermal comfort by reducing temperatures by 1-2°C.

2.2 Conceptual model

Figure 2 illustrates the conceptual model underlying this study, which originates from the context of post-war neighbourhoods. The integration of densification and urban green space is introduced into these pre-existing neighbourhoods. These elements are intrinsically linked, as both necessitate urban space and have the potential to mutually enhance each other. Their combination leads to various specific design implementations. Depending on the selected implementations, the UHI effect and OTC can be either increased or reduced.

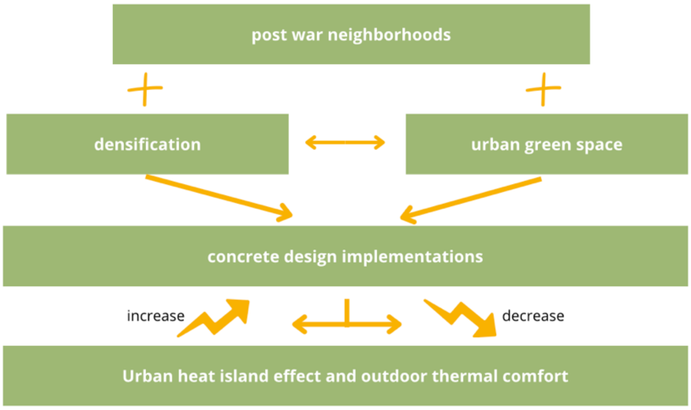

Figure 2 Conceptual model showing the relationship between the core concepts (own work, 2024)

2.3 Expectations

The expected outcome of this research is that it's possible to come up with a design solution that effectively addresses both challenges of increasing population density in post-war neighbourhoods and reducing the impact of urban heat islands. The anticipated outcome is to demonstrate a feasible and practical solution that can be implemented to achieve both goals at once. This requires the strategic implementation of green infrastructure, such as urban green spaces and cool roof systems, as well as sustainable urban planning practices to effectively mitigate the urban heat island effect during the densification process. The use of green spaces, together with specific materials and design strategies, is expected not only to support increased urban density, but to contribute to overall neighborhood sustainability and livability.

3 Methodology

3.1 Research method

In this research, a multi-method approach will be conducted to determine how densification of post-war neighbourhoods can be achieved while increasing the quality of urban green space and reducing the urban heat island effect. The research by design approach will be alternated with primary qualitative data and literary secondary data.

To address the main research question a design thinking methodology is the most effective approach. This methodology enables a more in-depth exploration of the intricacies of post-war neighbourhoods, densification and the UHI. As it considers not only statistical data but also spatial and experiential factors that affect those aspects. It's essential to consider all these aspects when attempting to comprehend the complexities and determine how to combine them. In addition, research by design allows for the generation of tangible prototypes and interventions, providing practical solutions that extend beyond mere analysis. Roggema (2016) emphasises that this approach enables the creation of innovative solutions that are both effective and impactful, tailored to specific challenges and needs.

This report is structured according to the stages of the design thinking methodology defined by Videnovik et al. (2019). According to Videnovik et al. (2019) the design thinking methodology consists of four stages: empathize, ideate, prototype, and evaluate. The initial stage, empathize, concentrates on user-centric research to gain an understanding of the problem addressed in this study. During the empathize phase, secondary data is employed to address the initial sub-questions. To uphold the integrity of the data utilized to address the central question, only articles or reports subjected to peer review or originating from government entities are analysed. Thereby ensuring the reliability and validity of the research's data. During the ideation phase, various ideation techniques, including brainstorming and sketching, were employed to produce potential solutions. The rationale behind the choices made in this phase is grounded in aligning them with the objectives established during the empathize phase. Each decision in this stage is supported by elucidating its contribution to these objectives, thereby enhancing the validity of the research.

Additionally, two interviews with an area developer and a landscapes architect were conducted during the ideation phase. According to Clifford et al. (2016) interviewing experts in the early stages of the design process can help identify potential problems before investing significant time and resources into a particular solution. Which can help to create more effective designs. During the prototype phase several visualizations were made of potential solutions, using SketchUp, Procreate and reverence imaging to formulate an answer to the last sub question.

3.2 Case selection

A singular neighbourhood was selected as the subject for design exploration. Selection of a singular neighbourhood facilitated a thorough examination of its distinct characteristics, challenges, and opportunities, thereby fostering a heightened comprehension of its dynamics and facilitating the generation of nuanced design solutions. This focused approach also optimized resource utilization within the constrained timelines and scope. Additionally, the chosen neighbourhood presents a compelling case study, affording insights translatable to wider contexts.

Because the Vinkhuizen neighborhood in Groningen met the design principles of a post-war neighborhood, as described in Chapter 2, it was selected as a case study. The selection of the Vinkhuizen neighbourhood in Groningen (see figure 2) was undertaken to enhance the research's viability through several considerations. Initially, the established institutional connections with the municipality provided access to resources that were crucial for a comprehensive analysis. This encompassed direct engagement with local experts and access to documentation, thereby offering nuanced insights into the neighbourhood that might not have been accessible otherwise. Additionally, the logistical convenience of geographic proximity facilitated multiple visits to the neighbourhood, thereby facilitating an enhanced comprehension of its characteristics, challenges and opportunities. Finally, the design features of Vinkhuizen align with those outlined in the theoretical framework concerning post-war neighbourhoods. These include aspects such as the layout of green spaces and road networks, the presence of tall buildings at the periphery of the neighbourhood, and the characteristic stamp structure.

Figure 3 Location and map of the Vinkhuizen neighbourhood (Google Maps, 2024)

3.3 Ethical considerations

This research relies on personal data obtained through interviews, making privacy a crucial consideration. To ensure participants comprehend the implications, a consent form (found in Appendix I) has been signed. Additionally, participants' names are withheld to safeguard their privacy. Interviews were recorded with participant agreement and securely stored, with names omitted for added security.

4 Results

4.1 Assessing current neighbourhood vulnerability to the UHI effect

As discussed in Chapter 3, a specific area of Vinkhuizen has been selected for the design phase. As previously mentioned, the first step in the design thinking methodology as describe by Videnovik et al. (2019) involves gaining a comprehensive understanding of the problem. Chapter 2 reviewed design principles from the literature related to the UHI and explored how urban green spaces and densification can be leveraged to reduce the UHI. This section delves deeper into the selected site to gain a better understanding of its characteristics and complexities, providing a foundation for generating potential design ideas. To get an better understanding of the area the layer approach made by de Hoog et al. (1998) is used so that all physical and functional elements of the neighbourhood can be taken into account during the ideation phase. The layer approach is a methodology in the spatial planning of the physical environment divided into three main layers: the subsurface, networks and occupancy. In figure 4 from left to right the road network, the building layer, the green network and the blue network are visualised.

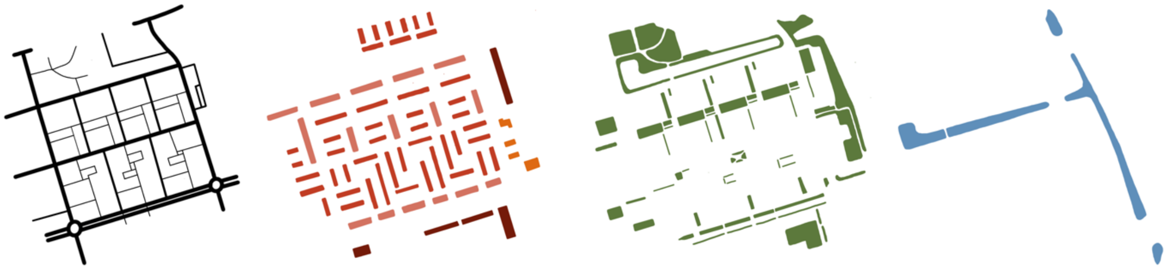

Figure 4 layer approach of the selected area (own work, 2024)

What stands out in the road network are the straight lines and the grid pattern of main roads, local roads, residential streets, and sidewalks. This results in a relatively high number of roads on a relatively small surface area. During the site visit, it was also noticeable that a large number of streets are relatively wide, as shown in Figure 5. These extensive amounts of asphalt and paving with a low albedo and no evapotranspiration can significantly contribute to increased temperatures, especially in direct sunlight. In the building layer, the stamp structure stands out, which is repeated three times in this area, with low-rise buildings and gallery flats alternating with high-rise buildings at the edge of the area. Figure 6 provides an overview of the ownership of the buildings and the construction year of the buildings. What stands out is that all apartment buildings are owned by housing associations and that the terraced houses are either privately owned or privately rented or owned by the housing association. Almost all buildings were constructed between 1960 and 1975, except for a row of terraced houses on the north side of the area. The combination of private ownership and the construction year makes the terraced houses in the area less suitable for densification than the apartment buildings.

Figure 5 Site visit observation relatively wide streets (own work, 2024)

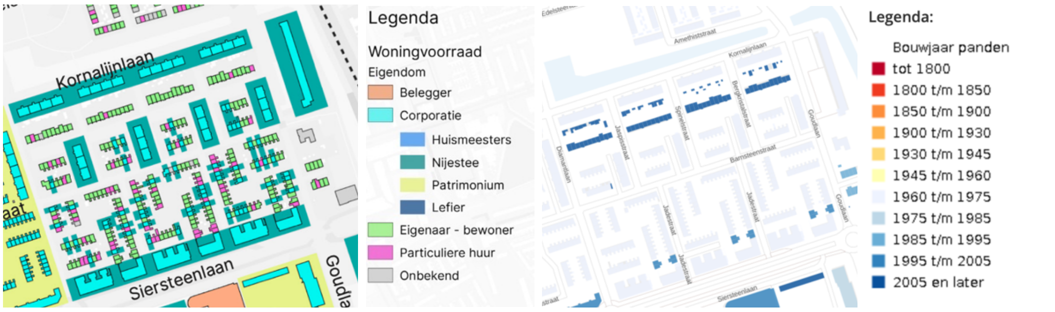

Figure 6 ownership distribution and construction year (Rijksinstituut voor Volksgezondheid en Milieu, 2018)

The green network is somewhat fragmented. The park occupies a large area, and the green edge highlighted in the theory is clearly visible at the boundary. In the neighbourhood, there are green strips combined with trees scattered here and there. During the site visit, it became evident that the existing greenery mainly consists of grass, hedges, and trees. The courtyards feature large trees that provide substantial shade, but otherwise, there is little greenery present, see figure 7. While the green network already includes several positive elements, such as the rows of trees along some streets, its impact on the UHI could be improved by increasing the connectivity of the green spaces and adding more trees. Water is present only as a ditch on the north and east sides of the area. Extending the water further into the neighbourhood and integrating it with the green network could help reduce the UHI effect more effectively.


Figure 7 site visit observation green network (own work, 2024)

4.2 Exploring strategies to reduce the UHI

In this section, we will explore how the design principles discussed in chapter 2 can be applied to reduce the UHI effect in Vinkhuizen. This exploration is guided by the five factors that influence the level of OTC and UHI, as also discussed in chapter 2 (see figure 8). Initially, the reduction of the UHI effect was approached by examining each factor individually. However, during the ideation phase, it became apparent that these factors should be viewed as an interconnected network. Focusing solely on one factor, such as albedo, is insufficient, as the effects of each element are interrelated and collectively influence the overall UHI impact. For this reason, this section will comprehensively address the five factors, despite their separate introduction in chapter 2.

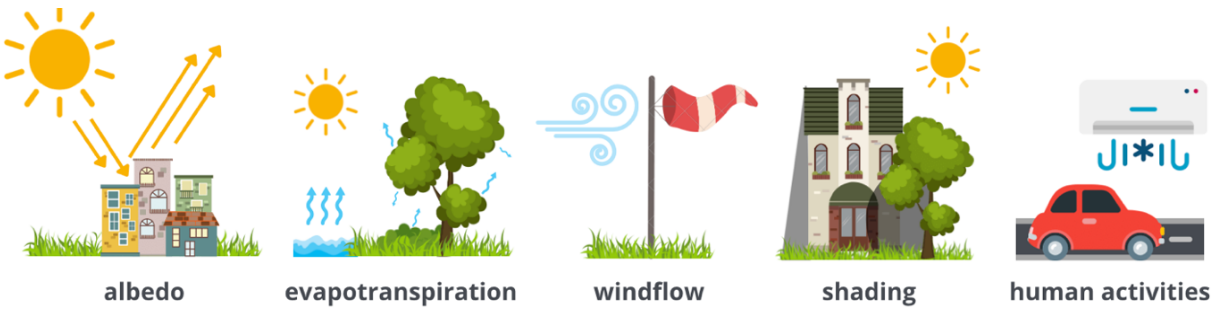

Figure 8 factors that influence OTC and the UHI (own work, 2024)

As this study primarily aims to develop an approach for designing the densification of a post-war neighbourhood, with a specific focus on reducing the Urban Heat Island (UHI) effect through optimized building morphology and the integration of urban green space, no rigid densification target is predetermined. The emphasis lies on formulating a flexible framework adaptable to various neighbourhood contexts, rather than imposing rigid densification targets.

4.2.1 Exploring strategies to reduce the UHI through densification

As outlined in the previous paragraph it is most feasible to densify the social housing units, by either replacing these buildings or adding a layer to the existing structures. Therefore, during the ideation phase, the decision was made to focus on the surroundings of these apartment complexes. When applying the design principle from Nasir et al. (2017) discussed in chapter two to reduce exposure to direct sunlight during peak hours, building A would need to rotate approximately a quarter turn, as shown in figure 9 by the orange circle. However, if the buildings were to be positioned with their short axis aligned with the prevailing wind direction, as investigated by Daemei et al. (2018), to optimize wind flow through the building. All buildings would need to rotate 45 degrees, as also shown in figure 9 by the blue line.

Figure 9 Sun orientation at 13:00 pm and prevailing wind direction southwest (SunCalc, 2024)

Nevertheless, the presence of nearby buildings and roads limits the potential for substantial changes to the shape and orientation of the complexes within the stamp structures. By raising the height of buildings A and B, the shadow cast by the structures can be extended and additional housing units can be incorporated. This results in a prolonged period of shade on the adjacent roads, particularly during the afternoon and evening, as shown in figure 10. According to Nasrollahi et al. (2020), as explained in Chapter 2, this extended shading on low albedo surfaces has a positive impact on mitigating the Urban Heat Island effect. In accordance, building C could be positioned closer to the street, causing the low-albedo parking spaces, currently exposed to sunlight throughout the day, to be shaded by the building, see figure 10.


Figure 10 Impression prolonged shadows and position building C (own work, 2024)

As outlined in chapter 2, studies by Prayudha et al. (2022), Tahooni and Kakroodi (2019), and Taha (2017) have shown that increasing albedo can effectively reduce the UHI effect. According to these studies, employing light materials such as white bricks or coatings can increase the albedo, thereby reducing the UHI effect and lower the temperature inside the building. Some impressions of these measurements can be found in figure 11. The reduction in indoor temperature resulting from the use of light materials could in turn contribute to lower air conditioning usage, thereby preventing the heat generated by these air conditioning units from being emitted into the public space.

Figure 11 impressions of high albedo materials on building surfaces (Roidou, 2021; van der Laan, 2024)

4.2.2 Exploring strategies to reduce the UHI through urban green space

Nasrollahi et al. (2020) and Pradipta (2018) stated in chapter 2 that the presence of vegetation and in particularly trees, due to their shading and evaporative cooling properties, can affectively reduce the temperature and improve the thermal comfort. In Vinkhuizen, trees can be planted along the wide-open roads to provide shade on the low albedo streets, as shown in Figure 12. They can also be implemented alongside the apartment complexes to offer shade for the buildings.

Figure 12 impression of the implementation of trees in Vinkhuizen (own work, 2024)

Robitu et al. (2006) and Zhou et al. (2011) have highlighted the use of water and water features as a means to mitigate the UHI effect. Notably, the road on the eastern side of complex A does not act as a through road and does not connect to driveways or front entrances of houses. One approach to addressing this is to relocate the parking spaces, creating an opportunity to replace the road with green space. This adjustment would allow the park's green functions and water features to expand further into the neighborhood, incorporating elements such as swales, depicted in Figure 13.

Figure 13 (own work, 2024; Civiel, 2021; Amersfoort Rainproof, 2023)

4.2.3 Uncovering contradictions in reducing the UHI through densification and urban green space

At the start of this chapter, it became apparent that the design principles derived from the literature mostly concentrate on one or two of the five factors that influence the intensity of the UHI effect. However, in an established neighborhood like Vinkhuizen, all these factors intersect. Making it challenging to find an optimal solution to minimize the UHI. The contradictions are exemplified through a design example depicted in Figure 14.

Figure 14 design example apartment complex C (own work, 2024)

In Figure 14, there is a new orientation for apartment complex C. This new orientation minimizes direct sunlight exposure during peak hours, which is in line with the findings of Nasir et al. (2017). According to her research, this change would lead to a decrease in temperature inside and around the building. The positioning of trees in front of the apartment complex also contributes to temperature reduction. According to Nasrollahi et al. (2020), the shade provided by these trees would help lower the temperature. However, there is a missed opportunity to passively cool the building by utilizing wind flows, as indicated by Daemei et al. (2018), because the most common wind flow now runs almost parallel to the complex. While this would have a cooling effect on the public space in the absence of trees, the trees block free airflow. This example clearly demonstrates how different design principles interact with various factors, sometimes contradicting each other. Due to limited research on the interplay between these factors, it is challenging to determine which design principle contributes more to reducing the UHI effect. While most studies highlight the temperature reduction achieved in their research, these studies were conducted in different locations, so the temperature differences in Vinkhuizen or other post-war neighborhoods may vary even when the same principle is applied.

Another instance to consider is the roofing of the apartment complex. According to Costanzo, Evola, and Marletta (2016) and Imran et al. (2018), reflective roofs have a more pronounced direct cooling effect compared to green roofs. Conversely, a study by Razzaghmanesh, Beecham, and Salemi (2016) revealed that green roofs can serve as an insulating layer to maintain warmer temperatures in buildings during winter. This example highlights the need to consider factors beyond the balance of the five main factors, such as winter temperatures, social cohesion, and safety, when making decisions.

5 Conclusion and discussion

This research aimed to illustrate how densification of a post-war neighbourhood can reduce the UHI effect by optimizing urban form and integrating urban green spaces. To gain a better understanding of the dynamics between these concepts, the following research question was formulated: "How can the densification of post-war neighbourhoods be strategically designed to reduce the urban heat island effect through optimized building morphology and the integration of urban green spaces?’’

To investigate this, a literature study has been conducted to get an understanding of the concepts and their relation to each other. This allowed for a comprehension of the fundamental concepts and the mechanisms and design principles that are underling these, which allowed for better informed discissions making in the upcoming design phases. To illustrate the application and interaction of the different design principles within a post-war neighborhood, the Vinkhuizen neighborhood in Groningen was chosen for a case study. The design thinking methodology was utilized, combining insights from literature with iterative prototyping to produce a practical solution that suits the complexities of an existing neighborhood. Nonetheless, a limitation of this methodology is that the results tend to be centered on the specific area, which may restrict their applicability to other contexts or situations.

Since research done by Nasir et al. (2017), Daemei et al. (2018), Nasrollahi et al. (2020) and numerous other studies showcased that urban green space as well as a buildings morphology could reduce the UHI effect, it was expected that it would be possible to develop a densification design for post-war neighborhoods that reduced the UHI effect through optimized building morphology and the integration of urban green spaces. Based on the findings several design strategies appeared to reduce the UHI effect in Vinkhuizen. It's crucial to emphasize that these strategies are derived from the design principles documented in existing reports. While it's logical to assume that the implementation of these design principles in the context of Dutch post-war neighborhoods may result in a reduction of the UHI effect, it's challenging to conclusively affirm this, as the actual temperature difference cannot be directly measured.

Taking this into consideration, based on the results it seems that besides the larger parks, there is limited space in post-war neighborhoods for implementing infill development on a significant scale. Therefore, properties containing apartment complexes or rows of terraced houses owned by housing associations seem to be the most suitable for densification. According to the results, the constrained space within the stamp structures presents challenges in adjusting the orientation of the buildings to align with prevailing wind directions or reduce exposure to sunlight. Nevertheless, in the green borders, building orientation can be adjusted according to these principles to lower temperatures both inside the buildings and in public spaces. Moreover, it seems that the UHI effect in post-war neighborhoods can be reduced by utilizing high albedo materials or coatings, incorporating vegetation on building surfaces, and creating shadows on roads through building morphology or trees.

However, it seems to be not possible to formulate one specific strategy as the results show that the interaction between different components is crucial and curtain design principles can in practice contradict each other. For example, as illustrated in research conducted by Schlaerth et al., (2023), a highly reflective building can reduce the temperature on its own, but when placed next to a green area with a low albedo, the effect can be counterproductive. This leads to the conclusion that there is no definitive answer to the main question. Both building morphology and urban green spaces have components that can theoretically contribute to reduction of the UHI effect, but the context of the location determines whether a particular adjustment can actually lower the UHI effect and there will always be concession to be made.

In this context, this research emphasizes the tension between reductionism and synthesis. Analyzing individual concepts in isolation can lead to a deeper comprehension of the fundamental mechanisms, thereby aiding in the identification of design principles. However, this singular approach may fail to consider the interplay between different concepts, which could lead to unforeseen consequences when applying these principles in a wider context. With this, this study complements a series of studies that examine the interplay between reductionism and synthesis. Furthermore, the research outcomes can contribute to the research on the reduction of the UHI effect in general.

5.1 Reflection

Throughout this research, I have gained insight into several aspects. First, I experienced the iterative nature of research. I discovered that the sequence of chapters does not necessarily mean that the previous chapter must be fully completed before beginning the next one. Throughout the process, new insights emerge, requiring revisions to previous chapters. Subsequently, I came to the realization that the relevance of literature is always tied to its context. While you can draw insights from other sources to inform your research, it's important to recognize that their findings are specific to circumstances. Finally, during the ideation phase I discovered the interplay between reductionism and synthesis, as mentioned in the previous paragraph.

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Appendix

Appendix I Informed consent form

INFORMATION SHEET
Research: Harmonizing urban form and function, exploring the synergy of green space, densification, and urban heat reduction in post-war neighbourhoods.

Dear participant,

Thank you for your interest in participating in this research. This letter explains what the research entails and how the research will be conducted. Please take time to read the following information carefully. If any information is not clear kindly ask questions using the contact details of the researcher provided at the end of this letter.

WHAT THIS STUDY IS ABOUT?
The primary objective of this study is to examine the potential strategies for enhancing the density of post-war neighbourhoods, improving the quality of green spaces, and reducing the impacts of the urban heat island phenomenon. The research employs a research by design approach, wherein solutions to the main question are developed through the creation of designs and sketches based on a specific case study. The investigation focuses on a segment of the Vinkhuizen district in Groningen to explore the feasibility of increasing the density of a post-war neighbourhood, enhancing green spaces, and mitigating the urban heat island effect from a multifaceted perspective.

WHAT DOES PARTICIPATION INVOLVE?
Participation as an interviewee involves answering questions, some of which are general to all participants and others are specific to the interviewee. These answers will be analyzed later on and the information will be added to the final report that will be submitted to the Bachelor Project course at the University of Groningen.

DO YOU HAVE TO PARTICIPATE?
Participation in this research is completely voluntary and interviewees may choose to withdraw from the study at any time and choose not to answer questions without consequences or providing reasons.

ARE THERE ANY RISKS IN PARTICIPATING?
All interviewees will be anonymous in the final product of this research to ensure the protection of the participants identity and personal information.

ARE THERE ANY BENEFITS IN PARTICIPATING?
There are no direct benefits from participating in this project as an interviewee other than the access to the results of the research as well as the final product. Moreover, the research may contribute to further knowledge on the research topic. All costs from the interview will be covered by the researchers.

HOW WILL INFORMATION YOU PROVIDE BE RECORDED, STORED AND PROTECTED?
If consent is granted, the interview will be recorded by phone and stored on a folder at the University's Google Drive. After the completion of the course, all recordings will be deleted. No record of the conversation will be kept. The actual names of the interviewees will not be explicitly mentioned in any document.

WHAT WILL HAPPEN TO THE RESULTS OF THE STUDY?

All information collected during the interviews will be employed as part of a thesis written for the bachelor course Bachelors Project at the University of Groningen. Once the thesis has been submitted and graded, the final report will be kept, but all records of the interviews will be deleted.

ETHICAL APPROVAL

The researcher will uphold themselves to relevant ethical standards in accordance with the University of Groningen and under the supervision of her tutor.

INFORMED CONSENT FORM

If you agree, with these terms, please sign the informed consent form. This will mean that you have the intention to participate while still being able to withdraw at any time.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

Danja Boerman: d.h.r.boerman@student.rug.nl

INFORMED CONSENT FORM

Title study: Harmonizing urban form and function, exploring the synergy of green space, densification, and urban heat reduction in post-war neighbourhoods.

Name participant:

Assessment

- I have read the information sheet and was able to ask any additional question to the researcher.
- I understand I may ask questions about the study at any time.
- I understand I have the right to withdraw from the study at any time without giving a reason.
- I understand that at any time I can refuse to answer any question without any consequences.
- I understand that I will not benefit directly from participating in this research.

Confidentiality and Data Use

- I understand that none of my individual information will be disclosed to anyone outside the study team and my name will not be published.
- I understand that the information provided will be used only for this research and publications directly related to this research project.
- I understand that data (consent forms, interview transcripts) will be retained on the Y-drive of the University of Groningen server for 5 years, in correspondence with the university GDPR legislation.

Future involvement

- I wish to receive a copy of the scientific output of the project: **yes/no**
- I consent to be re-contacted for participating in future studies: **yes/no**

Having read and understood all the above, I agree to participate in the research study: yes / no

Date

Signature

To be filled in by the researcher

- I declare that I have thoroughly informed the research participant about the research study and answered any remaining questions to the best of my knowledge.
- I agree that this person participates in the research study.

Date

Signature