THE INFLUENCE OF BUILT ENVIRONMENT ON MENTAL HEALTH ON A NEIGHBOURHOOD LEVEL

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Colophon

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Abstract

The influence of the built environment (BE) on the physical and mental health of residents has been the subject of extensive research in the context of an ever-increasing share of people living in urban environments. The study of the influence of the BE on the mental health in Dutch cities has come short; this study addresses that. The study utilised openly available secondary data on the mental health issues of residents and key figures of neighbourhoods. The correlations between residents that experience severe loneliness or that are at a high risk of anxiety/depression and the built environment are explored using simple linear regression. It was found that the BE correlates with the mental health issues of residents. While the share of green space has a negative correlation, population density, network integration and space syntax walkability have a positive correlation. Policy advisors and spatial planners should be aware of the influence of the built environment on the mental health on residents, especially the positive impact the share of green space has showed to have on mental health and consider this in the design and implementation of future development schemes. The study can be extended by considering different urban contexts within the Netherlands or Europe, or at a different spatial scale. Additionally, the demographic composition of the neighbourhoods could be considered in addition to the physical features of the built environment.

Keywords: built environment, green space, population density, network integration, space syntax walkability, mental health, risk of anxiety/depression, severe loneliness

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Introduction

Background

The Netherlands is known to have one of the highest shares of urban population in Europe. In 2020, more than 92% of the population lived in an urban environment. Additionally, the Netherlands have the highest population density out of all European countries of a population exceeding 500.000 (UN Population Division, 2020). Subsequently, the Dutch are disproportionately affected by experience a multitude of urban agglomeration issues (Beenackers et al, 2018). A result of the high levels of urban population and population density, cities and neighbourhoods have integrated various land-uses. This implementation of mixed-use neighbourhoods enabled the high density of people in relatively small urban areas. Combining many functions in smaller areas results in residents spending more time in their neighbourhoods, which increases the significance of the neighbourhood-level built environment (BE) that people live in. Accordingly, the BE can significantly contribute to mitigating and attempting to solve these issues. However, developers and urban planners are rarely considering intentional design of the built environment to improve mental health (Hoisington et al., 2019). Despite that, the potential upsides of utilising the abundance of research and proposed neighbourhood designs are evident. The general acceptance of the literature, stating that the design of the built environment has the power to actively support mental health and mitigate mental health burdens, can cause a shift to more mental health supportive proposals from urban designers and urban planners. Specifically, the consideration of mental health impacts in the design and implementation of urban renewal efforts and new neighbourhood projects will ensure the built environment contributes to the residents' mental health and rather than causing a burden on mental health. Therefore, the conclusions drawn from this study will be able to contribute to a better understanding of how urban environments can be designed and optimized to support residents' mental well-being. Thus, leading to the development of evidence-based strategies for creating healthier and more sustainable communities.

Simultaneously, the housing shortage is a growing concern within the Netherlands and the province and municipality of Groningen (The Northern Times, 2022). The housing crisis is characterised by the extremely low supply of affordable housing that has resulted in long waiting lists and overall uncertainty about the living situation for hundreds of thousands of people. This uncertainty can have profound impacts on the mental health and the future of many people. In response to this, there have been extensive efforts in the Netherlands to increase the available housing stock and create more residential areas for the population (Séveno, 2023).

Alongside these efforts, an increasing amount of academic literature is studying the influence of the built environment on wellbeing and the physical and mental health of residents. The research considers the BE at many different geographic scales, like neighbourhood, city, or regional level. Both the characteristics of the built environment and the indicators of physical and mental health vary throughout the literature. So, the influence of the BE on health has been extensively examined, also in the Netherlands, specifically Dutch neighbourhoods (Kramer et al. 2013 and Kramer et al. 2014). However, the research primarily focussed on the physical aspects of health. Therefore, this study aims at filling a research gap in exploring the influence of the neighbourhood-level built environment on mental health. Studying the relationship between the spatial composition of the neighbourhood and mental health outcomes is crucial in promoting and implementing healthier communities.

Research Problem

This study aims to find correlations between the neighbourhood-level built environment and mental health indicators in the municipality of Groningen. The influence of the share of green space, population density, mean network integration and space syntax walkability on the share of residents experiencing severe loneliness or being at a high risk of anxiety/depression will be explored. Subsequently, the following main research question and secondary questions were developed.

Research Question:

What is the relationship between the neighbourhood-level built environment and mental health indicators?

Secondary Questions:

To what extent do indicators of the built environment influence the share of inhabitants that experience loneliness?

To what extent do indicators of the built environment influence the share of inhabitants that experience anxiety/depression among the population of neighbourhoods?

Theoretical Framework

The theoretical framework will discuss the overall context of the research and explore the relationship between indicators of mental health and the indicators of the physical built environment. Finally, the indicators of BE will be explained and justified in terms of existing literature.

The effect of the built environment on health has been studied extensively (Bower et al., 2023; Domènech-Abella et al., 2020; Kramer et al., 2013; Yin et al., 2020). Researchers have explored relationships between many indicators of the built environment and mental and physical health (Yin et al., 2020; Domènech-Abella et al., 2020; Chen et al., 2015). However, there is a general consensus that the built environment is defined by a collection of physical features, such as population density (Renalds et al., 2010), green spaces (Gasco et al., 2015), land use-mix and accessibility to amenities (Yin et al. 2020). In this study, the built environment will be defined as “the human-made space in which people live, work, and re-create on a day-to-day basis” (Roof and Oleru, 2008). Their definition is commonly used in research into the effects of the built environment on mental health (Bower et al., 2023; Domènech-Abella et al., 2020).

The design of the BE can promote behaviour beneficial to physical health, while also being detrimental to health and increasing exposure to harmful environments (Frank et al., 2019). Yin et al. (2020) studied the effect on BMI (body mass index) in that regard. Equally, the BE also affects the mental health and an increased walkability in neighbourhoods has shown to relate with lower levels of depression (Renalds et al., 2010). Despite extensive research efforts, the influence of the built environment on mental health is not fully understood (Barnett et al., 2018; Hoisington et al., 2019; Mair et al., 2008).

Mental Health indicators

The risk of anxiety/depression

Within the scientific community there is disagreement about the influence the built environment has on depression or depressive symptoms in residents (Domènech-Abella et al., 2020). Barnett et al. (2018) suggested that, instead of physical features of the built environment, socioeconomic play a more significant role in the determination and causation of mental health indicators, specifically depression.

Contrastingly, the physical built environment has shown some significance in the effect on depression in other studies (Shahedi et al., 2020; Mair et al., 2008). Although critical and reserved about the causal influence of physical features of the built environment, Mair et al. (2008) found multiple studies to confirm a relationship between the BE and depression. Nevertheless, scholars find agreement on the lack of studies on the effect of built environment on depression (Mair et al., 2008; Barnett et al., 2018).

The perception of severe loneliness

Bower et al. (2023) raises an interesting point that one's perception of the built environment, instead of the BE itself, influences the mental health of residents in neighbourhoods. Furthermore, considering single physical features of the built environment are unlikely to lead to significant and relevant correlations with loneliness. Rather the built environment as a whole, incorporating multiple physical and societal features, can be linked to loneliness among residents (Bower et al., 2023). The walkability of a neighbourhood was identified as a factor influencing the loneliness of residents in a neighbourhood (Domènech-Abella et al., 2020). However, it is to be noted that only low walkability scores were found to correlate with loneliness. The relationship between loneliness and the walkability of the built environment in general is still largely unknown.

Physical features of the built environment

Green Space

Green space has been identified as a factor of the built environment in studies researching a correlation to health (Gascon et al., 2015; Renalds et al., 2010). Further, the importance of green space on the mental health of the residents of a neighbourhood has been established by scholars (Gascon et al., 2015; Bowler et al., 2010). Some studies have found that the presence of green space in the neighbourhood may have a positive effect on mental health and consequently leads to a decrease in the share of people experiencing depression or depressive symptomatology (Bowler et al., 2010). The systematic review of studies researching the benefits of exposure to natural environments however found limited evidence for a causal link between surrounding green spaces and benefits to mental health, while inadequate evidence was found for children (Gascon et al., 2015).

Population Density

Population density has been studied in research exploring the relationships between the built environment and health for decades (Renalds et al., 2010; Chen et al., 2015; Yin et al., 2020). Yin et al. (2020) explored the relationship between, among others, population density, accessibility to amenities and land-use mix with the life satisfaction, commuting patterns, and body mass index of residents in Chinese neighbourhoods. Moreover, the relationship between population density and overall health (including physical and mental health) has been studied (Renalds et al., 2010; Chen et al., 2015). Chen et al. (2015) found significant links between densely populated cities in China and residents with depressive symptoms.

Space Syntax Walkability and Mean Integration

In extensive research efforts to find a relationship between the built environment and health aspects, many different approaches have been taking to characterize features of the built environment. The walkability of a neighbourhood is a part of that, since it has shown to be beneficial to one's mental health and help decrease emotional distress (Domènech-Abella et al., 2020; Mau et al., 2021). Moreover, the effects of the walkability of neighbourhoods on physical health have been studied. Nordbø and Juul. (2023) utilise a walkability score outlined by Frank et al. (2001) to study levels of walkability in relation to physical activity.

Frank et al. (2001) rely on four data points to calculate the walkability index score, residential density, intersection density, retail floor area ratio and land-use mix. The challenge to apprehend the required data on a wider scale, inspired Koohsari et al. (2016) to develop an alternative walkability score, called space syntax walkability. The space syntax walkability score (SSW) integrates standardised population density and the standardised mean network integration to compute walkability. Network integration incorporates the ease of movement throughout the neighbourhood with the composition of the physical structures of the built environment (Ramezani et al., 2017). Specifically, the integration score measures how accessible any road segment is, in terms of the surrounding roads. The extend of the surrounding roads to be considered can be limited to 3 or 5 road segments or in terms of the entire network (Wineman et al., 2014).

SSW has been developed and applied in the urban planning and architecture field to interpret the interaction between the built environment and residents' movements (Koohsari et al., 2016; Ramezani et al., 2017), which impacts mental and physical health (Renalds et al., 2010; Domènech-Abella et al., 2020).

Conceptual Model

The conceptual model depicts the relationships between the independent and dependent variables, being the physical characteristics of the built environment and the indicators of mental health respectively. As outlined above, the share of green space, mean network integration and population density, and the two concepts combined as the space syntax walkability score are studied as independent variables and physical characteristics of the built environment. The perception of loneliness and the risk of anxiety/depression are, as discussed above, indicators of mental health and are the dependent variable in this study.

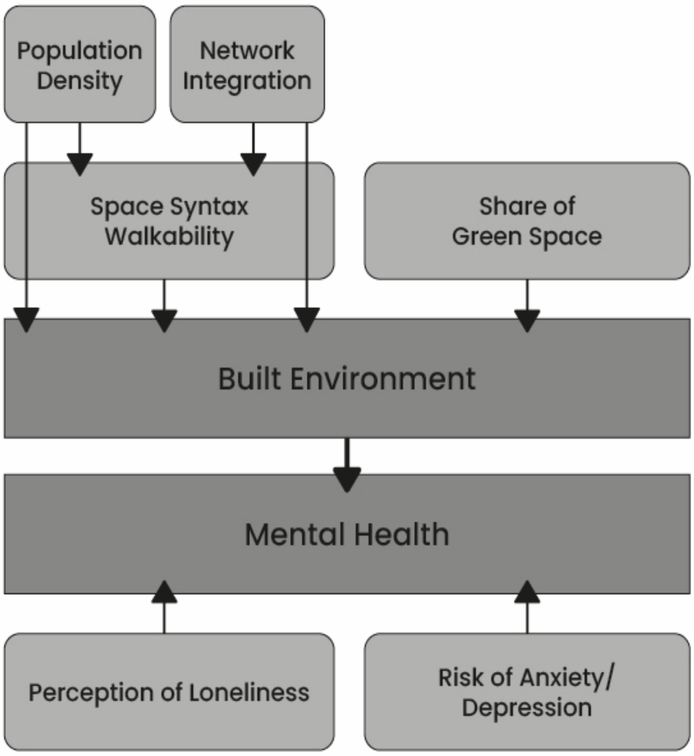

Figure 1 - Conceptual model outlining the relationship between the built environment and mental health

Hypotheses

Based on the literature discussed in the theoretical framework and the conceptual model, the following hypotheses have been formulated.

1. The share of green space will have a mitigating effect on the mental health issues of residents.
2. Population density has a significant effect in the mental wellbeing levels of the population of neighbourhoods.
3. The network integration of a neighbourhood will positively affect the mental health among inhabitants.
4. There is a positive correlation between the space syntax walkability score and the mental wellbeing of residents.

Methodology

The study focusses on quantitative data, specifically secondary quantitative data, to research links between the built environment and mental health. Quantifying the physical features of the built environment ensures a more standardized comparison of neighbourhoods since population density or the share of green space for example are easily comparable. Contrastingly, the qualitative data would provide insight into the perception of the built environment rather than the built environment itself. Arguably, the perception of the built environment plays a vital role in the effect it has on the mental health of residents, however this study concerns itself with the spatial distribution of residents with two different mental health issues. A significant number of studies explored in the literature review used primary data in their research, however the abundance of accurate data available led to the decision to use secondary data. Furthermore, secondary data allowed for the study of a greater sample size since the primary data collection of 100 neighbourhoods would have not been possible with the available resources and time.

Study Area

The municipality of Groningen is located in the north of the Netherlands (Figure 2) and has a population of around 235.000 people (CBS, 2022). Groningen was chosen as the study area since it makes for a unique case to study the relationship between the built environment and mental health indicators. With a third of the population being younger than 25, Groningen is known to be a student city (CBS, 2022). Furthermore, 15,7% of the population are students at a higher education facility, which is the second highest percentage in the Netherlands (Basismonitor Groningen, 2022). Therefore, the large student population should be taken into consideration when reflecting on the trends in mental health indicators. It is important to note that the built environment is only one of many factors that influence mental health issues of residents.

Figure 2 – Map of the Netherlands with the location of Groningen

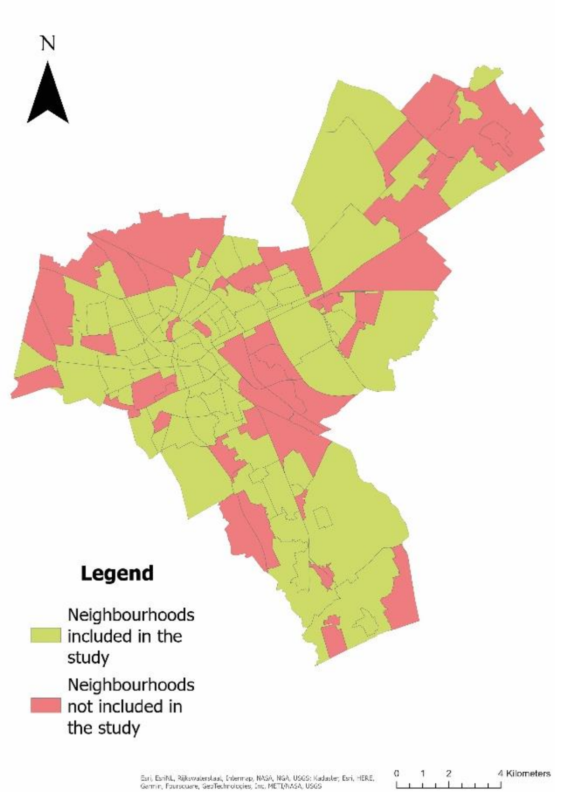

Figure 3 - Map of the municipality of Groningen and the neighbourhoods that are and are not included in the study

Within the municipality of Groningen, some neighbourhoods were not selected as a part of the research. The specific selection process is explained further onwards in the data collection. Figure 3 shows the spatial distribution of the neighbourhoods that were and were not included in the study.

Data Sets

The secondary data was extracted from two datasets, provided by CBS (the Dutch central bureau of statistics) and RIVM (the Dutch ministry for Public Health and the Environment). The sources of each variable can be seen in table 1 below.

Table 1 - shows the sources of the secondary data used

VARIABLE	DATASET
Severe Loneliness	RIVM health monitor
High Risk of Anxiety/Depression	RIVM health monitor
Share of Green Space	Basisregistratie Topografie
Population Density	CBS
Mean Network Integration	OpenStreetMap (Geofabrik)
Space Syntax Walkability	OpenStreetMap (Geofabrik)

The data on the mental health, specifically the risk of anxiety and depression and the loneliness of residents was based on data from the Dutch Health Monitor from 2020. Comparable data from the same survey is available for the years 2016 and 2012. The results from 2020 were based on approximately 539,000 people, with the province, municipality, and neighbourhood of each provided. Based on that, CBS and RIVM have published the mean values for each province, municipality, and neighbourhood.

Similar to the dataset above, CBS also has data on the physical characteristics of each province, municipality, and neighbourhood in the Netherlands. The Key figures of Neighbourhoods dataset from 2020 include, among others, the average income, age, marital status, density, population, and distance to amenities like large supermarkets or primary schools is available for each neighbourhood in the Netherlands. Extracted was the population density of the studied neighbourhoods.

To calculate the space syntax walkability scores for each neighbourhood, data from the municipality of Groningen and OpenStreetMap (prepared by Geofabrik) were utilised. They provided geodata and network data essential for the calculation. The geodata on the green spaces in the municipality were made available by the Registry of Topography in the Netherlands and found on PDOK, the official governmental website for open geodata.

Data Collection

In the dataset of the RIVM, many indicators of mental and physical health were available. Following the preliminary research and the development of the research aim, the available data on the share of residents of each neighbourhood that experience severe loneliness and that are at a high risk of anxiety/depression were extracted.

As previously discussed, the population, population density, and demographic distribution were apprehended for all neighbourhoods in the municipality of Groningen. To ease the preparation and analysis of the data, the CBS assigned neighbourhood codes and the neighbourhood names were included too. To ensure a high degree of accuracy in the data, an exclusion factor for all neighbourhoods was established. This was done to prevent individuals or households in manipulating the share of residents that experience the mental health implications in neighbourhoods with low population levels (less than 100 people). As a result of that selection procedure, 100 out of 150 neighbourhoods were selected as cases for the research (Figure 3). Even though that decreased the size of the sample by a third, 100 cases still provide a sufficient basis to perform the research and a large sample to perform statistical analysis on.

The data on the green spaces included numerous classifications for different kinds of green spaces like grasslands, forests, parks, etc. Contrary to some research, agricultural fields and other non-recreational green space was included in the study, since they influence mental and physical health, regardless of them being recreational or non-recreational.

Variables

The dependent variable for the research were two factors of mental health, the percentage of people at a high risk of anxiety and depression and the percentage of people who are severely or very severely lonely. Previously discussed literature has studied the relationship between the built environment and mental health using anxiety/depression and loneliness as indicators of mental health. (Chen et al., 2015; Domènech-Abella et al., 2020). Both factors were calculated based on the respondents answer to multiple questions and statements, followed by computing a score based on their answers. For the quantification of the risk of anxiety and depression among any respondent, the national survey followed the Kessler-10 questionnaire structure (appendix 1). There are 5 possible answers to 10 questions regarding anxiety and depression, with each answer quantifying the frequency a certain feeling is felt and a score allocated to each answer. An example for one of these questions is: “How often have you felt so down that nothing helped to cheer you up?”. The response to all 10 questions were summed to a score and ranked using a set scale (see appendix). To assess if residents feel lonely, a Dutch scale composed of 11 statements is used. The scale developed by Gierveld-de Jong & van Tilburg (2007) asks respondents to agree, stay neutral or disagree to statements like “I miss a close friend” (appendix 2). Similarly, to the Kessler-10 questionnaire, the responses are quantified and then computed to a score (Gierveld-de Jong & van Tilburg., 2007).

The independent variables were space syntax walkability, the population density, and the share of green spaces on a neighbourhood-level.

The space syntax walkability of the neighbourhoods in Groningen was computed and one of the four indicators of the neighbourhood-level built environment. A part of the calculation of SSW is the mean integration score of a neighbourhood. The spatial network analysis was carried out in Depthmap10 (depthmapX development team, 2017; Koohsari et al., 2016) and used an integration radius of 3. The mean integration score for all road segments in a neighbourhood and the gross population density were used to calculate the walkability score using the following formula:

$$Space\ Syntax\ Walkability = z[z\ gross\ population\ density) + 2 \times z\ (integration)]$$

The share of green areas in each neighbourhood, gathered using geographic information systems data was used as a characteristic of the built environment. Data from the municipality of Groningen provided the exact area of each neighbourhood in Groningen, which was used to calculate the share of green spaces for each neighbourhood. The total area of all green spaces for each neighbourhood, was calculated using data from PDOK and the Dutch national registry for topography containing all green areas in the Netherlands. Both the neighbourhood area and the green space data were imported into ArcGIS, a geographic information systems software. The first step was to select only the green space that is present within the municipality and remove all the green space outside the municipality. In the next step, the green space was overlayed with the neighbourhoods and then divided into each neighbourhood the green space is located in. In the last step, the sum of all green spaces in every neighbourhood was divided by the total size of the neighbourhood. The result of that was the share of green spaces in every neighbourhood.

Lastly, population density was used as a characteristic of the neighbourhood-level built environment. The data will be apprehended from the CBS dataset.

The statistical analysis of the variables was performed in SPSS. Since there was a high number of cases and the data can be categorised as interval data, the relationship between the independent variables and the dependent variables were tested using simple linear regression. The relationships that the research aimed to recover were linear, therefore simple linear regression was the most appropriate. Specifically, the Pearson regression coefficient and the r-squared value will be discussed in the discussion of the results.

Results and Discussion

The Built Environment and Loneliness

In this section the answer to the following research question will be discussed: *To what extent do indicators of the built environment influence the share of inhabitants that experience loneliness?*

As previously discussed, the relationship between the three indicators of neighbourhood-level built environment and the share of population that experience severe loneliness will be explored. Simple linear regression was used to test for the presence and significance of the correlation between the independent and dependent variables. In the following the standardised correlation coefficient or *beta*, the significance level and r-squared value will be analysed for each regression test. It is important to note that a correlation doesn't always mean causation.

Share of Green Space and Severe Loneliness

The null hypothesis for the test is: *In the population there is no linear relationship between the share of residents that are lonely and the share of green space.*

Table 2 - the regression coefficients for green space and loneliness

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	11,870	,479		24,790	<,001
	Share_of_Green_Space	-,035	,009	-,359	-3,803	<,001

a. Dependent Variable: Severely_Lonely

The first thing to point out is that the test is significant with a sig. value of less than p=0,05 (p<0,001), so the null hypothesis is rejected. The standardised correlation coefficient (beta) determines the direction and strength of the relationship. In this case, the negative value indicates a negative relationship. Aside from the direction, the b-value of -0,359 provides insight into the strength of the correlation, namely a weak relationship. Subsequently, an increasing share of green space in a neighbourhood in Groningen is weakly linked to fewer people feeling severely lonely in a neighbourhood. However, the relationship doesn't need to be causal. This was also presented in the research by Gascon et al. (2015). Gascon et al. (2015) found insufficient evidence for this correlation in children, which might explain the weak relationship found, considering all age groups were present in the data.

Table 3 - the R-values for the simple linear regression of green space and loneliness

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	F Change	df1	df2	Sig. F Change
1	,359[a]	,129	,120	3,8322	,129	14,462	1	98	<,001

a. Predictors: (Constant), Share_of_Green_Space

The r-squared value (or r^2) highlights the explanatory power of green space in explaining loneliness. With 12,9% it seems surprisingly low, bearing the literature that supports the correlation in mind.

Population Density and Severe Loneliness

Null hypothesis: *In the population, there is no linear relationship between the share of residents that are lonely and population density.*

Table 4 - the regression coefficients of population density and loneliness

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	8,678	,554		15,675	<,001
	Population_Density	,000	,000	,455	5,053	<,001

a. Dependent Variable: Severely_Lonely

This simple linear regression is statistically significant with a p-value of less than 0,05 (p<0,001), which rejects the null hypothesis. The strength of the correlation can be characterised as moderate and positive since beta is greater than 0. Based on this, it can be concluded that an increasing population density in neighbourhoods in Groningen correlates with an increase in the share of the population that feels severely lonely. This might be surprising since a greater density of people living in a neighbourhood could provide more opportunities for social interaction and communication decreasing the feeling of loneliness among residents. However, research from Chen et al. (2015) showed that population density has negative effects on the mental health of residents. Additionally, the demography of neighbourhoods in Groningen may explain the correlation. Since Groningen is a student city, many people experiencing severe loneliness might miss a close friend or guardian after having moved out of their home and starting their studies.

Table 5 - the R-values of the simple linear regression of population density and loneliness

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	,455[a]	,207	,199	3,6565	,207	25,536	1	98	<,001

a. Predictors: (Constant), Population_Density

The R-squared value suggests that population density contributes 20,7% percent to the explanation of the dependent variable. Subsequently, the population density, among other factors, can inform on the levels of severe loneliness in a neighbourhood.

Mean Network Integration and Severe Loneliness

The null hypothesis for the simple linear regression test between the share of people feeling severely lonely and the mean network integration is: *In the population there is no linear relationship between the share of residents that are lonely and the network integration score.*

Table 6 - the regression coefficients for mean network integration and loneliness

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-4,875	3,460		-1,409	,162
	Mean_Network_Integration	12,205	2,683	,418	4,550	<,001

a. Dependent Variable: Severely_Lonely

Similarly, also the simple linear regression is statistically significant with the p-value being less than 0,001 (p<0,05). Therefore, the null hypothesis can be rejected. The correlation coefficient (0,418) suggests that there is a positive moderate relationship between the mean network integration and the share of residents that feel severely lonely. Contrary to results found by Domènech-Abella et al. (2020), an increase in the mean network integration of a neighbourhood correlates with a greater the share of inhabitants that experience severe loneliness. Subsequently, a more accessible network seems to correlate with a more wide-spread feeling of loneliness in the population. The reasons for this might be independent of the network integration, since Mau et al, (2021) discussed the beneficial aspects of residents' ability to go for long walks. Therefore, the cause of the relationship may lead back to the high population density or sociodemographic factors not regarded in the study.

Table 7 - the R-values of the simple linear regression of mean network integration and loneliness

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	,418[a]	,174	,166	3,7302	,174	20,701	1	98	<,001

a. Predictors: (Constant), Mean_Network_Integration

The r^2 value for this test is 17,4%, contributing to the suspicions about the correlation found.

Space Syntax Walkability and Severe Loneliness

Null hypothesis: *In the population there is no linear relationship between the share of residents that are lonely and the space syntax walkability score.*

Table 8 - the regression coefficients of space syntax walkability and loneliness

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	10,778	,361		29,836	<,001
	Space_Syntax_Walkability	,711	,133	,475	5,345	<,001

a. Dependent Variable: Severely_Lonely

The test is statistically relevant with the p-value being lower than 0,05 (p<0,001). The null hypothesis can be rejected. The b-value of 0,475 shows a moderately strong and positive correlation. An increasing space syntax walkability score comes with an increasing share of residents that experience severe loneliness. Since the space syntax walkability score is calculated using standardised population density and standardised mean network integration, both of which had a moderately strong positive correlation, the moderately strong and positive correlation in this test is consistent. Nevertheless, the results differ patterns found by Domènech-Abella et al. (2020) and Mau et al. 2021. This may be due to the methodology associated with calculating the integration score, specifically setting the integration radius to 3. A larger radius, so the consideration of more surrounding roads in the network, may alter the integration scores and even lead to a negative correlation, as per Domènech-Abella et al. (2020).

Table 9 - the R-values of the simple linear regression of space syntax walkability and loneliness

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	,475[a]	,226	,218	3,6124	,226	28,567	1	98	<,001

a. Predictors: (Constant), Space Syntax Walkability

The explanatory power of the independent variable, as indicated by the R-squared value, is 22,6%.

The Built Environment and Anxiety/Depression

In this section the answer to the following research question will be discussed: *To what extent do indicators of the built environment influence the share of inhabitants that experience anxiety/depression among the population of neighbourhoods?*

As previously discussed, the relationship between the three indicators of neighbourhood-level built environment and the share of population that are at a high risk of anxiety/depression will be explored. The relationship will be tested using simple linear correlation and the beta value, significance level and r-squared value will be discussed.

Share of Green Space and Anxiety/Depression

Null hypothesis: *In the population there is no linear relationship between the share of residents that are at a risk of anxiety/depression and the share of green space.*

Table 10 - the regression coefficients for green space and anxiety/depression

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	6,442	,287		22,474	<,001
	Share_of_Green_Space	-,021	,005	-,367	-3,905	<,001

a. Dependent Variable: High_Risk_Anxiety_Depression

The relationship between the share of green space of a neighbourhood and the share of residents at a high risk of anxiety/depression was tested using simple linear regression. The p-value for the test was less than 0,05 rendering the test significant and rejecting the null hypothesis. Similarly, to the relationship between share of green space and loneliness, the correlation between the share of green space and high risk of anxiety/depression is also negative. The correlation coefficient of -0,367 indicates a weak correlation. Subsequently, an increase in the share of green space in a neighbourhood correlates with the decrease in the share of residents that are at a high risk of anxiety and depression. This is in accordance with the other test with green space above and the literature discussed in the literature review. Therefore, a high degree of accuracy and reliability can be associated with the correlation. The trends found in the study by Domènech-Abella et al., 2020 were confirmed by these results.

Table 11 - the R-values for the simple linear regression of green space and anxiety/depression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,367[a]	,135	,126	2,2943	,135	15,247	1	98	<,001

a. Predictors: (Constant), Share_of_Green_Space

The r^2 value speaks to the weak correlation since the independent variable only accounts for 13,5% of the relationship. This highlights the existence of other explanatory variables that contribute to the share of residents at a high risk of anxiety and depression (Barnett et al., 2018).

Population Density and Anxiety/Depression

Null hypothesis: *In the population, there is no linear relationship between the share of residents that are at a risk of anxiety/depression and population density.*

Table 12 - the regression coefficients of population density and anxiety/depression

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4,176	,306		13,666	<,001
	Population_Density	,000	,000	,575	6,954	<,001

a. Dependent Variable: High_Risk_Anxiety_Depression

The simple linear regression test for the relationship between population density and share of inhabitants at risk of anxiety/depression displayed a statistically significant result ($p<0,05$), which rejects the null hypothesis. At a beta value of 0,575 the correlation between the two variables is moderately strong, but the strongest correlation of all tests run in this research. Therefore, the share of residents at a high risk of anxiety/depression has a relationship with population density. Despite the study considering neighbourhoods as cases and Chen et al. (2015) using Chinese cities, the results are similar. Also, Renalds et al. (2010) has found evidence for the positive correlation between population density and depression. In combination with the other test using population density above, one can derive that population density contributes to an increasing share of population that are at a high risk of anxiety/depression and feel severely lonely.

Table 13 - the R-values of the simple linear regression of population density and anxiety/depression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,575[a]	,330	,324	2,0181	,330	48,358	1	98	<,001

a. Predictors: (Constant), Population_Density

The R-square value, 33%, is among the highest r-squared values of the tests run in the research.

Network Integration and Anxiety/Depression

Null hypothesis: *In the population there is no linear relationship between the share of residents that are at a risk of anxiety/depression and the network integration score.*

Table 14 - the regression coefficients of mean network integration and anxiety/depression

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3,766	2,073		-1,817	,072
	Mean_Network_Integration	7,436	1,607	,424	4,628	<,001

a. Dependent Variable: High_Risk_Anxiety_Depression

As all previous tests have, the simple linear regression is statistically significant, with the p-value being less than 0,05 ($p<0{,}001$). So, the null hypothesis can be rejected. The beta value (0,424) signifies a moderate and positive correlation that shows an increasing mean network integration contributes to a greater share of people that are at a high risk of anxiety/depression. This trend was not supported by literature discussed (Domènech-Abella et al., 2020; Mau et al., 2021) and is somewhat surprising, despite already being discussed in the relationship between loneliness and network integration. Overall, it seems like a higher network integration, although desirable, has a positive correlation with the share of residents that experience explored mental health implications.

Table 15 - the R-values of the simple linear regression of mean network integration and anxiety/depression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,424[a]	,179	,171	2,2342	,179	21,420	1	98	<,001

a. Predictors: (Constant), Mean_Network_Integration

The contribution of the mean network integration can be quantified using r^2, which is 17,9%. The low contribution is in accordance with the surprising trend found may point to errors in the methodology.

Space Syntax Walkability and Anxiety/Depression

Nully hypothesis: *In the population there is no linear relationship between the share of residents that are at a risk of anxiety/depression and the space syntax walkability score.*

Table 16 - the regression coefficients of space syntax walkability and anxiety/depression

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	5,771	,210		27,467	<,001
	Space_Syntax_Walkability	,471	,077	,524	6,086	<,001

a. Dependent Variable: High_Risk_Anxiety_Depression

The simple linear regression testing the relationship between the space syntax walkability score and the high risk of anxiety/depression among residents is statistically significant (p<0,05) and based on that the null hypothesis can be rejected. With a standardised correlation coefficient of 0,524, the relationship is among the strongest so far, while still being moderate. In comparison to the simple linear regression between the share of people who experience severe loneliness and space syntax walkability, the relationship between the share of residents at a high risk of anxiety/depression and space syntax walkability is also positive and moderately strong. The results show that population density, mean network integration and the SSW score (the combination of both previous indicators) positively correlates with both mental health indicators. Even though a positive correlation between population density and anxiety/depression is supported by literature and previously discussed, the positive correlation of space syntax walkability and anxiety/depression is not supported. No studies were found supporting an increase in space syntax walkability relating to an increase in depression. However, studies did come across insufficient evidence and very weak correlations when computing the space syntax walkability (Ramezani et al., 2017).

Table 17 - the R-values for the simple linear regression of space syntax walkability and anxiety/depression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	,524[a]	,274	,267	2,1011	,274	37,034	1	98	<,001

a. Predictors: (Constant), Space_Syntax_Walkability

The R-squared value (27,4%) seems high considering the doubts discussed with the correlation.

Conclusion

The results of the research and data analysis shed light on the relationship between the neighbourhood-level built environment and the mental health implications of the population of neighbourhoods. Especially, the effects on the share of population that experience severe loneliness and the share of the population at a high risk of anxiety/depression was highlighted. The share of green space in a neighbourhood negatively correlates with depression/anxiety and loneliness among residents. However, all other indicators of the built environment showed a positive correlation with the share of the population that experienced either one or both of the mental health implications studied. It was found that population density positively correlates the mental wellbeing of residents. The third hypothesis, which stated that the network integration of a neighbourhood will positively affect the mental health of residents was disproved in neighbourhoods in Groningen. Rather, an increase in network integration led to a higher share of discussed mental health implications. Similarly, the space syntax walkability score also showed a positive correlation with the share of loneliness and residents with a high risk of anxiety/depression. This contrasts the fourth hypothesis and literature studied in the literature review.

In conclusion the share of green space should gain more importance in the design of new neighbourhood plans and neighbourhood renewal initiatives. According to research, neighbourhoods with a greater share of green space show lower percentages of residents that feel severely lonely or are at a high risk of anxiety/depression. Even though green space wasn't identified as directly causing the lower levels of the two mental health implications, the correlation should cause some rethinking in the urban design practices. Moreover, existing policy could be extended by a minimum level of green space in every neighbourhood. Similarly, the correlation between population density and both mental health implications should be analysed by policy makers. The continuing emphasis on the densification of urban areas should include the consideration of mental health impacts that have been identified. Densification stays an important concept in the design of our urban areas; however, the mental health of residents cannot come short in the development of new or existing neighbourhoods. Lastly, the application of the space syntax walkability score should receive more attention from scholars to increase the understanding of the index and the benefit it provides to studies of the built environment and health.

Limitations and further research opportunities

The unique demographic composition of Groningen, which wasn't considered in the research, may have a significant impact on the share of residents experiencing mental health shortcomings. Disregarding this, may jeopardise the validity of relationships found in the research. Furthermore, the selection procedure involving the disregard of neighbourhoods with a population of less than 100 was initiated without consensus among literature. Neglecting these neighbourhoods may have influenced the relationships found in the data analysis.

Further research can be conducted into different indicators of health, especially physical health within the same study area. Additionally, the research can be supplemented with the consideration of socioeconomic and demographic factors in each neighbourhood to increase accuracy of the correlations. The methodology applied to calculating the integration score can be adjusted to reflect other radii like 5 road segments or a global radius. Apart from the indicators of mental health and the built environment, the geographic context of the research could be expanded. To increase the explanatory power and comparability of the results, the same methodology could be applied to other cities in the Netherlands or Europe and cities with different population levels.

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Appendix

Appendix 1: Kessler-10 Questionnaire

Each question has 5 answer categories: 1 'Always'; 2 'Mostly'; 3 'Sometimes'; 4 'Occasionally'; 5 'Never' 9 'Unknown'

With answer 1 'always' you get the highest score 5 in this case, with answer 5 'never' the lowest score gets 1.

(With 3 or more items Impossible, the indicator gets the value Impossible. With 1 or 2 items Impossible, the value is imputed based on the average score for that item)

The following questions are about how you felt in the past 4 weeks.

1. How often have you felt very tired for no apparent reason?
2. How often did you feel nervous?
3. How often have you been so nervous that you couldn't calm down?
4. How often did you feel hopeless?
5. How often did you feel restless or restless?
6. How often have you felt so restless that you could not sit still?
7. How often did you feel sad or depressed?
8. How often did you feel that everything took a lot of effort?
9. How often have you felt so down that nothing helped to cheer you up?
10. How often did you find yourself disapproving, inferior, or worthless?

The answers to the K10 are summarized in a score between 10-50.

10 to 15: no or low risk

16 to 29: moderate risk

30 to 50: high risk of an anxiety disorder or depression.

Appendix 2: Loneliness Scale

The scale as developed by Gierveld-de Jong & van Tilburg (2007).

The loneliness scale consists of 11 statements about emotional loneliness and social loneliness. Preceding the statements is the question: "Would you please indicate the extent to which each of the following statements applies to you as you are lately?", with the explanation "You can answer no, more or less, yes". For example, a statement for measuring emotional loneliness is "I miss a real close friend". Social loneliness is measured with, among other things, the statement: "When I need it, I can always go to my friends".

The entire questionnaire of 11 questions could not be found after extensive research .

Someone is socially or emotionally lonely if they score unfavourably on at least three of the corresponding items. Someone is lonely if there are at least three unfavourable scores on all items. With nine unfavourable scores, that is "seriously lonely".

Not Lonely: Score 0-2

Moderately lonely: score 3-8

Severely lonely: Score 9-10

Very Severely Lonely: Score 11

The questionnaire is intended for research among large groups of people. The loneliness scale is not applicable for diagnosing individuals.

Appendix 3: Correlation Tables

Correlations

		Severely_Lonely	Share_of_Green_Space
Severely_Lonely	Pearson Correlation	1,000	-,359
	Sig. (1-tailed)	.	<,001
	N	100	100
Share_of_Green_Space	Pearson Correlation	-,359	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between levels of severe loneliness and share of green space

Correlations

		Severely_Lonely	Population_Density
Severely_Lonely	Pearson Correlation	1,000	,455
	Sig. (1-tailed)	.	<,001
	N	100	100
Population_Density	Pearson Correlation	,455	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between levels of severe loneliness and population density

Correlations

		Severely_Lonely	Mean_Network_Integration
Severely_Lonely	Pearson Correlation	1,000	,418
	Sig. (1-tailed)	.	<,001
	N	100	100
Mean_Network_Integration	Pearson Correlation	,418	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between levels of severe loneliness and mean network integration

Correlations

		Severely_Lonely	Space_Syntax_Walkability
Severely_Lonely	Pearson Correlation	1,000	,475
	Sig. (1-tailed)	.	<,001
	N	100	100
Space_Syntax_Walkability	Pearson Correlation	,475	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between levels of severe loneliness and space syntax walkability

Correlations

		High_Risk_Anxiety_Depression	Share_of_Green_Space
High_Risk_Anxiety_Depression	Pearson Correlation	1,000	-,367
	Sig. (1-tailed)	.	<,001
	N	100	100
Share_of_Green_Space	Pearson Correlation	-,367	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between high risk of anxiety/depression and share of green space

Correlations

		High_Risk_Anxiety_Depression	Population_Density
High_Risk_Anxiety_Depression	Pearson Correlation	1,000	,575
	Sig. (1-tailed)	.	<,001
	N	100	100
Population_Density	Pearson Correlation	,575	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between high risk of anxiety/depression and population density

Correlations

		High_Risk_Anxiety_Depression	Mean_Network_Integration
High_Risk_Anxiety_Depression	Pearson Correlation	1,000	,424
	Sig. (1-tailed)	.	<,001
	N	100	100
Mean_Network_Integration	Pearson Correlation	,424	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between high risk of anxiety/depression and mean network integration

Correlations

		High_Risk_Anxiety_Depression	Space_Syntax_Walkability
High_Risk_Anxiety_Depression	Pearson Correlation	1,000	,524
	Sig. (1-tailed)	.	<,001
	N	100	100
Space_Syntax_Walkability	Pearson Correlation	,524	1,000
	Sig. (1-tailed)	<,001	.
	N	100	100

Correlation table for the relationship between high risk of anxiety/depression and space syntax walkability