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How does your type of neighbourhood influence your health?

A quantitative study of the influence of the Dutch neighbourhood typology on local physical and mental health.

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Colophon

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Abstract

Non-communicable diseases such as diabetes and cardiovascular diseases have become the number one cause of death worldwide as well as the main cause of the global disease burden. The loss of healthy life years is largely preventable, in part through neighbourhood planning and design. In the Netherlands knowledge on healthy neighbourhoods is almost exclusively practice-based. The National Institute for Public Health and the Environment (RIVM) has set out a survey among 250 professionals to find what constitutes a healthy neighbourhood. The conclusion was a Vinex-style neighbourhood. This raised the question: What is the influence of neighbourhood typology on local physical and mental health?

A review of academic literature helped to identify three categories of health determinants (greenery, environmental hygiene and complete & compact city) and the mechanisms they use to influence health. It also became clear that health is an unambiguous concept that can be approached from different angles. Different Dutch neighbourhood types were identified that all feature these categories in different compositions.

Through multiple linear regression analysis neighbourhoods, the relationship between neighbourhood type and health has been investigated in neighbourhoods in Groningen and Nijmegen (N=103). As a variable for local physical and mental the Global Activity Limitation Indicator (GALI) was used. A separate model was used to test the relationship between the health determinant variables and GALI. Due to unexpected results for the walkability index, an additional model was tested with the three variables underlying the walkability index.

Statistical analysis showed that the relationship between neighbourhood types and health is minor. All three health determinants had a result opposite of what was expected based on the literature review. Decreases in the green space ratio and walkability index led to worse health outcomes. Reversely, increases in average noise exposure led to better health outcomes. When further exploring the elements of the walkability index, it became clear that increases in land-use mix and street connectivity do not lead to better health outcomes, as would be expected based on academic literature. Only increases in population density lead to better health outcomes. Possible explanations include the Dutch tradition of compact city policies where more increases in walkability no longer improve health outcomes. It can be concluded that neighbourhood type is not very relevant when it comes to planning healthy neighbourhoods. The only statistically significant outcome of the analysis shows some benefits of Vinex-neighbourhoods but that can likely be attributed to variables that were not included in the analysis.

Keywords: neighbourhood typology, health, greenery, walkability index, environmental hygiene, land-use mix, street connectivity, population density

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Abbreviations

Bg2015	Bodemgebruik, wijk- en buurtcijfers 2015
CAPI	Computer Assisted Personal Interviewing
CAWI	Computer Assisted Web Interviewing
DALYs	Disability-adjusted life years
dB	Decibels
EU	European Union
EU-SILC	European Union Statistics on Income and Living Conditions
GALI	Global Activity Limitation Indicator
GGD	Gemeentelijke Gezondheidsdienst (Municipal Health Service), plural GGD'en
HLY	Healthy Life Years
Kwb2016	Kercijfers wijken en buurten 2016
L_{den}	Levels day-evening-night
L_{night}	Levels night
MEHM	Minimal European Health Module
NCDs	Noncommunicable diseases
OLS	Ordinary least squares
$PM_{2,5}$	Particulate Matter smaller than 2,5 micrometres
PBL	Planbureau voor de Leefomgeving (Netherlands Environmental Assessment Agency)
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
SWB	Subjective well-being
SWLS	Satisfaction With Life Scale
WHO	World Health Organisation
YLD	Years lived with disability
YLL	Years of life lost
VIF	Variance Inflation Factor
Vinex	Vierde Nota Ruimtelijke Ordening Extra (Fourth Memorandum Spatial Planning Extra), neighbourhoods built as a result of this Memorandum are often referred to as Vinex-neighbourhoods.

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1. Introduction

1.1. Background and problem definition

The beginning of this decade is globally marked by the COVID-19 crisis. The virus forced many to work or study from home and to limit travel movements. At the end of 2020, 48% of the Dutch worked from home and a quarter of the Dutch intent to continue working from home after COVID-19 (TNO, 2021). This puts the residential environment in a different light. For many people it is suddenly a place where they spend their days as well as their evenings and nights. The residential environment is also increasingly the setting for leisure activities due to COVID-19. The pressure on the residential environment that is created by new national pastimes such as walking, calls for more public space for exercise, relaxation and social activities (RIVM, 2020).

The COVID-19 pandemic has also uncovered another pandemic. People that are overweight or suffer from chronic illnesses such as diabetes, cardiovascular diseases and COPD run a higher risk of a severe or even deadly course of COVID-19 once infected (RIVM, 2020). These types of chronic ailments are often classified as noncommunicable diseases (NCDs) or lifestyle diseases and are a relatively new cause of morbidity and mortality globally. In the past, deaths were often the result of acute illnesses or epidemics. Due to improved sanitary measures and active healthy city policies, this image started to shift in the nineteenth and twentieth century, especially in the western world (Chan, 2019). The construction of sewage systems, the development of vaccines and advances in medicine all led to great improvements of public health (Gunning-Schepers, 2004). However, sharp increases in wealth in the second half of the twentieth century gave rise to NCDs in western countries through lifestyles becoming unhealthier (Münzel et al., 2018). Now that many other countries are enjoying increased wealth as well, NCDs have taken first place in the list of mortality causes, a dubious honour (Chan, 2019).
In the Netherlands NCDs are also the primary cause of morbidity and mortality. At least half of the deaths can be attributed to lifestyle or living environment. In reality, this share may be even larger since there are still many factors that are unknown or inconclusively proven such as the impact of stress on morbidity and mortality (RIVM, 2018b). Currently, an increasing number of people in the Netherlands suffer from overweight or (morbid) obesity. In 2018, over 50% of all adults suffered from overweight compared to 35% in 1990. Over the same period, the share of obese people has more than doubled (Volksgezondheidenzorg.info, 2020). If we are to continue on this foot, this percentage is predicted to further rise to 62% in 2040 (RIVM, 2018b).

Both lifestyle and the living environment are, however, factors that can be influenced, meaning a large part of morbidity and mortality can be prevented. One of the ways to do this is through urban design. It has been proven that the environment has a direct negative impact on health through poor air quality and noise nuisance (Lim et al., 2012; Münzel et al., 2018). This impact is often expressed in disability-adjusted life years (DALYs)[1] (Lim et al., 2012). For the Netherlands environmental factors are estimated to account for 4% of all DALYs. These are mainly DALYs caused by the outdoor environment. Again, this share could be higher in reality as not all health risk factors are currently known (RIVM, 2018b). Besides these direct effects, the living environment also influences health through lifestyle. It is proven that neighbourhood walkability positively impacts mental health and reduces the prevalence of hypertension and diabetes (Ige-Elegbede, 2020). A lack of physical activity is one of the main risk factors of NCDs in western Europe but can be stimulated through the design of the built environment (Lim et al., 2012; Smith et al., 2017). Evidence has been found that the presence and quality of parks, playgrounds and active transportation infrastructure has a positive effect on physical activity (Smith et al., 2017). Research has shown that park users have a lower risk of cardiovascular diseases and diabetes and are less likely to be obese than non-park users (Ige-Elegbede, 2020). Also, density has a positive effect on health. There is a positive relation between walking and population density (McCormack & Shiell, 2011). Residential density influences mental health as well. Research has shown that high densities in combination with good public transport connections lead to lower numbers of prescription for antidepressants among men (Melis et al., 2015). Besides the positive effects the living environment can have, effects can also be negative. Neighbourhood deprivation negatively impacts mental health and can increase the incidence of functional loss (Ige-Elegbede, 2020). This can lead to sharp divides in health between neighbourhoods in the same city. In the Netherlands, the difference in healthy life expectancy between neighbourhoods in the lowest quintile of median incomes and those in the highest quintile is nearly 11 years. It is estimated that 50% of this difference can be attributed to differences in lifestyle (PBL, 2020). The environments where people spend most of their time also have the largest influence on health. These are usually the home and work environments (Melis et al., 2015). Especially due to the earlier mentioned spatial effects of COVID-19, this makes the residential environment the key location for NCD prevention.

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[1] DALY is the sum of years lived with disability (YLD) and years of life lost (YLL). YLL and YLD are calculated as follows:
YLL = number of deaths (N) * standard life expectancy at age of death in years (L)
YLD = number of incident cases (I) * disability weight (DW) * average duration of disability in years (L)
(Incident cases are the people that are affected by disability)

1.2. Scientific and societal relevance

Academic research on the effects of the built environment on public health is frequently aimed at isolating a single aspect of the built environment, such as green space. By doing this, the inherent complexity of cities and neighbourhoods is often not taken into account (Melis et al., 2015). As Zhang et al. (2019) state in their article, only few studies address multiple aspects of health (such as physical and mental health) and multiple environmental measures. There is still little evidence on how specific types of neighbourhoods – as an aggregate of earlier mentioned environmental factors – influence local health.

In the Netherlands, knowledge on healthy neighbourhoods is almost exclusively practice-based. The National Institute for Public Health and the Environment, *RIVM*, is the lead authority for information about healthy cities for local governments. They have formulated a list with the twelve most important characteristics of a healthy city based on a large survey among 250 professionals in the fields of health, urban planning and environment (see table 1). Most of these characteristics are in line with the 1990s/early 2000s Vinex-neighbourhoods (RIVM, 2018a). Empirical evidence to support this claim is missing. In light of the large number of neighbourhoods that have to be constructed or renewed in the Netherlands in the next two decades as a response to the housing shortages, scientific evidence on the health impact of neighbourhood typology is essential in the prevention of NCDs. Besides the individual tragedy that can be avoided through prevention, it can also reduce the billions of euros the Netherlands is currently spending on the treatment of NCDs (RIVM, 2018b).

1. where children can play outside.
2. where it is easy to move around by bike.
3. with a good air quality.
4. where it is easy to move around on foot.
5. where people feel safe.
6. with green areas for playing.
7. with safe bike routes.
8. that seduces to move.
9. a safe city.
10. that approaches health from different perspectives, for example spatial, traffic, health organisations.
11. with sufficient and qualitatively good sport- and movement amenities.
12. where people in vulnerable situations get sufficient support.

Table 1:“To me, a healthy city is a city…” The twelve most important characteristics of a healthy city according to Dutch professionals (Source: RIVM, 2018a).

1.3. Research objectives

This research aims to investigate the relationship between the Dutch neighbourhood typology and local physical and mental health. To that end, a set of research questions has been formulated.

The main research question is:

What is the influence of neighbourhood typology on local physical and mental health?

The following sub-questions will help to answer the main research question:

a. *How can health be defined and measured?*
b. *What are the effects of the built environment on health?*
c. *What characterises the Dutch neighbourhood typology?*
d. *Which neighbourhood types can promote health?*

1.4. Outline

In chapter 2 a theoretical framework will be established to serve as the base for the empirical research. In this chapter, sub-questions a, b and c will largely be answered. Chapter 3 will explain the empirical method and dataset used. The results of this empirical study will be described in chapter 4 and further discussed in chapter 5. Finally, chapter 6 will set out the conclusions of the study as well as recommendations for planning practice and future research.

2. Theoretical Framework

2.1. Health definition and measurement

There are roughly three ways to look at health. First, there is the bio-medical perspective that defines health as the absence of illness. Second, there is the economic perspective that considers physical and mental health to be a commodity. And last, there is the holistic perspective that defines health in a much broader, interdisciplinary sense (Sartorius, 2006).

The bio-medical definition of health is the most straight-forward definition of the three. According to current medical standards, someone is either suffering from disease or not. This makes it a very easy definition to understand. The downside is that the individual has no say in the matter since health perception is not included in this definition. A second drawback lies in measurement. Health standards change frequently and therefore the threshold for being healthy changes as well (Sartorius, 2006).

In 1972, Grossman introduced the concept of Health Capital. The departure point is classic demand theory. Like in businesses, individuals invest in themselves. For example, individuals invest in education to improve their position later in life. The level of investment varies in different stages of life but is always intended to maximise human capital (Grossman, 1972). Health capital is a type of human capital. There is, however, an important difference: unlike knowledge, health cannot be bought. It is a goal, not a good. Grossman (1972) therefore explains a difference between market goods and services and commodities. Medical care is a consumer service that can be used to maximise the commodity "good health". Everyone is born with a certain stock of "good health" and can increase it through investments in, for example, diet and exercise. The "product" in this model is healthy time (Currie, 2011; Grossman, 1972). The difficulty of this way of looking at health is that it assumes that all people have equal opportunities in life. In reality, lower educated people have less knowledge on how to invest in their health as well as less opportunity for these investments (Currie, 2011). The Health Capital concept also disregards other exogenous factors that directly or indirectly influence physical and mental health.

The World Health Organisation (WHO) has been very influential in promoting the holistic perspective of health. In its 1946 constitution, health is explained as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 2006). 75 years ago, this was a revolutionary approach to health as it was more wide-ranging than previous definitions had been (Huber et al., 2011). The downside of having such a broad interpretation of health is that it can be difficult to operationalise it. As a result, within the holistic perspective there are multiple viewing angles. These angles have a focus on health pathways in common. Health pathways describe the connection between health determinants and mental and/or physical health. The simplest type of pathways are direct pathways. In this case, a determinant has a direct effect on health. In reality, indirect health pathways are more common. Here, a determinant influences health through an intermediary determinant (Barton & Grant, 2006).

1. In most ways my life is close to my ideal.
2. The conditions of my life are excellent.
3. I am satisfied with my life.
4. So far I have gotten the important things I want in life.
5. If I could live my life over, I would change almost nothing.

Table 2: The items of the Satisfaction With Life Scale (SWLS). (Source: Diener et al., 1985).

One of the viewing angles of the holistic approach is that of subjective well-being (SWB), a concept frequently used in various social sciences and closely related to the WHO definition of health. SWB is often measured using the Satisfaction With Life Scale (SWLS) (Ettema & Schekkerman, 2016). This scale measures satisfaction on a seven-step scale from very unsatisfied to very satisfied on five different items (see table 2). It is per definition a subjective measure and therefore comprises a wide range of topics relating to well-being, from perceived safety to physical health (Diener, 2000; Diener et al., 1985; Ettema & Schekkerman, 2016). SWB is also known colloquially as 'happiness'. Over the last decades, happiness studies have shifted their focus from researching which demographic groups are happier than others to investigating why people are happy and which pathways lead to increased well-being (Diener, 2000). These pathways leading to subjective well-being are complex and can be direct and indirect.

The holistic perspective does not always concern itself with subjective health. In many academic papers, more objective physical and/or mental health is discussed. The holistic study of objective health is in some aspects similar to biomedical research but distinguishes itself through the use of health pathways. Practically, this means not only determining if someone suffers from illness or not, but also finding out why some people are suffering from illness whereas others are not (Dahlgren & Whitehead, 2006). One of these pathways, the direct relationship between mental and physical health has been debated for centuries. Philosophers like Plato and Aristotle reasoned on the dualism between body and soul in ancient Greece. Both had different views on whether the soul was imprisoned in the body or if it was a property of the body. This debate was continued in the centuries that followed until the philosopher René Descartes proposed a different theory in the seventeenth century. He believed the human body functioned as a machine. Through pulls and levers, this machine could be influenced. The mind was merely one of these levers (Robinson, 2020). This Cartesian dichotomy became the modern paradigm in Western health care. Subjective health was deemed irrelevant or even superstitious. The emergence of the field of psychology in the nineteenth century marked the beginning of a shift. After the Second World War not only the hygienic conditions of housing became an issue, but also psychological stress caused by the residential environment (Wagenaar & Mens, 2018). Since then, researchers have found a strong link between physical and mental health (Ohrnberger et al.,

2017) and between various environmental determinants and physical and mental health (Ige-Elegbede, 2020). Quotes like 'healthy body, healthy mind' are common expressions of the pathways between physical and mental health.

Another angle of the holistic perspective is that of human ecology. The term ecology was born in the nineteenth century in the field of biology and is a contraction of the Greek *oikos* (house) and *logos* (the study of). At the beginning of the twentieth century, when parts of the world were experiencing rapid urbanisation and industrialisation, the term human ecology was coined by the Chicago-based sociologists Park and McKenzie. Different from biological ecology, human ecology put the focus on the relation between the built environment and human existence. After the Second World War, the concept of human ecology became more widespread under academics. Especially in the social sciences such as geography, economics and psychology the concept was used as a way of exploring links between human beings and their environment (Honari, 1999). Uncoincidentally, this is around the same time as when the psychological effects of the living environment were first studied (Wagenaar & Mens, 2018). One of the ways that human ecology can be formally defined is as "the study of fundamental, complex and inter-related factors. Such factors, whether of a global or individual nature, impinge upon the health and environment of individuals, communities and the globe" (Honari, 1999, p. 1). Human ecology is not only a way to understand health, but health is also a core element of human ecology. Health is defined as "a state of balance, an equilibrium that an individual has established within himself and between himself and his social and physical environment" (Sartorius, 2006, p. 662) and not merely the absence of illness or the ability to cope in life. Compared to the biomedical and economical (Health Capital) perspectives, the holistic perspective (especially the human ecology perspective) is the most encompassing.

In conclusion, the holistic perspective is the most suitable for this research. The biomedical and economic perspectives do not sufficiently consider environmental influences on health and are therefore not appropriate. The holistic perspective has different angles. Since this research does not consider subjective well-being or happiness, the first angle is not suitable. This leaves the more objective health and the human ecology angle. The latter has the benefit of also serving as a tool to understand complex situations. This study will therefore use the human ecology angle of the holistic perspective but will be limited to include only factors that are relevant to answer the research question.

2.2. Health determinants and health pathways

Researchers have attempted to grasp the complexity of health pathways into conceptual models such as the model of the main determinants of health by Dahlgren & Whitehead (figure 1). Central in this rainbow-shaped model are the individuals and their personal characteristics. These are, for example, age and genetics and are largely fixed determinants of health. Around the core, there are the four layers. The first layer comprises the effect of individual behaviour on health through, for instance, physical activity. The influence of an individual's social network is covered in the second layer. The third layer covers the conditions under which someone can maintain good health. Examples are a person's living and working conditions. In the fourth layer, the scale changes from the individual to the general public. Socio-economic, cultural and environmental conditions are key determinants of individual health through their influence on public health (Dahlgren & Whitehead, 2006). This model is frequently referenced in academic literature because of the way it incorporates the social environment, as well as the physical and economic environment, as a determinant of health (Barton & Grant, 2006). The various determinants of health can either be positive health factors, protective factors or risk factors. Starting with the latter, risk factors can aggravate health and cause potentially preventable diseases. These can be either social or economic factors but also environmental and lifestyle factors such as air pollution and poor diet. Positive health factors help maintain good health. These are mostly related to autonomy: secure income and housing, for example, give people control over their live and therefore over their well-being. Protective factors diminish the risk of becoming ill. Examples of these are physical activity and a balanced and nutritious diet (Dahlgren & Whitehead, 2006).

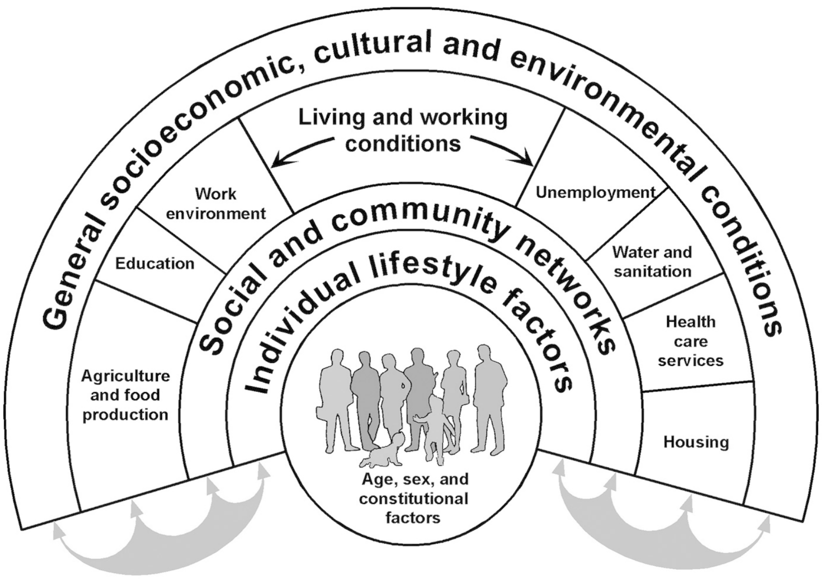

Figure 1: The Dahlgren-Whitehead model of determinants of health. (Source: Dahlgren-Whitehead, 2006).

Barton & Grant (2006) have extended the Dahlgren-Whitehead model to include an ecosystem approach. In line with human ecology, the relationship between people and their living environment (the neighbourhood) is central to this model called the Settlement Health Map (figure 2). This makes the model spatially oriented. In the centre of the model, there are people, similarly to the Dahlgren-Whitehead model. Around this core are two sets of each three layers that move outwards in scale from the individual to the planet. The first two layers, Lifestyle and Community, are the same as the Dahlgren-Whitehead model. Barton & Grant (2006) have, however, added local economy as a separate layer that involves neighbourhood income and investments. The second set of layers concern the human living environment. Working outwards we have the Activities layer that includes human movement through public space as well as living and other activities within buildings. Next is the layer Built Environment. This layer comprises the physical infrastructure for all human activities: buildings, streets, etc. Wrapped around this is the layer Natural Environment that is the base for our human habitat. Elements are, for instance, soil and water. These two sets of layers are placed within the wider sphere of the Global Ecosystem: human ecology is placed within biological ecology (Barton & Grant, 2006; Barton, Grant & Guise (2010).

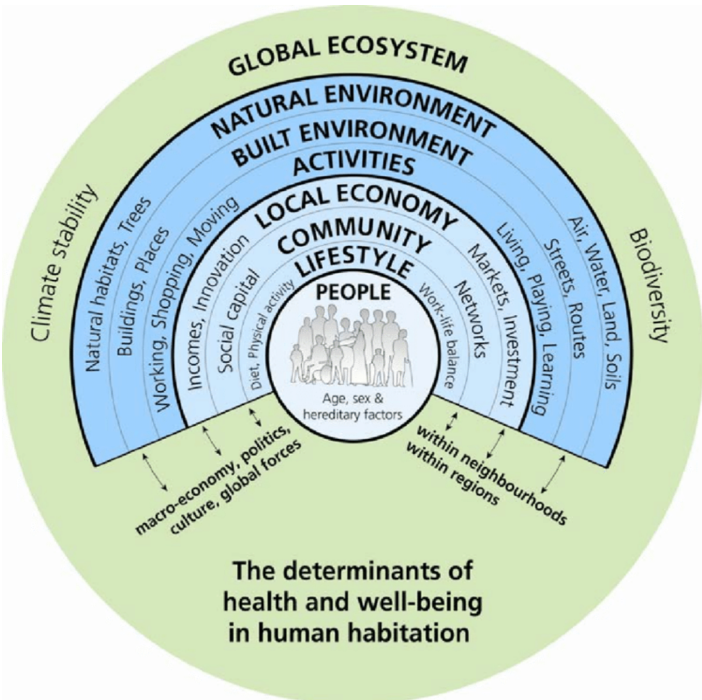

Figure 2: The Settlement Health Map. (Source: Barton & Grant, 2006).

In the field of health promotion, ecological models have been widely used to understand (un)healthy behaviour. The starting point is a form of complexity thinking where it is presumed that individual behaviour is dependent on the environment a person is in. In order to establish substantial and lasting behavioural change, a combination of interventions is necessary on the individual, policy and environmental level (Sallis & Owen, 2015). Due to the high number of health determinants and the complexity that brings, ecological models are often fitted to a specific issue. An example of an ecological model for health can be found in figure 3. This model has been made to better understand active living. To do so, the authors have split their theme into four domains: active transport, occupational activities, household activities and active recreation. In the layer surrounding the four domains of behaviour, the setting where the behaviour takes place is described. This can be, for example, the neighbourhood, the home environment or the school environment. Both behaviour layers are influenced by the policy environment. On the bottom of the model, the socioeconomic environment can be found. This spans multiple levels: individual, behavioural and policy. The information and natural environment influence the behaviour settings and policy environment (Sallis et al., 2006).

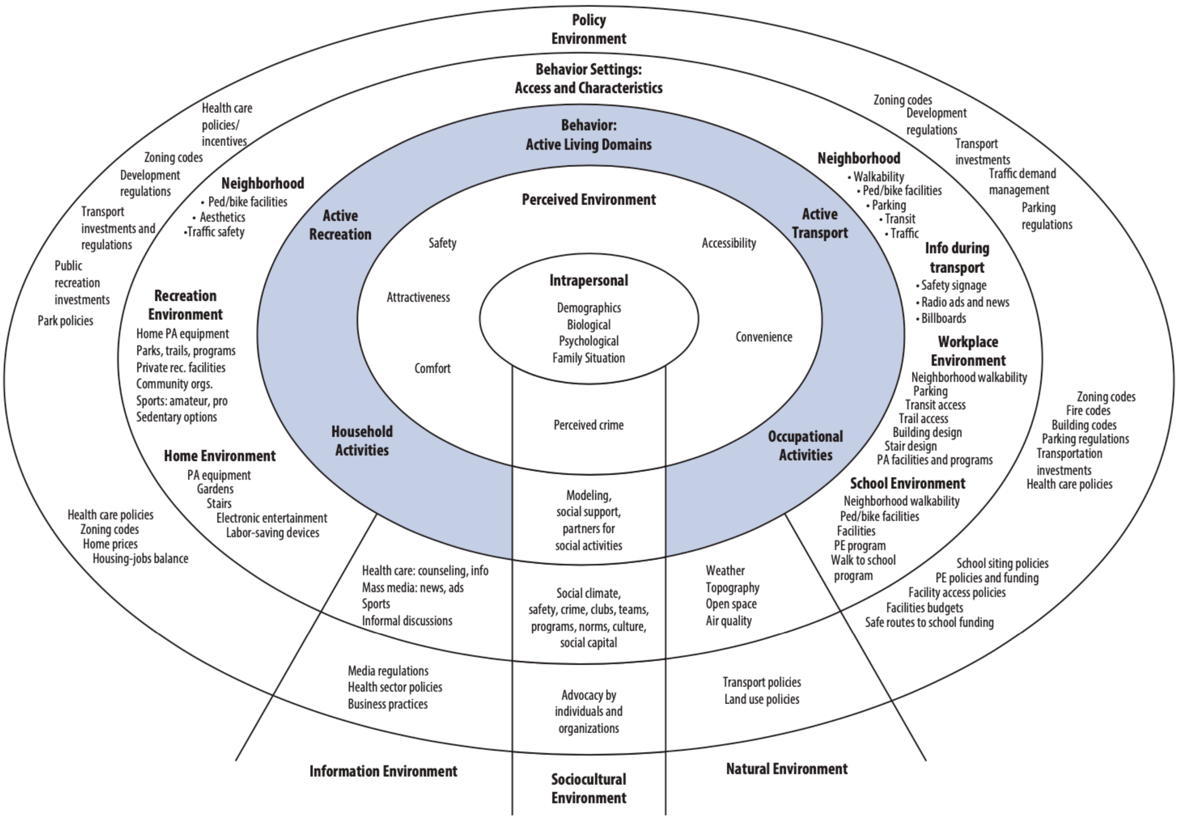

Figure 3: Ecological Model of Four Domains of Active Living. (Source: Sallis et al., 2006).

In conclusion, models can be useful to understand a situation. A model is not an exact representation of reality but a tool to understand reality. The type of model depends on the issue that's being researched. A multilevel approach is, however, crucial in understanding the complexity of different health pathways and in guiding positive change in public health. This study will focus on the level of the physical living environment in neighbourhoods and its effects on the physical and mental health of neighbourhood inhabitants.

2.3. Built environment and health

Over the past years, several studies have investigated the influence of the built environment on public health. Findings can roughly be classified in the following categories: environmental hygiene, green space and complete & compact neighbourhoods (Bird et al., 2018; Ige-Elegbede et al., 2020; McCormack & Shiell, 2011).

Environmental hygiene is the most straightforward category of health determinants. Air and noise pollution can be measured with special equipment and are easily reducible to its source. There are different air pollutants. In this study the two with the largest harmful effect on health are mentioned (EEA, 2021; Gezondheidsraad, 2018). Research has shown that particulate matter in the air (fine particles smaller than 2,5 micrometres, often referred to as $PM_{2,5}$) can lead to lower respiratory infections, cancer in the respiratory organs, various cardiovascular diseases and COPD (Lin et al., 2012; Gezondheidsraad, 2018). In 2014, $PM_{2,5}$ led to an estimated 9.200 premature deaths in the Netherlands (Gezondheidsraad, 2018). The source of $PM_{2,5}$ can be from a primary or secondary fraction. The primary fraction includes all human and natural emissions. The secondary fraction is the result of chemical processes in the atmosphere. Human emissions are the result of industry, agriculture, traffic and the burning of wood (Compendium voor de Leefomgeving, 2017; InfoMil, n.d. a). Most of these sources cannot be found in neighbourhoods except for one: traffic. Figure 4 and 5 show the annual concentrations of $PM_{2,5}$ and NO_2 in the Netherlands and Groningen respectively. In both cases, the road pattern is visible in the emission of air pollution. Road traffic can however be influenced, for instance through traffic-calming measures. Figures 4 and 5 show differences in the concentration and spread of air pollution. Natural emissions of $PM_{2,5}$ include sea salt and wind-blown soil dust These very small particles can be transported through the air over long distances. At least 43,2% of the $PM_{2,5}$ in the Netherlands is the result of human action in a neighbouring country, compared to at least 15,3% that is the result of human action in the Netherlands (Gezondheidsraad, 2018). Because of the wide reach and spread of $PM_{2,5}$, similar levels of $PM_{2,5}$ per neighbourhood in the same city is expected although some higher concentrations along large roads are common (PBL, 2020). As far as knowledge on $PM_{2,5}$ goes, there is no safe concentration level. In order to reduce air pollution, EU member states use a limiting value of 25 $\mu g/m^3$ per year and an exposure requirement of 20 µg/m³ per year. The value of $PM_{2,5}$ as advised by the WHO is 10 µg/m³ per year. As shown in figure 4, the annual values of $PM_{2,5}$ are below the EU limiting value and the EU exposure requirement. In the less urbanised or traffic-heavy areas (roughly everything north of the imaginary Alkmaar-Zwolle line), the WHO advisory level is reached (Compendium voor de Leefomgeving, 2017; Atlas Leefomgeving, 2021). A more local type of air pollution is nitrogen dioxide (NO_2). In the Netherlands, the primary source of NO_2 is motorised traffic. This leads to a very local dispersion of air pollution around larger roads as can be seen in figure 5. The EU limiting value for NO_2 is the same as the WHO advisory level of 40 µg/m³ per year (InfoMil, n.d. b). Short exposure to NO_2 can lead to respiratory diseases. Chronic exposure can lead to asthma, especially among children, as well as other respiratory diseases. It is estimated that 2.600 people died prematurely in the Netherlands in 2014 as a result of NO_2-pollution (Gezondheidsraad, 2018).

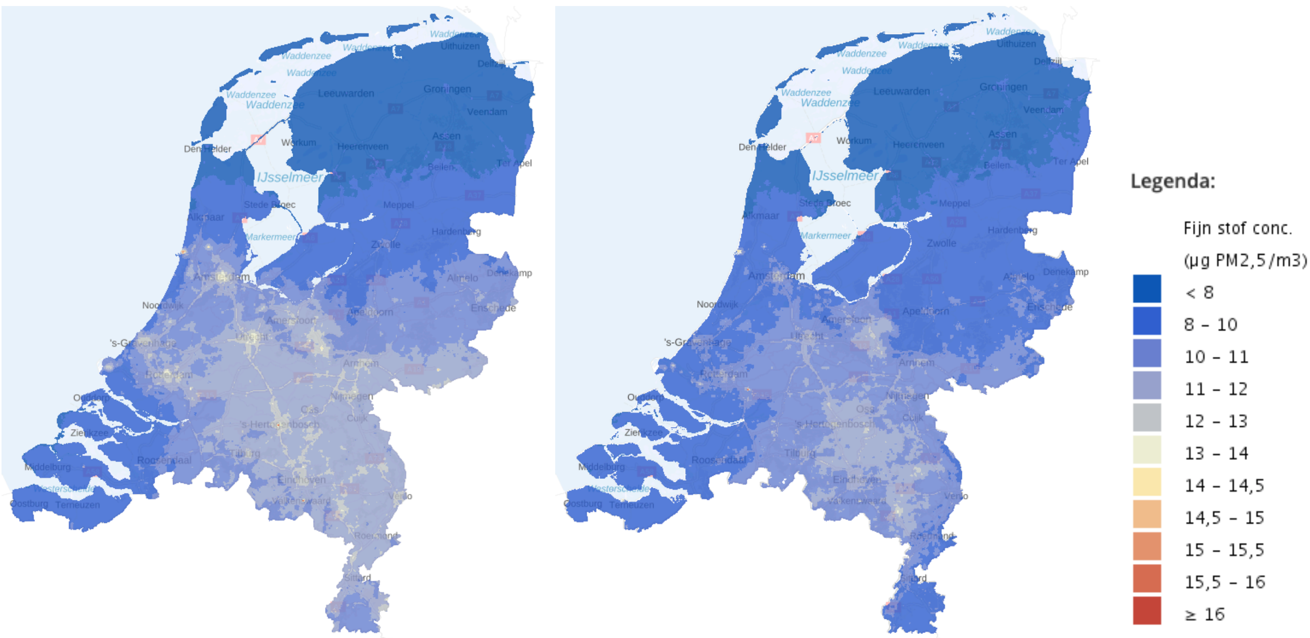

Figure 4: Annual concentrations of particulate matter in 2016 and 2019 (µg PM2,5/m³).
(Source: Atlas Leefomgeving, 2021).

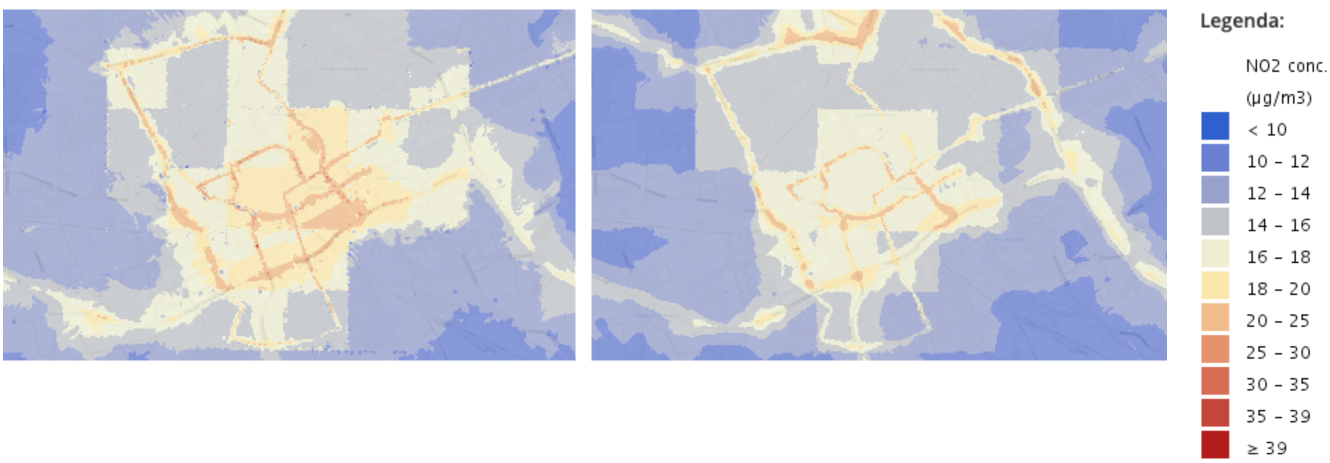

Figure 5: Annual concentrations of nitrogen dioxide in Groningen in 2016 and 2019 (µg NO_2/m^3). (Source: Atlas Leefomgeving, 2021).

Another pollutant in the category of environmental hygiene is noise. Exposure to environmental noise leads to the production of stress hormones in the human body. After a noisy and stressful event, the level of stress hormones in your blood drops again. Things are however different when stress becomes chronic, for instance if someone lives close to an airport. In this case, the body experiences a constant state of stress. As a result, the high level of stress hormones in the blood stream starts to compromise the normal system of the human body. Eventually this leads to vascular dysfunction. Unhealthy veins are the source of a large range of cardiometabolic diseases: obesity, heart failure, diabetes, coronary artery disease, arrythmia and hypertension (Münzel et al., 2018). In 2018, the WHO published new advisory levels for noise nuisance. Research has shown that the risk for cardiometabolic diseases is present at lower levels of noise than expected. On average, the WHO recommends an exposure from traffic of no more than 53 decibel (dB) L_{den}[2] in order to prevent adverse health effects. During the nights, the WHO advises a maximum noise level of 45 dB L_{night}[3] in order to safeguard undisturbed sleep (WHO, 2018). For railway noise, the maximum exposure levels are 54 dB L^{den} and 44 dB L_{night} and for aircraft noise a maximum of 45 dB L^{den} and 40 dB L_{night}. The 2018 WHO advisory guidelines also included a new source of environmental noise: wind turbines. The maximum of levels of noise of wind turbines is advised not to exceed 45 dB L^{den}. In the Netherlands, it is estimated that an average of 541.000 people suffer from severe sleep disturbances due to noise from road traffic, an average of 31.500 people from noise of rail traffic and an average of 151.900 people from noise of air traffic. Numbers are not available for noise of wind turbines (Welkers et al., 2020).

Figure 6: Decibel scale (Source: Münzel et al., 2018).

[2] L_{den} = Levels day-evening-night
[3] L_{night} = Levels night

The next category is green space. Urban green space offers many benefits. It helps with climate mitigation by retaining rainwater and reducing the effect urban heat island effect, it contributes to social cohesion, adds value to business parks, housing complexes and offices by making them more attractive, it increases biodiversity and it supports public health and well-being (Stuiver et al., n.d.). The latter has our particular interest for this thesis. Whereas air and noise pollution are often risk factors for health, green spaces can be a protective factor for health (speaking in terms of positive, protective and risk factors of the model of Dahlgren & Whitehead, 2006). The first evidence of the benefits of greenery on health was found in the early 1980s. In a ten-year long research, the American researcher Roger Ulrich researched the recovery of 46 patients that underwent a cholecystectomy. Half of these patients recovered in a room that looked out onto a brick wall. The other half had a similar room but with a view of a natural scene. As it turned out, the second group recovered faster from surgery and with fewer pain medication (Ulrich, 1984). The underlying effect of the benefits is similar to the stress effect that results from noise nuisance. Through several processes, stress hormones disrupt the functioning of the vascular system which manifests in a range of cardiometabolic diseases (Münzel et al., 2018; Vienneau et al., 2017). The pathways between greenery and health are however less straightforward than they may seem. Many studies show conflicting results, making it difficult to extrapolate the effect of greenery. General categories of pathways that are commonly found in research are air quality, stress reduction, physical activity and social cohesion (Vienneau et al., 2017). The mechanisms behind air quality and stress reduction have been discussed earlier in this chapter. Physical activity is the underlying mechanism for a large range of protective health effects. It helps protect against cardiovascular diseases, cancer, diabetes, depression, anxiety and premature mortality (WHO, 2020). Social cohesion in a neighbourhood has been found to associate with fewer smoking, drinking and depression (Echeverría et al., 2008). These different mediators in combination with different types of green spaces are likely the cause of these inconsistent findings (Picavet et al., 2016). Urban green space has, for instance, the opposite effect on physical activity than agricultural green space. In urban areas, green space is associated with more walking and cycling and less time spent gardening and doing odd jobs. More agricultural green space had the opposite effect. The percentage of green space has no effect on physical activity (Picavet et al., 2016). This is in line with research into streetscape greenery by De Vries et al. (2013). This showed that perceived general health, acute health-related complaints and mental health were impacted by both the quantity and quality of streetscape greenery but that this effect was larger for the quality of greenery (De Vries et al., 2013). Coombes et al. (2010), also researched the effect of different types of green space. They identified the following types: young people's, formal, sports, natural and informal types. People living close to a formal type of green space such as a park were more physically active than people living on a larger distance from a park. Other types of green spaces did not have this effect. The reason for this may be that parks are often high-quality green spaces that offer good infrastructure for walking, cycling and jogging and that they serve a broad range of people (Coombes et al., 2010). Research by Tamosiunas et al. (2014) did not find a relation between the distance of a park and cardiovascular disease and cardiovascular risk factors. This effect was however different for park-users. Compared to non-park-users, the prevalence of diabetes and cardiovascular risk factors was significantly lower (Tamosiunas et al., 2014). In a longitudinal study by Paquet et al. (2014) it has been found that in areas with larger public open spaces and greater walkability, the risk factor for (pre-)diabetes was lower. In all these studies, the specific situation regarding urban green space seems to be important for the research outcomes, as well as the study design (Tamosiunas et al., 2014).

The category complete & compact neighbourhoods can be broken down into Diversity (of land-uses), Design (of connected streets) and Density (of population/residences), also known as the 3 Ds of the built environment (Cervero et al., 2009). The 3 Ds are often used to determine the walkability of a neighbourhood. Walkability is generally considered a key health determinant. It is a protective factor through the mechanisms of physical activity (Frank et al., 2007) and of reduction of stress, especially when walking in natural environments (Gidlow et al., 2016). In complete & compact neighbourhoods with a high residential density and highly connective streets, local facilities and amenities tend to be more accessible. Research has shown that this leads to increases in physical activity due to better walkability and also to better mental health (Bird et al., 2018). Melis et al. (2015) found that good accessibility by public transport, in combination with high urban density (opposed to low-density sprawl) reduces the risk for depression, especially among women and older people. Through the combination of these two, people have more opportunity to move around and to meet people frequently (Melis, 2015). High residential densities are also required to make public transport, facilities and amenities economically feasible. To acknowledge this intercorrelation, Cervero et al. (2009) present the 3 Ds as a Venn diagram (see figure 7).

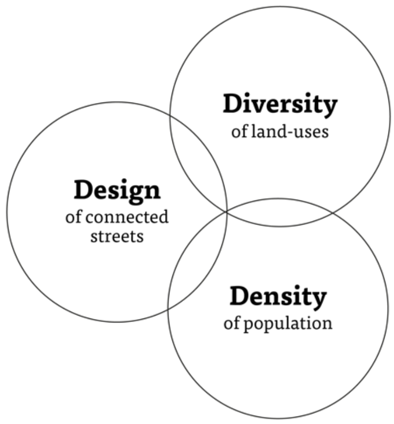

Figure 7: The 3 Ds (Source: Cervero et al., 2009; adapted by author).

To conclude, environmental hygiene, green spaces and complete & compact cities are the categories of environmental health determinants that are most commonly found in academic literature. The different elements of these categories work as risk or protective factors through the mechanisms of physical activity, stress, social cohesion and air quality.

2.4. The Dutch neighbourhood typology

The Netherlands has a rich history of urban planning. In the seventeenth century, a period often referred to as the Golden Age, Dutch cities were booming in economy, wealth and population. Around 60% of the population lived in cities which meant cities needed to be expanded in order to provide in housing and food production. In this century, the urban planner makes its first appearance by drawing up holistic and strategic plans for city expansions. After the seventeenth century, the prosperity of the Dutch Republic demised and so did many Dutch cities. People moved out of the cities again to find housing, food and work. At the end of the nineteenth century, the tide turned. The Industrial Revolution meant also an urban revolution. New types of jobs appeared in cities leading to a new wave of urbanisation. During this period, governmental interference in urban planning was limited. In many cities this led to slums. As a reaction two key laws were instated. First of all, the Vestingwet (Fortification law) of 1874, which gave cities permission to tear down the fortresses. This gave cities more space to expand. Secondly, there was the 1901 Woningwet (Housing law) that set higher standards for the quality of homes. Around the 1930s, urban planning became even more influential. From that time until the 1970s top-down planning was increasingly the standard. The national government held a firm grip on where new neighbourhoods needed to be constructed. In the 1970s, urban planning became more bottom-up. Many Dutch deemed the modernist top-down planning tradition to be inhuman and therefore called for more participation in the planning process. The neo-liberal wind that blew through the western world in the 1980s started to reimagine this. People became consumers and it was up to the market to satisfy their residential wishes. In the 1990s, the Dutch national government interfered in spatial planning of the Netherlands for the last time with the Fourth Memorandum Spatial Planning Extra (Vierde Nota Ruimetelijke Ordening Extra, abbreviated to Vinex). In this memorandum, large sites near big cities were appointed for new housing development. These suburban city expansions were largely developed by commercial parties and were meant to tailor to the residential wishes of future inhabitants, fully in line with the neo-liberal wind that was blowing. Today, the government still has a tight grip on urban planning but has decentralised nearly all control ever since Vinex (Van der Cammen & De Klerk, 2012).

All these large shifts in urban planning in the Netherlands in the twentieth century left their mark on the Dutch urban fabric. Under all the different urban planning doctrines, different types of neighbourhoods were built that are characteristic for their time. Although there is no official classification of Dutch neighbourhood types, some classifications are available. These are, however, often made for a specific purpose and may differ slightly for that reason.

To assess the Dutch 'krachtwijken' ('power neighbourhoods', a euphemism for disadvantaged neighbourhoods), the Planbureau voor de Leefomgeving (Netherlands Environmental Assessment Agency, abbreviated to PBL) have published a classification of neighbourhood types. They have, however, only included the types that are seen in one of the 40 'krachtwijken'. 28 of all 'krachtwijken' was built as a post-war open building block. For this reason, Lörzing et al. (2008) have decided to further specify the category 'open building block' into four subcategories: strips, stamps, courtyards and free-standing high-rise (types IV – VII in table 3).

Type	Period	Density	Characteristics
I. Historical city blocks	circa 1880-1910	High	Privately-developed housing with varied streets. No large public areas or parks. Similar building height throughout the street.
II. Closed city blocks, pre-war	circa 1910-1940	High	Master-planned residential blocks. A lot of attention was paid to architectural details. Similar building height throughout the street.
III. Garden villages and garden neighbourhoods	circa 1910-1955	Medium	Village-like living in the city. Often narrow residential streets. Less green than expected. Much of the greenery is private property. Similar building height throughout the street.
IV. Open building blocks: strips	circa 1935-1970	Low to medium	Houses on residential streets. Strips of greenery in between housing. Varying building heights.
V. Open building blocks: stamps	circa 1945-1970	Low to medium	Traditional residential streets were abandoned. Housing amidst greenery and of different heights.
VI. Open building blocks: courtyards	circa 1950-1970	Medium	Traditional residential streets were abandoned. Housing along open (green) courtyards that were public spaces. Predominantly mid-rise housing.
VII. Open building blocks: free-standing high-rise	circa 1950-1975	Medium	No traditional building block or residential streets. Extreme separation of functions (housing, mobility, etc.). Often within a park-like setting.
VIII. City renewal	circa 1975-1990	Medium to high	Transformation areas within type I and II neighbourhoods. Height matches the rest of the

			neighbourhood. Streets according to the woonerf paradigm: low on car traffic and often dead-ends. Parks and public squares were added. New houses were often larger than previously existing housing.
IX. Urban renewal	circa 1990-now	High	Transformation of areas within types I-VII. Compact building blocks, sometimes closed again. Transformations are either made to fit with the rest of the neighbourhood architecturally, or they are designed to contrast.
X. Heterogenic neighbourhoods	various periods	varying	Built from fragments of different periods and architectural types, usually around old spatial elements such as roads and waterways. This leads to a kaleidoscopic streetscape. These types of neighbourhoods often have a diverse set of functions as well (housing, shops, businesses).

Table 3: Neighbourhood types of 'Krachtwijken' ('power', or disadvantaged neighboorhoods (Source: Lörzing et al., 2008; translated and summarised by author).

Kleerekoper (2016) has created a classification of Dutch neighbourhood types in order to study possibilities for urban climate design (see table 4). Kleerekoper (2016) has combined typology with a similar microclimate and has included twenty-first century neighbourhood types such as Vinex.

Type	Period	Height	Footprint	Green
Historical city block & pre-war city block	before 1910 '10 – '30	Middle high	Closed urban block	Little green
Garden town	'10 – '30	Low	Closed urban block	Moderate to much green
Residential housing	'30 – '40	Low	Closed urban block	Little green
Post-war garden city low-rise	'45 – '55	Low	Open urban block	Moderate to much green

Post-war garden city high-rise	'50 – '60	Middle high / high	Open urban block	Moderate to much green
Community neighbourhood	'75 – '80	Low	Strips Open urban block	Little to moderate green
Sub-urban expansion - Vinex	'90 – '05	Low	Strips Closed urban block	Moderate green
High-rise city centre	'60 – present	High	Spread buildings	Little green

Table 4: Neighbourhood types and their microclimates (Source: Kleerekoper, 2016).

A third, less specific, classification was also published by researchers from PBL. The goal of the classification was to investigate the opportunities for urban transformation. Bijlsma et al. (2008) categorised transformation neighbourhoods into three types of urban fabric: post-war fabric, city renewal fabric and 'woonerf' fabric. The category post-war fabric has three subcategories: homogenic fabrics, heterogenic fabrics and large-scale fabrics. The category city renewal fabrics also has subcategories: clustered fabrics and interwoven fabrics. Finally, the 'woonerf' fabric has low-rise and high-rise fabrics as its two subcategories.

Type of neighbourhood	Type of fabric
Post-war	homogenous heterogenous large-scale
City renewal	clustered interwoven
'Woonerf'	low-rise high-rise

Table 5: Neighbourhood types based on their type of urban fabric (Source: Bijlsma et al., 2008; translated and summarised by author).

For the purpose of identifying the healthiest neighbourhood type, a custom classification will be created based on the classifications of Lörzing et al. (2008), Kleerekoper (2016) and Bijlsma et al. (2008).

Three types of pre-war neighbourhoods can be distinguished: the 19th century historical closed city blocks, the 20th century pre-war closed city blocks and the garden villages. The historical closed city blocks were often built before the Woningwet of 1901 by private developers, often in areas that used to be part of the fortification. Today, this still means a relatively high residential density and little public open space. Their location is often close to the city centre, meaning amenities are close to home. In the 1970s, this type of neighbourhood was often the subject of city renewal. The pre-war closed city blocks were the first planned city expansions. They were often meant for the wealthier citizens and are still characterised by a rich architecture, tree-lined streets and small parks. The garden villages or garden neighbourhoods were built for the labour class. Inspired by Ebenezer Howard's Garden City-movement, they tried to combine ‘town’ with ‘county’. The result are neighbourhoods with (often privately owned) streetscape green and with open green spaces (Van der Cammen & De Klerk, 2012; Wagenaar, 2011).

After the Second World War, the ideas of modernism were embraced. This led to open-block neighbourhoods that can be classified in different ways. For the purposes of this study, post-war reconstruction neighbourhood are divided into three neighbourhood types based on their urban fabric. The urban fabric has a large influence on green spaces and land-use mix which makes this division most suitable. Homogenous post-war reconstruction neighbourhoods often have the majority of houses in the portico-type. These apartment buildings are in many cases not situated on a traditional street but are instead positioned on large lawns. This style of portico flats can also be found in the heterogenous fabric. The difference is however, that they are more often situated along a traditional street and that they are alternated with single-family homes and high-rise flats. This leads to more mixed neighbourhoods. The third category, large scale fabrics, is the least common in the Netherlands. These neighbourhoods follow the modernist tradition the closest with an extreme separation of functions and high-rise flats in park-like surroundings (Van der Cammen & De Klerk, 2012; Wagenaar, 2011).

The post-war reconstruction neighbourhoods soon faced a lot of criticism. The large roads led to many deadly car accidents and many neighbourhoods were not suitable to the human scale. Together, these points of critique were translated into a new type of neighbourhood: the ‘woonerf’-type. The ‘woonerf’ is a typically Dutch type that comprises low-traffic streets, often with dead-ends and many bends. The goal was to re-introduce as small-scale village feel into urban neighbourhoods (both in the transformation of 19th century neighbourhoods that were part of city renewal as well as in new construction). Along came an innovative traffic concept where pedestrians and especially children had plenty of (safe) space due to the slowing down of motorised traffic through street design measures. New construction ‘woonerf’ neighbourhoods are often called cauliflower neighbourhoods due to their complicated urban structure that resembles the florets of a cauliflower in bird’s-eye view and were generously endowed with greenery. Cauliflower neighbourhoods are often monofunctional residential neighbourhoods with a majority of single-family houses. The ‘woonerf’ trend was relatively short-lived but had a large impact on the Dutch housing stock. 27% of all houses are built in a ‘woonerf’ neighbourhood. Critique from architects, economic decline and a new political wind in the 1980s eventually led to a new neighbourhood type in the 1990s: Vinex. In Vinex neighbourhoods, the future inhabitant was seen as a consumer and it was up to the market to fulfil the residential wishes of that consumer. Developers concluded that the modern (relatively rich) consumer wanted to live in a peaceful suburban neighbourhood, in single-family homes in a relatively pluriform retro-architecture surrounded by greenery (but not as much as in the ‘woonerf’ neighbourhoods) and with parking spaces in front of their home. In some larger Vinex-locations such as Utrecht Leidsche Rijn construction is still going on (Ubbink & Van der Steeg, 2011; Van der Cammen & De Klerk, 2012). After Vinex, no new neighbourhood types have been established (yet).

In conclusion, a custom classification of neighbourhood types has been made. The type, dominant period of construction and the characteristics can be found in table 6.

Neighbourhood type	Period (circa)	Characteristics
Urban block	1880-1910	Privately-developed housing with varied streets. No large public areas or parks. Similar building height throughout the street (2-4 stories).
Pre-war closed building block	1910-1940	Master-planned residential blocks (3-4 stories). A lot of attention was paid to architectural details. Streets feature similar building heights throughout, a rich architecture, tree-lined streets and small parks.
Garden town/garden neighbourhood	1910-1955	Village-like living in the city. Often narrow residential streets. Much of the greenery is private property and can be less than expected. Similar building height throughout the street (3-5 stories). Upper and lower houses is a common housing type.
Post-war reconstruction homogenous fabric	1955-1970	Modernist-style neighbourhoods with housing mainly in portico flats (4-5 stories) or terraced houses (2-3 stories) in repeated styles. Open building blocks, not always traditional residential streets.
Post-war reconstruction heterogenous fabric	1945-1970	Modernist-style neighbourhoods with often traditional residential streets. Housing of various types (terrace, portico flat and gallery flat) and of different heights (2-15 stories).
Post-war reconstruction large scale fabric	1955-1975	No traditional building block or residential streets. Extreme separation of functions (housing, mobility, etc.). Often high-rise flats within a park-like setting.
'woonerf'/cauliflower neighbourhoods	1970-1985	Streets according to the 'woonerf' paradigm: low on car traffic due to many obstacles and often dead-ends. New construction neighbourhoods are called cauliflower neighbourhoods due to their intrinsic urban structure. They are often monofunctional residential neighbourhoods with a majority of single-family homes and lots of greenery.
Vinex	1990-2005	Monofunctional residential neighbourhoods with a majority of terraced or (semi-)detached housing. Street patterns are often geometric but are not repeating too much as they did in post-war reconstruction neighbourhoods or too complicated as they were in cauliflower neighbourhoods.

Table 6: Classification of Dutch neighbourhood types (Source: author).

2.5. Conceptual model

In chapter 2.1, it was concluded that a holistic perspective would be best suited for research on the relationship between the built environment and health. When looking at this relationship holistically, health pathways can be distinguished on multiple levels. Ecological models are often used to help understand how environmental factors influence local health. For that reason, the conceptual model for this study is an ecological model (figure 7).

Centrally in the model are the people that live in a certain neighbourhood and their health. This level of the model also includes the sociodemographic characteristics of the neighbourhood inhabitants such as age distribution and average income. The health of this group of people is influenced by environmental health determinants through four mechanisms: physical activity, stress, air pollution and social cohesion. The three categories of health determinants, greenery, environmental hygiene and complete & compact city, appear in different compositions in the eight neighbourhood types. The aim of this research is to find out which composition, and therefore which neighbourhood type, has the best outcomes on the health of the neighbourhood inhabitants.

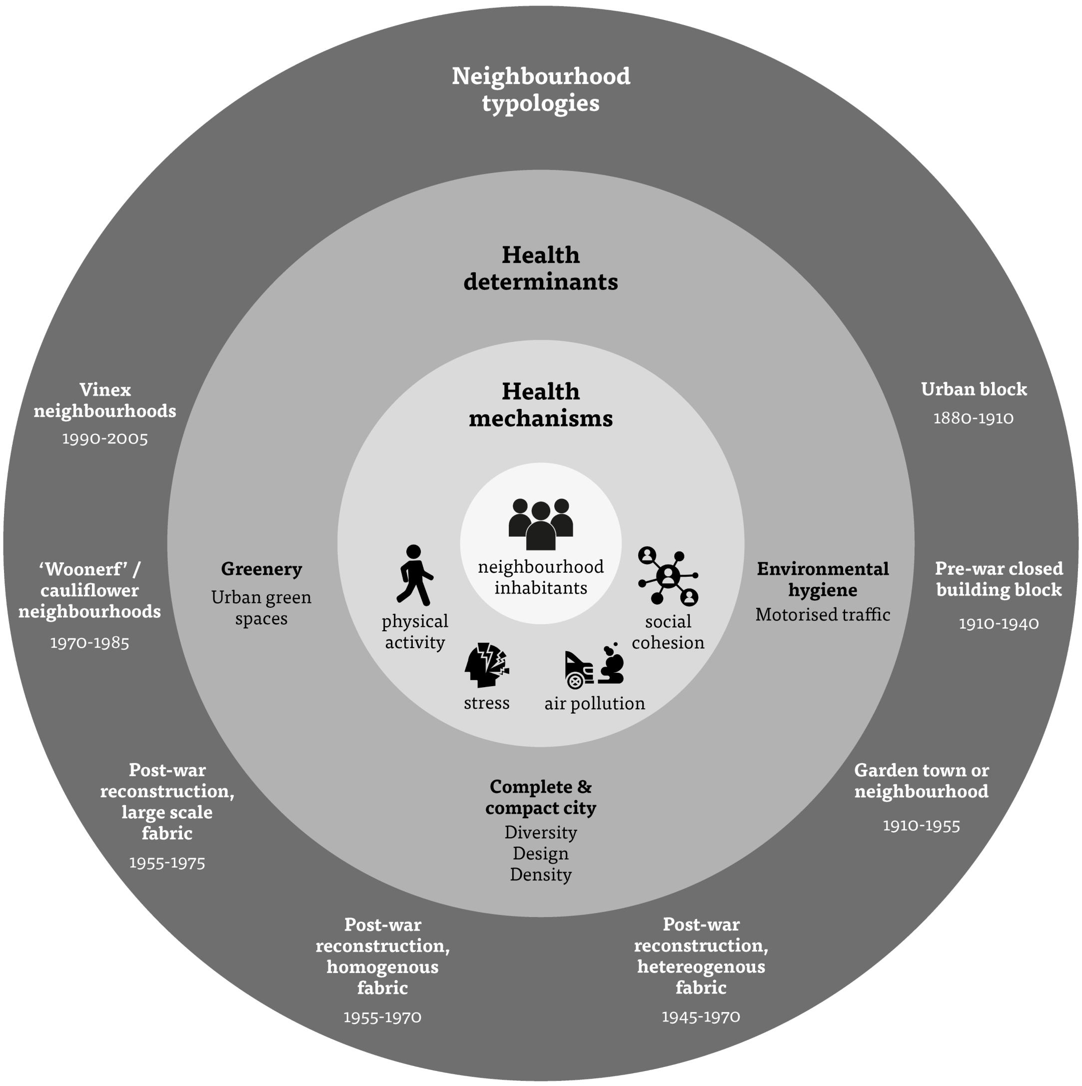

Figure 8: Conceptual model (Source: author).

Based on the conceptual model, several hypotheses have been formulated. The outcomes of these will be discussed in chapter five.

Hypothesis 1: There is a relationship between neighbourhood types and local physical and mental health.
Hypothesis 2: Greenery positively influences local physical and mental health.
Hypothesis 3: Environmental hygiene positively influences local physical and mental health.
Hypothesis 4: Complete & compact city positively influences local physical and mental health.

3. Methodology

To explore the relationship between various Dutch neighbourhood types and local physical and mental health, a quantitative approach is chosen. Many other studies on this topic also feature a quantitative approach which makes it possible to compare and contrast results. Besides that, for the Dutch context little evidence-based knowledge is available. Quantitative research offers the possibility to make generalisations on healthy neighbourhoods based on something else than loose observations or professional opinions. This chapter first describes the dataset and variables used. Then it discusses the limitations of the data and the study area. Finally, the cases will be described and the empirical model will be explained.

3.1. Dependent variable: Global Activity Limitation Indicator

This study uses a dataset that is compiled from various sources. For the dependent variable, the Dutch Public Health Monitor is used. Every four years, the 25 Municipal Health Services (GGD'en) in the Netherlands together with the National Institute for Public Health and the Environment (RIVM) and the Central Bureau for Statistics (CBS) set out a large representative survey among almost 460.000 adults aged 19 and over (a proportional sample of 3,0% of the Dutch population) (Van de Kassteele et al., 2017). The data of the Dutch Public Health Monitor is collected separately by the different institutes. CBS set out the Health Survey (Gezondheidsenquête) in 2016. Data was collected with a mixed-method survey design. The sample population was first approached online (Computer Assisted Web Interviewing). The follow-up among non-responders was done via an interview at their homes (Computer Assisted Personal Interviewing). The GGD'en set out an Adult Monitor as well as an Elderly people Monitor in 2016. The sample population was again first approach online. Some GGD'en sent out the survey on paper (Paper and Pencil Interviewing) at first contact, others used this method to reach non-responders. In some large cities a small portion of all responses was collected through a verbal interview (CBS, 2017). Decentralisation of spatial planning and public health policy creates the urgency for neighbourhood statistics. It is however very costly to oversample a large number of neighbourhoods. For that reason, the RIVM uses small area estimation to obtain neighbourhood-level data on public health. With a structured additive regression model health-related predictors[4] can be related to the health-related indicators in the dataset (Van de Kassteele et al., 2017). The eventual modelled data is referred to as SMAP (small area estimates for policy-makers) and is expressed in numbers without decimals (RIVM, 2021). The accuracy of the SMAP-data cannot be guaranteed but appears

[4] The health-related predictors consist of population characteristics that were retrieved from the national registry data and were chosen based on expert opinions of the GGD'en and the RIVM (Van de Kassteele et al., 2017).

to be close to reality when it comes to estimating the prevalence of the health-related indicators at the neighbourhood level (Van de Kassteele et al., 2017). For more information about the SMAP-model, please refer to the paper of Van de Kassteele et al. (2017).

One of the health-related indicators from the SMAP-modelled Dutch Public Health Monitor data will serve as the dependent variable: the Global Activity Limitation Indicator. As part of an EU strategy aimed to combat preventable diseases and death, the Minimal European Health Module (MEHM) was developed. The MEHM is part of the broader EU Statistics on Income and Living Conditions (EU-SILC) that is used by EU member states to jointly monitor well-being (Bogaert et al., 2018). As an EU member state, the Netherlands has implemented the MEHM into the surveys underlying the Dutch Public Health Monitor. Part of the MEHM is the Global Activity Limitation Indicator (GALI), a way to measure long-term disability. GALI has proven to compare well to other health indicators in the way that it appropriately measures the influence of mental and physical illnesses on long-term disability (Van Oyen et al., 2006). GALI is collected through the following survey question: *"for at least the past six months, to what extent have you been limited because of a health problem in activities people usually do? Would you say you have been: severely limited? limited but not severely? not limited at all?"*. In the Dutch Public Health Monitor, GALI can be found as two separate variables: limited because of health and severely limited because of health. For the purpose of this study, only the first variable will be used. This variable is continuous in nature and expresses the SMAP percentage of people in a neighbourhood that are limited because of their health.

3.2. Independent variables

Neighbourhood type: The selected neighbourhoods will be classified into the different neighbourhood types mentioned in table 6 based on observations of the author. These observations are done through neighbourhood visits, with footage from Google Street View and by examining the morphology and building stock of neighbourhoods with the use of Geographical Information Systems (GIS) software. During classification it became clear that two additional neighbourhood types are required: free-standing/villa and historical city centre. Free-standing/villa comprises neighbourhoods from different era's but with the shared characteristic of having a majority free-standing houses. Greenery in these neighbourhoods is often on private grounds only. Historical city centre is characterised by an intricate network of streets, a land-use mix that is divided relatively evenly among functions and very little greenery. The historical city centre is a relatively rare type of neighbourhood since most cities in the Netherlands have none or just one. During the classification, the urban pattern of the neighbourhood was leading, not the architecture of the buildings. This was especially the case in older neighbourhoods that lacked a clear type due to (multiple) city renewal operations.

Walkability index: As was mentioned in chapter 2.3., the health determinant complete & compact city bears resemblance with its 3 Ds to research on walkability. In this study, the walkability index that was developed by Frank et al. (2005; 2010) will be calculated for all selected neighbourhoods and used as an indicator for complete & compact city. Besides the 3 Ds, density, design and diversity, a fourth element was added to the walkability index by Frank et al. in 2007: Retail Floor Area Ratio[5]. This element will be left out of the walkability index for this study because it is not one of the 3 Ds. Also unlike Frank et al. (2007; 2010), no extra weight has been given to any of the 3 Ds because there are no theoretical grounds for it in this study. The walkability index is the sum of the z-scores of the different elements (Christian et al., 2011):

Walkability = [(z-land use mix)+(z-intersection density)+(z-net residential density)]

Data from the BAG (Basisadministratie Adressen en Gebouwen; Basic Administration Addresses and Buildings) on all properties, their function and their floor surface area has been joined spatially to the boundaries of the neighbourhoods using GIS software. Afterwards, all features were summarised based on the total area of the different functions per neighbourhood. The square feet building floor area of all different functions serve as the input for a formula to calculate an entropy-based land-use mix index (Christian et al., 2011):

$$\text{LUM} = -1\left(\sum_{i=1}^{k} P_i \times \ln(P_i)\right) / \ln(k)$$

The formula is structured as follows: k refers to the number of building use categories, P_i is the proportion of building area for the use i. This diversity index is then divided by the natural logarithm of k in order to standardise the land-use mix index. All land-use mix scores range on a scale from zero to one, where zero means no mix and one means that all uses are evenly distributed. In this study, the floor area of buildings is used instead of the area of the parcels. The reason for this is to account for vertical mix in land-uses as well. Depending on the research question and data availability, different land-use categories can be included into an entropy-based land-use mix index. This study will include six categories of building uses (see table 7). Residential, retail and office use can be used directly from the summarised BAG-dataset. Leisure will be compiled from the sum of

Categories
Residential
Retail
Offices
Education & health
Leisure
Other

Table 7: Categories of building uses (Source: author).

[5] This index is derived by dividing the retail building floor are (sq. ft.) by retail land area (sq. ft.). The goal of this ratio is to determine the setback of a store on the plot and give through that an indication of the parking facilities in front of a store.

BAG functions 'gathering' (bijeenkomstfunctie), 'sports' (sportfunctie) and 'lodging' (logiesfunctie). Education & health will consist of the sum of BAG functions 'education' (onderwijsfunctie) and 'health care' (gezondheidsfunctie). The category other consists of BAG functions 'industry' (industriefunctie), 'prison' (celfunctie) and 'other' (overige functies). Together, these categories add up to 100% of all land uses.

The next item of the walkability index is street connectivity: the number of intersections per square kilometre. The NWB (Nationaal Wegenbestand; National Road File) was spatially joined to neighbourhoods with GIS software. The NWB consists of junctions and road sections (nodes and edges). All road sections are marked by an ID-numbered start and an end junction. In Microsoft Excel, all start and end junctions per neighbourhood were combined and duplicates were removed. Subsequently, the number of junctions per neighbourhood was counted and divided by the square kilometre area of each neighbourhood.

The third item of the walkability index is population density. In many studies, such as those by Frank et al. (2007, 2010), the number of residences per acres in residential use in used for this element of the index. However, based on the theoretical framework (especially on the findings of Melis et al., 2015) it was decided to use population density instead. The number of neighbourhood inhabitants can be retrieved from the earlier mentioned BAG. The acreage in residential use is retrieved from the bg2015 (neighbourhood level land-use statistics) from the Central Bureau for Statistics (CBS).

Green space ratio: The amount of urban green space has been summarised in square kilometres per neighbourhood using the BGT (Basisregistratie Grootschalige Topografie; Basic Registration Large-scale Topography) dataset and GIS software. The category (urban) green space in BGT encompasses a range of types of greenery: forest park or shrubbery, grasses and herbs, plants, rose bushes, shrubs and ground cover. Within a large formal green space such as a park, multiple types of greenery may be present. Trees and private green spaces are not part of the BGT.

Average noise exposure: The two main categories of environmental hygiene are air pollution and noise nuisance. A large part of air pollution in neighbourhoods is either blown over the city from other regions or is very locally emitted by motorised traffic. This makes it very difficult to assess air quality on a neighbourhood level. City data is available for a large number of European cities but is not suitable to use in this study because it does not consider differences between neighbourhoods. The variable used for the category environmental hygiene will be based solely on noise. The average exposure to noise per neighbourhood in 2016 has been retrieved from the dataset bgwt2016 (Blootstelling aan Geluid van Weg- en Treinverkeer, wijken en buurten 2016; Exposure to noise from road- and rail traffic, districts and neighbourhoods 2016) of the RIVM. This variable is binned into multiple variables: percentage of noise exposure below 50 decibels (dB), between 50 and 55 dB, between 55 and 60 dB and above 60 dB. This type of variable is not suitable to use in statistical analysis because the four variables would be interdependent: the total sum of the four percentages is always 100 so if one X-variable would increase with 1 unit, the other three would decrease. To avoid this problem, the four variables were transformed into one variable: average noise exposure from road traffic. To do so, the mean value of each category was taken. The end of the fourth variable was approached using the decibel scale in figure 6 and set at 120dB in order to be able to use the mean of this category. The percentages of noise exposure were multiplied by the mean value of the corresponding categories. The values were summed per neighbourhood and divided by 100. The result is an approximation of the average noise exposure level during a 24-hour period.

Control variables: To control for age, income and level of education, data from the kwb2016 of the CBS will be used. Data on age and level of education was only available in a binned form with five categories. With the same method used to create a continuous variable for noise, the average age was approximated. The end of the last age category was set to 90. Data in average income can be used without transformations. Values are x1000 and represented in euros. Level of education was again binned in multiple variables: low, middle and high level of education. These variables were numbered 1, 2, 3 respectively. The number of people in each category was multiplied by the number corresponding to the level of education. The results were summed for each neighbourhood and divided by the total number of people of which we know the level of education in each neighbourhood. The final average level of education was rounded off with two decimals.

3.3. Data limitations

There are some limitations in the data that is used for this study. First of all, only the neighbourhood types and health determinants are investigated, and not the health mechanisms. Unfortunately, it was not feasible to also research the mechanisms due to a lack of data. The number of intersections per neighbourhood turned out to be difficult to find. Fortunately, the walkability index can be adapted to work with slightly different datasets than those originally used by Frank et al. (2005) (Christian, 2011). The NWB-data comes closest in measuring the number of intersections. In most cases, junctions are 3- or more-way. Roads with corners are registered as one road segment, not two. This means that there are no two-way intersections in the dataset. The exception are dead-end-streets that end with a 'junction' where in reality, there is not one. Despite the limitations, the NWB-dataset still provides a good approximation of the number of intersections per squared kilometre. As mentioned earlier, the data on environmental

hygiene is also limited. Neighbourhood-level data on air quality was not available and city-level data was not adequate to answer the research question.
Another limitation regards the types of greenery. The variable used in this research only includes public green spaces. This means that trees and private green spaces are not included. The reason for this is a lack of data.

3.4. Study area

For this study, neighbourhoods in Groningen and Nijmegen, are selected. In order to have a broad selection of different neighbourhood types within one city, the focus lies on the large Dutch cities. In 2016, the municipalities with the highest number of inhabitants were respectively Amsterdam, Rotterdam, The Hague, Utrecht, Eindhoven, Groningen, Tilburg, Almere, Breda and Nijmegen. The first three are the largest cities in the Netherlands and vary from roughly 500.000 to 850.000 inhabitants. Utrecht is approaching this category with roughly 340.000 inhabitants in 2016. These four cities are often referred to as the G4. The remaining six cities form a class of middle-large cities with a size varying around the 200.000 inhabitants (CBS, 2019).

Almere is a special case in this line-up because this so called 'new town' was founded in 1975 (Van der Cammen & De Klerk, 2012). Because of this, only a small part of the aforementioned neighbourhood types can be found in Almere, making it unsuitable for this study. Groningen and Nijmegen are both middle-large university cities. In size, they vary from 172.064 inhabitants (Nijmegen) up to 200.952 inhabitants (Groningen) (CBS, 2019). The cities have similar level of facilities (CBS, 2019), are both in the periphery of the Netherlands. Besides that, the cities have a similar disability-free life expectancy. From all G10 cities, Groningen scores the highest with an average of 69,9 healthy life years and Nijmegen scores third place with 68,8 healthy life years. (RIVM, 2017).

3.5. Descriptive statistics

In 2016, Groningen and Nijmegen together had 149 neighbourhoods. Only neighbourhoods that could be classified as one of the types were selected. This leaves out industrial- and business areas, parks and unbuilt agricultural land. In table 8, the descriptive statistics of the remaining 103 neighbourhoods can be found. The variables are divided into three categories: sociodemographic variables including age, income and level of education; neighbourhood variables including the 3 Ds, greenery, noise exposure and neighbourhood typology; and the health variable that will be used as the dependent variable. The average age of neighbourhood inhabitants ranges from 29,59 (Zeeheldenbuurt, Groningen) to 50,76 (Villabuurt, Groningen). Average income varies between €15.700 in Selwerd, Groningen and €48.200 in Villabuurt, Groningen. This is the total income earned in the neighbourhood divided by the number of inhabitants (including children and elderly people). The average income of €24.180 is close to the national average income in 2016 of €24.700 (CBS, 2019). The average level of education is 2,25, comparable to the Florabuurt in Groningen. Since this variable was coded 1 for low-level education, 2 for mid-level and 3 for high-level education, the average level of education in the selected neighbourhoods is somewhat higher that mid-level. This relatively high number is expected since Groningen and Nijmegen are both university cities that house a large number of students. The lowest average level of education can be found in Meijhorst, Nijmegen. The Villabuurt in Groningen has the highest average level of education.

The three variables that are used to calculate the walkability index all vary greatly between neighbourhoods. As was mentioned before, the land-use mix index ranges theoretically ranges from 0 (no mix at all) to 1 (perfectly balanced mix). In the investigated neighbourhoods, the land-use mix index ranges from 0 in the Ruischerwaard in Groningen to 0,93 in Binnenstad-Noord in Groningen with an average of 0,38 (comparable to Altrade in Nijmegen). The number of junctions per km^2 also varies greatly from 0,06 in Noorddijk, Groningen to 6,45 in Benedenstad, Nijmegen with an average of 1,8 (comparable to Kostverloren, Groningen). The number of inhabitants per km^2 residential land differs from 17,74 in the Villabuurt in Groningen to 440,75 in the Stadscentrum in Nijmegen. The average net residential density can be compared to Paddepoel-Noord in Groningen with 108,87. The z-scores of these three variables have been summed to create the walkability index. As the index increases, the walkability of a neighbourhood increases. The lowest scoring neighbourhood is Klein Harkstede in Groningen with an index of -3,29. The most walkable neighbourhood is Stadscentrum in Nijmegen with an index of 8,99. The average of 0,32 is comparable to the walkability index of Ulgersmaborg in Groningen.

Other neighbourhood variables include the green space ratio. In the selected neighbourhoods, this ranges from 1,89% public greenery in Binnenstad-West, Groningen to 44,14% public greenery in Ooyse Schependom, Nijmegen. The average is, however, much lower at 17,91%, and can be compared to De Hunze, Groningen. The most silent neighbourhood is Klein Martijn in Groningen. 74,75% of all neighbourhoods have an average noise exposure from road traffic lower than the 53 dB that was recommended by the WHO (2018). Ooyse Schependom in Nijmegen is not only the neighbourhood with the highest percentage public greenery but also faces the highest average exposure of road noise with an L_{den} of 72 dB. The average noise exposure from road traffic is roughly 47 dB which compares to the Oosterpoort in Groningen. The dataset contains no neighbourhoods with a post-war reconstruction, large-scale fabric type. This neighbourhood type has not been built frequently in the Netherlands so it could be expected to not have it present in the dataset. Vinex is the most frequently identified neighbourhood type. 17,48% of neighbourhoods fall into that category[6].

The dependent variable, limited by disability, ranges from 23% in among others Reitdiep, Groningen to 48% in Meijhorst, Nijmegen. The average percentage of neighbourhood inhabitants that are limited by health problems is 32,37. The Villabuurt, the neighbourhood with the highest average age and highest average level of education has the same percentage of people limited by health problems as the average of all neighbourhoods in the dataset.

Table 8: Descriptive statistics of all variables (N=103)

Category	Variable		mean/%	std. dev.	min.	max.
Sociodemographic	Age	Average age	39,08	4,55	29,59	50,76
	Income	Average income per person (x €1000)	24,18	6,08	15,7	48,2
	Level of education	Average level of education	2,25	0,24	1,71	2,68
Neighbourhood	3 Ds	Land-use mix index	0,38	0,22	0	0,93
		Junction per km²	1,80	0,98	0,06	6,45
		Net residential density	108,87	70,99	17,64	440,75
		Walkability index	0,32	2,19	-3,29	8,99
	Greenery	Green space ratio	17,91	10,16	1,89	44,14
	Noise exposure from road traffic	Average exposure (in dB)	46,62	9,19	27,68	72,71
	Neighbourhood typology	Historic city centre	1,94%			
		Urban block	8,74%			
		Pre-war closed building block	2,91%			
		Garden town/-neighbourhood	16,50%			
		Post-war reconstruction, homogenous	12,62%			
		Post-war reconstruction, heterogenous	13,59%			
		Post-war reconstruction, large-scale	0%			
		'Woonerf'/cauliflower	12,62%			
		Vinex	17,48%			
		Free-standing / villa	13,59%			
Health		Limited by health problems > 6 months	32,37	5,96	23	48

3.6. Multiple linear regression analysis

The theoretical framework has made clear that health is influenced by various (environmental) factors. For that reason, multiple linear regression was chosen as the empirical model to analyse the data. Through multiple linear regression, it is possible to control for sociodemographic

[6] Please note that the typological definition of Vinex has been used here. Not all neighbourhoods that were identified as Vinex were appointed as such in the Vierde Nota Ruimtelijke Ordening Extra.

characteristics that also influence health when estimating the effect of environmental factors. Statistical analysis was performed in Stata 16 (Stata Corp, College Station, Texas).

Multiple linear regression is in a lot of ways similar to simple linear regression. The main difference is however, that simple linear regression is performed with one dependent and one independent variable whereas multiple linear regression uses one dependent and multiple independent variables. The dependent variable is always a continuous variable, the independent variables can be categorical and/or continuous (Mehmetoglu & Jakobsen, 2017). The mathematical form of multiple linear regression is as follows:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \varepsilon_i$$

The statistical principle that underlies multiple linear regression is that of Ordinary Least Squares (OLS). Stata calculated the estimates values of the dependent variable ($\hat{Y}_i$). These estimated values may not exactly match the observed values of the dependent variable (Y_i). The difference between $\hat{Y}_i$ and Y_i is called the residual ($\hat{\varepsilon}_i$). The OLS method minimises the sum of the square of the residuals for all the values of Y. Through this method, a regression line that is the closest to the observed values for Y, and thus has the least amount of squared residuals, is calculated which leads to better estimations. The regression coefficients that result from OLS are known as BLUE (best linear unbiased estimates) on the condition that they meet the Gauss-Markov assumptions (number 1-3 in table 9) (Mehmetoglu & Jakobsen, 2017).

Table 9: OLS assumptions (Mehmetoglu & Jakobsen, 2017)

No.	Assumption	Description
1	$E(\varepsilon_i \mid X_1, \dots, X_n) = 0$	Error term has a conditional mean of zero
2	$\text{Var}(\varepsilon_i \mid X_1, \dots, X_n) = \sigma_u^2, 0 < \sigma_u^2 < \infty$	Error term has a constant variance (homoscedacity)
3	$E(\varepsilon_i\, \varepsilon_j \mid X_1, \dots, X_n) = 0,\ i \neq j$	Errors are uncorrelated (autocorrelation)
4	$\varepsilon_i \sim N(0, \sigma^2)$, for all i	Residuals are normally distributed
5		The model is correctly specified
6		Absence of multicollinearity

Before regression, the normal distribution of all variables is checked with the help of Stata's commands *histogram, normal* and *summarize, detail*. Potential problems are skewed, flat or pointy distributions of the variables. It turns out that the variable *av_income* has a positive skew of 1,57 and is leptokurtic with a kurtosis of 6,35. To avoid problems when running the regression, *av_income* has been transformed using the natural logarithm. The new variable, *ln_income*, has a better distribution with a skewness of 0,78 and a kurtosis of 3,67.

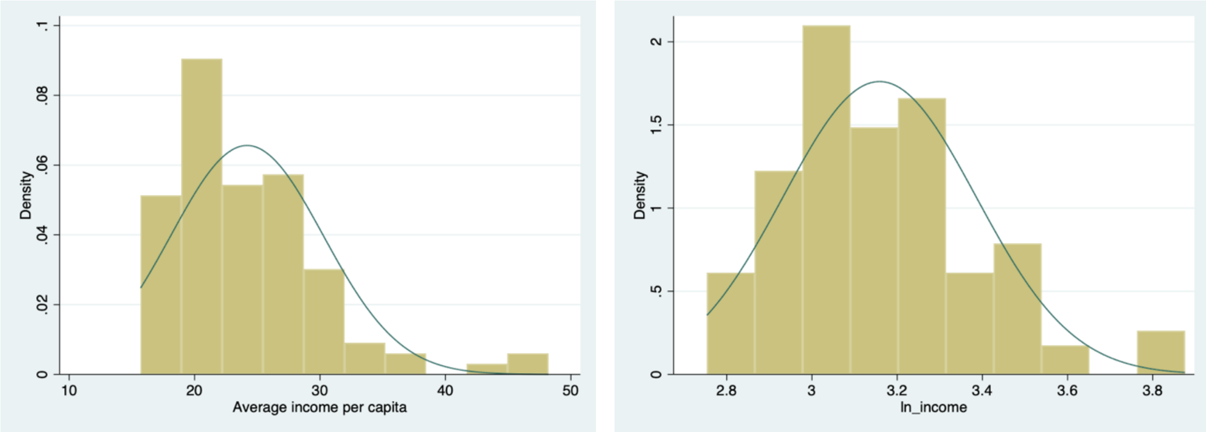

Figure 9: Normal distribution of the variable *av_income* before and after transformation.

The variable *Type* has a flat distribution with a skewness of -0,15 and a kurtosis of 1,79. Variables with los kurtosis are called platykurtic. To solve this problem, the category *Post-war reconstruction, large-scale* was removed. This is a rare neighbourhood type that has a frequency of 0 in the dataset.

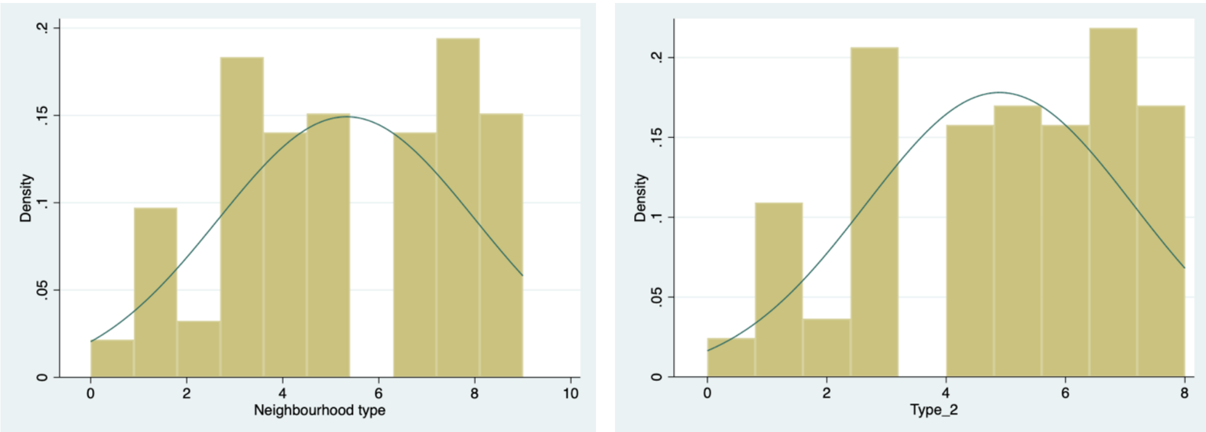

Figure 10: Normal distribution of the variable *Type* before and after transformation.

Several models are specified. First there is the baseline model that only includes sociodemographic variables:

$$p\_limited = \beta_0 + \beta_1 av\_age_i + \beta_2 ln\_income_i + \beta_3 av\_edu_i + \varepsilon_i$$

In this formula, *i* stands for the specific neighbourhoods. Next, the different categories of the neighbourhood typology were added to the baseline model. This way, it is possible to compare the influence of the various neighbourhood types on health. The Vinex neighbourhood (type 8) has been excluded of the model in order to serve as the base category to compare the effects of the other neighbourhood types to:

$$p\_limited = \beta_0 + \beta_1 Type\_t1_i + \beta_2 Type\_t2_i + \beta_3 Type\_t3_i + \beta_4 Type\_t4_i + \beta_5 Type\_t5_i + \beta_6 Type\_t6_i + \beta_7 Type\_t7_i + \beta_9 Type\_t9_i + \beta_{10} av\_age_i + \beta_{11} ln\_income_i + \beta_{12} av\_edu_i + \varepsilon_i$$

It is also interesting to investigate the effects of the three health determinants to find out which elements of a neighbourhood design have the largest effect. Because neighbourhood types are different compositions of these three determinants, the variables cannot be in the same model:

$$p\_limited = \beta_0 + \beta_1 av\_noise_i + \beta_2 walk\_index_i + \beta_3 p\_green_i + \beta_2 av\_age_i + \beta_3 ln\_income_i + \beta_4 av\_edu_i + \varepsilon_i$$

4. Results

4.1. Model 1: baseline

The command *regcheck* was used to examine whether assumptions number 2, 4, 5 and 6 (table 9) were violated. *Regcheck* revealed that the data has heteroscedastic residuals. To solve this problem, the regression for model 1 is ran using robust standard errors. As can be seen in table 10, the adjusted R-value of model 1 is 0,82. This means 82% of the variance in the dependent variable is explained by the three sociodemographic predictor variables. Because the natural logarithm of average income per capita was used for the regression analysis, interpretation is less straightforward. When holding the other predictor variables constant, it can be concluded that a 10% increase in average income per capita leads to a decrease in people limited by health problems of 0,84%.[7] An increase in the average age of neighbourhood inhabitants by one year, leads to an 0,88% increase in people limited by health problems. Similarly, a 1-level increase in education (for example from middle- to high-level) leads to a decrease in people limited by health problems of 8,83%.

4.2. Model 2: neighbourhood types

In model 2, neighbourhood type was included as polytomous dummy variables. Besides a problem with heteroscedasticity, *regcheck* also identified multicollinearity, a violation of OLS assumption 6 (table 9). Multicollinearity occurs when one variable (almost) perfectly predicts another. This makes it unclear to tell which variable causes what. Via the command *estat vif* Stata computes the Variance Inflation Factors (VIF) for each variable in the regression. A VIF higher than 5 indicates severe multicollinearity, which is the case for multiple neighbourhood types. To solve this problem, categories of neighbourhood types were combined to create the new variable *Type_cat*. Historic city centre and urban block together form the new category: 'pre-WWI'; pre-war closed building block and garden town/-neighbourhood together form the new category: 'interbellum'; the three types of post-war reconstruction neighbourhoods are combined to form the category 'post-war reconstruction'. The other categories of building types remain the same. Regression was run with the new variable *Type_cat* and with robust standard errors to solve the heteroscedasticity problem.

The base category for neighbourhood type is the Vinex-neighbourhood that is believed to be the healthiest type according to the professionals that were interviewed by the RIVM (see introduction). Because all other neighbourhood types will be compared to Vinex, there are no

[7] The effect of a 10% increase in income on health limitation can be calculated as follows: -8,833964*LN(1,10). More generally: coefficient *LN(increase/decrease).

regression coefficients for Vinex in table 10. The result of the multiple linear regression analysis is that only the pre-WWI neighbourhood type has better health outcomes than Vinex neighbourhoods. People living in these older neighbourhoods suffer 0,3% less from limitations because of health problems compared to people living in Vinex-neighbourhood. This result is, however, not statistically significant. People living in interbellum, 'woonerf'/cauliflower or free-standing/villa neighbourhoods are worse off compared to people living in Vinex-neighbourhoods: in those neighbourhoods respectively 1,34%, 0,94% and 0,76% more people are limited because of health problems. Again, these results are not statistically significant. This is different for post-war reconstruction neighbourhoods. Here people are statistically significantly suffering more from limitations because of health problems than in Vinex-neighbourhoods, 1,94% more to be specific (significant $p < 0{,}10$). The effects of ln average income per capita, average age and average level of education on limitation because of health problems are smaller than in model 1 but are still significant. The R^2 of model 2 is 0,83. This means that 83% of the variance in limitation because of health problems can be explained by this model.

4.3. Model 3: environmental health determinants

The third model includes the sociodemographic control variables and the three health determinant variables: walkability index, green space ratio and average noise exposure. All variables are statistically significant. If the walkability index increases with 1 in a neighbourhood and all other variables remain constant, 0,37% more people will be limited by health problems. This is contradictory to academic theory which suggests that higher neighbourhood walkability will lead to more physical activity and therefore to better health outcomes. A 1% increase in public green space leads to 0,07% more limitation because of health problems if all other variables remain constant. As was mentioned earlier, it is not uncommon to find contradictory results when it comes to the relationship between green space and health. Unexpectedly, increases in noise have a beneficial effect on health. A 1 dB increase in average noise exposure from road traffic, leads to a decrease in the percentage of people limited by health problems of 0,07%.

4.4. Model 4: the 3 Ds

Because the walkability index provided an unexpected result, the three variables that together form the walkability index were investigated further. The multiple linear regression model is as follows:

$$p\_limited = \beta_0 + \beta_1 LUM_i + \beta_2 junc\_sq\_km_i + \beta_3 net\_pop\_den_i + \beta_4 ln\_income_i + \beta_5 av\_age_i + \beta_6 av\_edu_i + \varepsilon_i$$

The results are statistically significant for all variables. As it turns out, an increase of 1 for the land-use mix index leads to a 4,07% increase in the percentage of people limited by health problems. An increase in the number of junctions per squared kilometre also leads to increases in the percentage of people limited by health problems. An increase of 1 junction per km^2, leads to an increase in limitation of roughly 0,96%. An increase of 1 in net residential density leads to a 0,015% decrease in the percentage of people limited by health problems in a neighbourhood. The effects of ln average income per capita, average age and average level of education on limitation because of health problems are similar to those of model 2. The R^2-value is higher than model 2, with 85,5% of the variance in the dependent variable explained by model 4.

Table 10: Multiple linear regression estimates

	Model 1	Model 2	Model 3	Model 4
Pre-WWI		-0,3061423 (1,031775)		
Interbellum		1,34715 (1.025616)		
Post-war reconstruction		1,940017* (1,06919)		
'Woonerf'/cauliflower		0,9435997 (1,149255)		
Vinex				
Free-standing / villa		0,7621827 (1,358512)		
Land-use mix index				4,075884** (1,700654)
Junctions per km²				0,9568646** (0,3838565)
Net residential density				-0,0150506*** (0,0037973)
Walkability index			0,3738149** (0,1446187)	
Green space ratio			0,0714369 ** (0,0292615)	
Average noise exposure			-0,0733647** (0,0295056)	
Ln average income	-8,833964*** (1,7228)	-7,070867** (2,689834)	-8,671899*** (2,250954)	-7,591655*** (1,868084)
Average age	0,8859339*** (0,0622611)	0,7964952*** (0,0881967)	0,8752046*** (0,0718653)	0,8108219*** (0,0686325)
Average level of education	-8,979372*** (1,666732)	-9,261552*** (2,56419)	-8,106462 *** (2,120777)	-9,410285*** (1,786642)
Observations	100	100	98	98
R^2	0,8205	0,8332	0,8530	0,8550

Coefficients and (robust) standard errors, $^{*}p < 0{,}10$, $^{**}p < 0{,}05$, $^{***}p < 0{,}01$.

5. Discussion

The theoretical framework has made clear that neighbourhood types are composites of three categories of health determinants: green spaces, complete & compact city and environmental hygiene. Through one of the four health mechanisms, the various neighbourhood types influence health in different ways. Multiple linear regression analysis provided information about the relationship between the neighbourhood type-variables and the percentage of people limited by health in neighbourhoods (model 2 in figure 11) as well as information about the three health determinants and three elements of the walkability index in relation to the percentage of people limited by health in neighbourhoods (model 3 & 4 in figure 11).

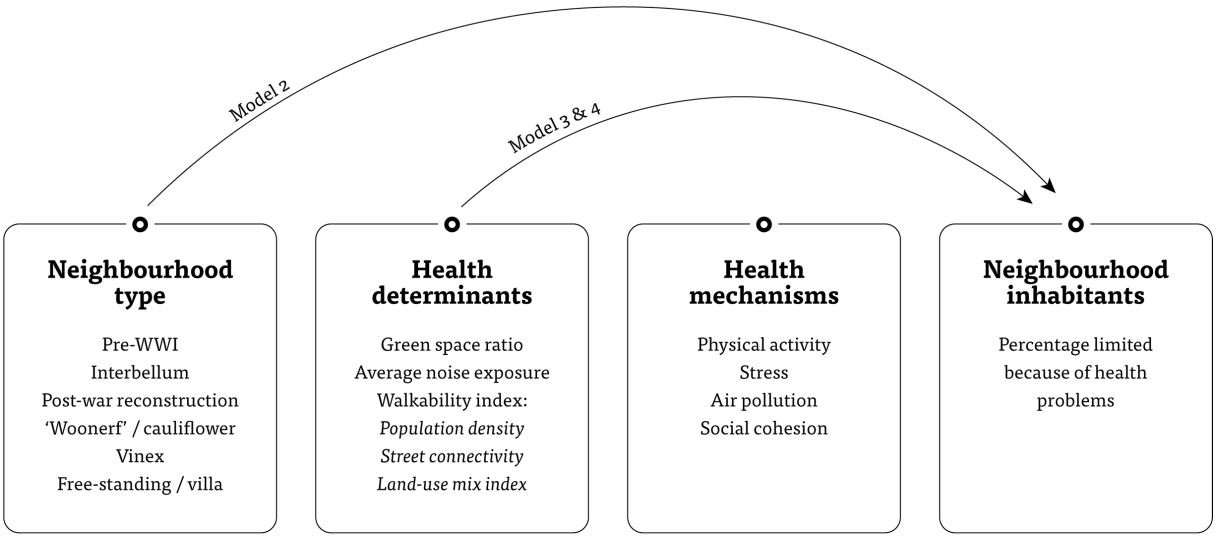

Figure 11: Graphical representation of examined relationships between variables.

The guide for the multiple linear regression analysis were the four hypotheses that were formulated alongside the conceptual model. As it turns out, three out of four hypotheses had statistically significant effect in the opposite direction of what was expected based on the literature review.

5.1. Greenery

The first hypothesis with an unexpected result was the second one. It is as follows:

Hypothesis 2:	Greenery positively influences local physical and mental health.

The literature review in chapter 2 already briefly pointed out that research into the health effects of greenery can be ambiguous. This thesis confirms that once more. Greenery is the only category of environmental determinants that influences health through all four of the identified mechanisms which makes it difficult to determine the exact effect of urban greenery. Besides that, there is also a wide-range of types of greenery that all have different health effects for different demographic groups. This variety of types can also be seen in the neighbourhood types. In the classifications of Kleerekoper et al. (2016) and Lörzing et al. (2008), the quantity of greenery in public spaces in neighbourhoods is mentioned. For example, post-war reconstruction neighbourhoods are classified as (very) green whereas pre-WWI neighbourhoods are not. In practice, the public greenery in a lot of post-war reconstruction neighbourhoods consist mostly of small lawns between buildings that are usually not used by nearby residents. In pre-WWI neighbourhoods, public greenery is usually scarce but an attractive park may be closer to home and invite people to take a stroll or do sports.

It has been well established that urban green spaces are beneficial for making cities more climate adaptive, which is essential for a sustainable living environment (Stuiver et al., n.d.). Other studies have confirmed that certain types of greenery can be protective factors for local physical and mental health (Coombes et al., 2010). It is however still unclear which specific (mix of) types of greenery have this protective effect and through which specific health mechanisms they influence health. Future studies should investigate the effects of all types of green, also including trees and privately owned streetscape greenery, and the distance to formal parks and the qualities of those parks. This will require a mixed method approach of both quantitative and qualitative research.

5.2. Environmental hygiene

In the category environmental hygiene only the effect of average noise exposure of road traffic has been studied. It was expected that more environmental hygiene (so less air pollution and noise nuisance) has a protective effect on local physical and mental health. The hypothesis was formulated as follows:

Hypothesis 3:	Environmental hygiene positively influences local physical and mental health.

The results of the multiple linear regression analysis indicated the opposite. Higher levels of average noise exposure from road traffic over a 24-hour period led to better health outcomes. It should however be noted that roughly 75% of all neighbourhoods had average exposure levels below 53 dB, the maximum level recommended by the WHO (2018) and that they therefore do not experience very harmful effects of noise nuisance. Another explanation could be that noise nuisance is often very local to its source. By taking the neighbourhood average, the negative health effect of living in a noisy street may have been cancelled out by the quiet streets in the same neighbourhood. Another explanation can be that more and more households have double or triple glazing or 'deaf' facades and therefore are less affected by outdoor traffic noise.

Noise nuisance mainly affects health through the mechanism of stress. In psychiatry, a new field of research is emerging called neurourbanism. Neurourbanism studies the effect of the built environment on mental health by investigating the stress mechanism (Adli et al., 2017). Because the urban environment is inherently complex, a multi- and interdisciplinary effort is required to come up with new spatial interventions that promote stress-free, and therefore healthier, urban living.

5.3. Complete & compact city

To study the effect of complete & compact city, the walkability index was used in statistical analysis. This index is built up from the 3 D's: diversity of land-use, design of connected streets and density of population. Based on academic literature, it was expected that a higher walkability index, and thus a more complete & compact city, would result in better health outcomes. The hypothesis is as follows:

Hypothesis 4: Complete & compact city positively influences local physical and mental health.

Multiple linear regression analysis indicated a statistically significant relationship between walkability and health in the opposite direction. For that reason, another model was run with the 3 Ds as separate variables. Based on the literature review of chapter 2, one would expect that a higher land-use mix index, a higher number of intersections per km^2 and a higher population density would separately all have a protective health effect.

The first variable, land-use mix index, is statistically significantly related to health outcomes but in the opposite direction than expected. A possible explanation could be that research on walkability and land-use mix is often done in the United States. The urban sprawl that is present in American cities cannot be found in Dutch cities. As was mentioned in chapter 2.4., the Dutch government held a firm grip on urban planning throughout the twentieth century. Active compact city policies were implemented from the 1960s onwards to avoid a cluttered countryside and urban sprawl. New housing developments were planned in suburbs close to city centres. Vinex-neighbourhoods are a good example of such active top-down policies (Van der Cammen & De Klerk, 2012). Compactness in combination with extensive biking infrastructure leads to high levels of active transportation, and thus physical activity, in the Netherlands (Pucher & Buehler, 2008). Many of the neighbourhoods in the dataset have a neighbourhood shopping centre and all other facilities within a maximum of 15 minutes by bike and through compact city policies, hyperstores on the edge of cities are uncommon in the Netherlands. Cervero et al. (2009) faced the same issue in their research on the influence of the built environment on walking and biking in Bogotá, Colombia. They found that land-use mix in itself was not a contributor to physical activity because many areas of Bogotá are compactly built and have similar levels of land-use mix and access to public transport. Conversely, they found that road facility designs did have a significant impact on choosing an active mode of travel (Cervero et al., 2009). Similar to greenery, it seems that quality of urban design plays an important role when it comes to influencing health. Based on the literature that suggests land-use mix is a protective factor and the findings of this study, it is likely that land-use mix is an influencing factor but only to a certain extent or only in certain contexts. It would be interesting to find out what this extent or context is in future studies, especially now that more and more cities around the world are implementing 15-minute-city policies.

Closely related to land-use mix is the number of intersections per km^2. More intersections mean a denser street network and thus shorter distances to walk or bike. Here the national context could again be of play. Many American suburbs are built with a cul-de-sac structure. This makes distances to shops or schools often unnecessarily long and therefore not walkable. In the Dutch context, very low intersection densities are uncommon in cities. In the dataset used for this study, there was quite a broad range of densities among neighbourhoods. The lowest scoring neighbourhoods are, however, former villages that have been annexed by the cities. Examples are Klein Harkstede or Noorddijk in Groningen. Another explanation could be the Dutch cycling culture. Many foreign studies solely focus on walkability. Compared to walking, biking requires a less intricate street network. In future studies, the bikeability of various Dutch neighbourhoods could be further explored. Similar to the study in Bogotá, it would be interesting to see which (design) elements lead to better walk- and bikeability and therefore better health outcomes.

The third variable was population density. The outcome of the multiple linear regression analysis is that higher population densities are related to less limitation because of health problems. Based on the literature review, this outcome was expected. Melis et al. (2015) came to a similar conclusion when comparing neighbourhoods in Turin, Italy. For many people, high-density cities are however a spectre. This is not fully unjust. Referring back to the research on neurourbanism mentioned in chapter 5.2., extremely high densities could lead to increased stress and therefore become a risk factor for health (Adli et al., 2017). In the Dutch context, this is however not (yet) the case. Explanations for the protective effect of higher densities are that destinations are closer to home. Higher population densities are usually accompanied by a more complete supply of facilities and better public transport connections. Instead of linking this effect to the mechanism of physical activity, as is usually done in studies, Melis et al. (2015) attributed the protective effect of population density to access to friends, family and society. Especially in the face of the rapidly ageing population, the protective effect of higher population densities could prove extra important. The results of this study suggest that the effect of population density reaches further than physical activity alone since it is the only variable underlaying the walkability index that is a protective factor for health.

5.4. Neighbourhood types

Given all the knowledge provided by the analysis of the health determinants, the final hypothesis can be discussed. As was mentioned earlier, very little research done on the relationship between neighbourhood types and health. The RIVM bases their healthy neighbourhood policies on the opinion of 250 professionals in the fields of public health, urban planning and environmental sciences. Their conclusion was a Vinex-type neighbourhood. The following hypothesis was formulated following from this:

Hypothesis 1:	There is a relationship between neighbourhood types and local physical and mental health.

From the results of the multiple linear regression analysis, it can be concluded that there is a relationship between neighbourhood types and health but that for most types it is not a statistically significant relationship. When looking at the information gathered in models 3 and 4 (see figure 11), the pre-WWI neighbourhoods should be the healthiest. These neighbourhoods have relatively high population densities, especially the city centres, they do not have a lot of greenery and are not very silent. They do, however, often have a high land-use mix index and intersection density as well which does not improve health outcomes. The multiple linear regression analysis confirmed this image, albeit that the result is not statistically significant. Only the post-war reconstruction neighbourhoods had a significant outcome. Compared to Vinex neighbourhoods and controlled for sociodemographic characteristics, post-war reconstruction neighbourhoods have worse health outcomes. In the basis, many of these neighbourhoods are relatively similar. They are often residential neighbourhoods with a neighbourhood shopping centre. Differences lie in the architecture of the houses and in the public spaces around the houses. As mentioned earlier, Vinex was built in an era of consumerism. This demanded relatively unique (but not too unique) architecture and streets in varying geometric patterns. The rationale was that the housing consumer wants to stand out, but also wants something recognisable. Vinex-neighbourhoods often have housing in strips, or less commonly in closed blocks. The neighbourhoods have a varied range of types of public spaces. Neighbourhoods usually have many large courtyards and playgrounds for children and streets are often lined with trees or small lawns. Post-war reconstruction neighbourhoods come in different sub-types but are in all cases characterised by monotone mass-produced housing. Housing is usually in strips with repeating street patterns throughout the neighbourhood. Green spaces are usually in the form of large lawns between portico flats. Some neighbourhoods feature tree-lined streets. Since many post-war reconstruction- and Vinex neighbourhoods have similar levels of land-use mix (between 0 and 0,7), it is unlikely that this is a major influence. Street connectivity, density and noise vary more among all neighbourhoods but not in favour of one type. Some post-war reconstruction neighbourhoods are denser populated and/or have a more intricate street network than other neighbourhoods of the same type. It is possible that greenery has an effect through various types. More likely is however, that the indoor climate of Vinex-houses is better than that of post-war reconstruction houses. During the reconstruction period, the quantity of housing was more important than the quality of housing. This quickly led to depreciation of the neighbourhoods and may still affect neighbourhood health. Vinex houses are relatively new and are generally isolated and ventilated well. The quality of housing stock was not a variable in this study, which in hindsight is a limitation.

6. Conclusion

In this study the influence of neighbourhood typology on local physical and mental health stood central. Looking back at the main research question, the following conclusion can be drawn: neighbourhood typology has a minor influence on local physical and mental health.

To be able to draw this conclusion, first academic literature has been studied on how health can be defined and measured. It has become clear that health is not an unambiguous concept. When regarding it from a holistic human ecology perspective, a wide range of positive, protective and risk factors are at play. Cities are inherently complex constructs and different elements of the city jointly affect health through multiple determinants and mechanisms.

Based on academic literature, three categories of health determinants and four health mechanisms were identified and analysed. This study focussed only on the health determinants and their various compositions within different neighbourhood types. Unfortunately, it was not possible to investigate the mechanisms as well. Especially about the effects on health through the mechanisms of stress and social cohesion much is still unknown. Compared to physical activity and air pollution, these mechanisms are more abstract and not easy to measure in a large population. It would however be beneficial for the knowledge on healthy cities to further investigate the causal workings of the various health determinants. The statistical analysis had some surprising results. General points to take away are:

- The effect of greenery is very dependent on the type of greenery and the demographic group it affects.
- On a neighbourhood level, noise exposure from road traffic does not necessarily lead to adverse health effect.
- It depends on the extent and context if increases in land-use mix and street connectivity are beneficial for local health outcomes.
- Increased population density is beneficial for health, likely through mechanisms that are unrelated to physical activity.

The Netherlands has a long tradition of compact city policies. These have made sure that many people live in a so-called 15-minute city where they can reach important amenities within 15 minutes by bike. It is recommended that planners continue these policies and also densify existing neighbourhoods. The average household size continues to diminish, partly because of population ageing. This could lead to decreases in population density which in turn could have a negative effect on neighbourhood physical and mental health.

Neighbourhood type is not very relevant when it comes to planning healthy neighbourhoods. The only statistically significant outcome of the analysis shows some benefits of Vinex-neighbourhoods but it can be reasoned that this is caused by variables that were not included in the analysis. This study has provided some more evidence on factors in the built environment that influence health but also leaves many recommendations for future research. Combined quantitative and qualitative research will hopefully provide a better picture in the future on the workings of health determinants. As for now, a neighbourhood type that significantly promotes local physical and mental health has still to be planned.

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Appendices

Appendix I: do-file Stata

```
clear all
cd "~/Documents/Scriptie EIP/3. Methodology & data/Data/Stata/
use HealthyNeighbourhoods.dta
drop AB AD AF Hoog Laag Lden_0050 Lden_50_55 Lden_55_60 Lden_60_00 Middelbaar a_00_14
a_15_24 a_25_44 a_45_64 a_65_00 a_man a_vrouw sum_edu total_edu
egen float z_LUM = std(LUM), mean(0) sd(1)
egen float z_junc_sq_km = std(junc_sq_km), mean(0) sd(1)
egen float z_net_res_den = std(net_res_den), mean(0) sd(1)
generate walk_index = z_LUM + z_junc_sq_km + z_net_res_den
drop if Type == .
summarize

label variable av_age "Average age"
label variable av_noise "Average noise exposure"
label variable av_edu "Average level of education"
label variable av_income "Average income per capita"
label variable av_bjaar "Average year of construction"
label variable junc_sq_km "Junctions per km2"
label variable net_res_den "Net residential density"
label variable p_green "Green space ratio"
label variable p_limited "Limited by health problem"
label variable LUM "Land-use mix index"
label variable walk_index "Walkability index"
label variable Type "Neighbourhood type"
label variable Bu_code "Neighbourhood code"
label variable a_inwoners "Number of inhabitants"
label variable gm_naam "Municipality"
label variable p_sev_limited "Severely limited by health problem"

histogram Type, normal
summarize Type, detail
```

```
generate Type_t = Type
recode Type_t (7=6) (8=7) (9=8)
histogram Type_t, normal
summarize Type_t, detail
generate ln_income = ln(av_income)
summarize ln_income, detail
histogram ln_income,normal
label variable Type_t "Neighbourhood type, transformed"
label variable ln_income "Natural log of average income per capita"

*model 1
reg p_limited ln_income av_age av_edu
regcheck
reg p_limited ln_income av_age av_edu, robust

*model2
reg p_limited i.Type_t ln_income av_age av_edu
regcheck
estat vif

generate Type_cat = Type
recode Type_cat (0=1) (1=1) (2=2) (3=2) (4=3) (5=3) (6=3) (7=4) (8=5) (9=6)
reg p_limited i.Type_cat ln_income av_age av_edu
regcheck
estat vif
reg p_limited ib(5).Type_cat ln_income av_age av_edu, robust

*model3
reg p_limited ln_income av_age av_edu p_green walk_index av_noise
regcheck

*model4
reg p_limited ln_income av_age av_edu LUM junc_sq_km net_res_den
regcheck
reg p_limited ln_income av_age av_edu LUM junc_sq_km net_res_den, robust
```