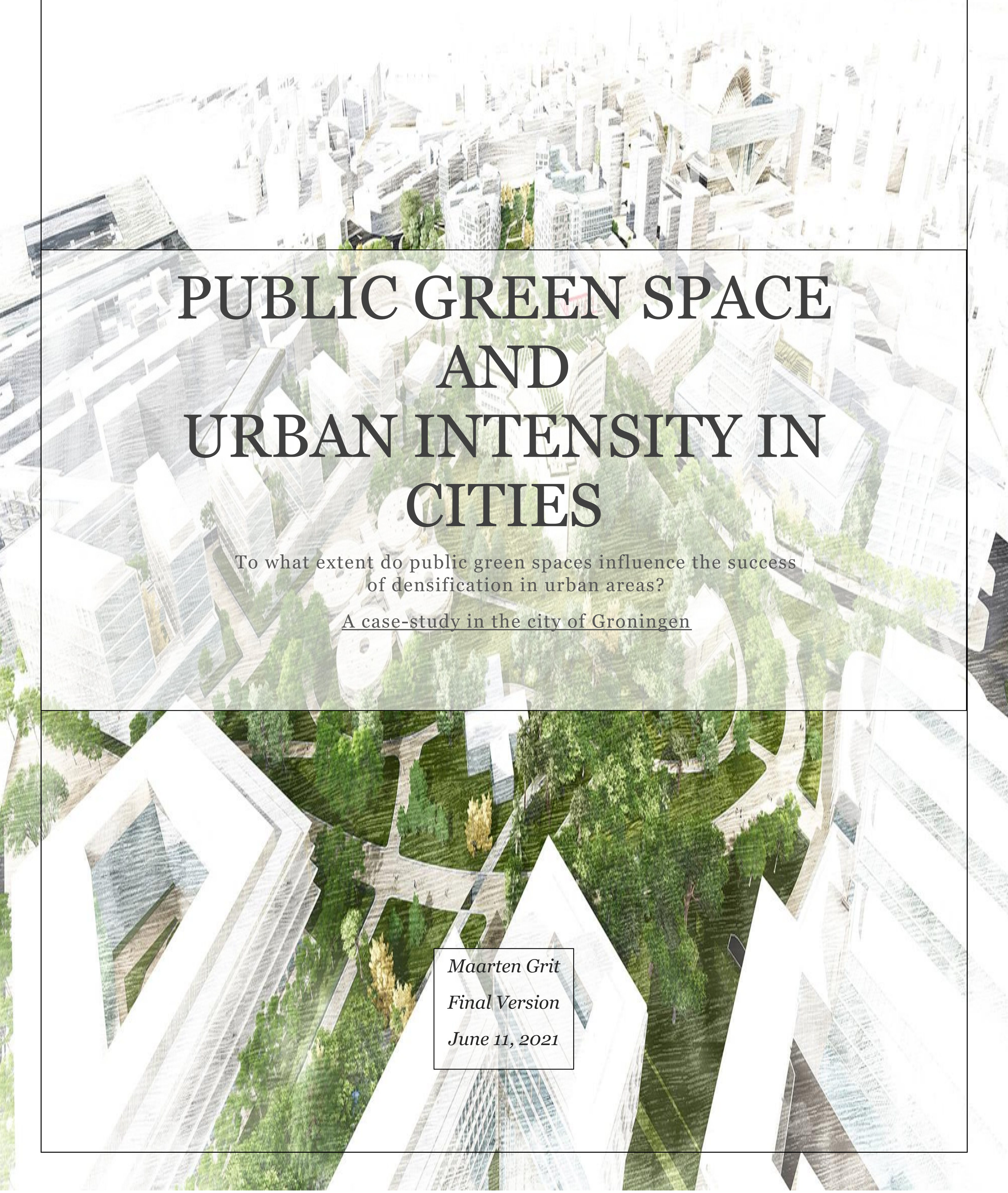

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PUBLIC GREEN SPACE AND URBAN INTENSITY IN CITIES

To what extent do public green spaces influence the success of densification in urban areas?

A case-study in the city of Groningen

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Abstract:

Currently, urban areas are representing a significant part of the ongoing sustainability problems. At this moment, the concept of 'planning for proximity' is believed to be a promising solution for these problems, within the urban planning community. This concept utilizes densification to ensure environmental, social, and economic sustainability by increasing the urban intensity. However, these sustainability benefits might be outweighed by the loss of open green space. This paper therefore investigated the influence of access to public green space on the success on densification. The research applies an approach according to Geographical Information Systems (GIS) on 15 selected neighbourhoods in the city of Groningen. Subsequently, the access to public green space and urban intensity in these neighbourhoods are measured. The composite performances on these components are statistically compared with three urban liveability indicators (nuisance, social cohesion, and heat stress). Ultimately, a graph between access to public green space and urban intensity is composed to identify the influence of the range between the two componenents on the urban liveability indicators. Consequently, the findings suggest that access to public green space can have enhancing effects on liveability, whereas urban intensity can have degrading effects on urban liveability. Lastly, there is indicated that a balance between access to public green space and urban intensity is still complex, but a promising strategy for urban planning.

Keywords: Access to public green space, urban intensity, urban liveability, densification, balance, urban planning, Groningen.

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1. Introduction:

Background

In the last decades, sustainability is becoming increasingly important as the world is closing in on the depletion of finite, fossil resources and already experiences consequences of the rising global greenhouse emissions (Blanco et al, 2014; Höök & Tang, 2013). Urban areas are believed to represent a significant part of these problems, as about 67-76 percent of the global energy supply is used in cities (Athanassiadis et al, 2018), and their contribution to carbon-dioxide emissions is estimated to be 71-76 percent (Seto et al, 2014). Simultaneously, the current urban population is expected to reach a 66 percent increase in 2050 (United Nations, 2014). This rapid, urban increment rises the concern about urban sprawl, where cities immoderately expand spatially in an outwards direction (Neumann, 2005; Brueckner, 2000). The conjunction of these urgent problem's positions urban planning at a central role in establishing a sustainable future for urban populations (Lehmann, 2016). At this moment, the concept of 'planning for proximity' receives a great amount of attention within the urban planning community (Gin Solá & Vilhelmson, 2018). Decreasing distances to essential amenities for people in urban areas is expected to enhance environmental, social, and economic sustainability (Gil Solá & Vilhelmson, 2018). The concept is already practically developed till the point that in Paris a 15-minute-city design is adopted, where 'hyper-proximity' is the main underlying principle (Yeung, 2021; Moreno, 2019). In order to establish close proximities within cities, densification is considered as one of the most essential elements (Gila Solá & Vilhelmson, 2018).

Scientific and Societal relevance

Whereas the proximity-based rational seems to be a promising new policy within urban planning, around the concept of densification remains still a lot of uncertainty within current, urban planning literature. Especially, about the influence of densification on sustainability versus liveability (Howley et al, 2009). Since, although densification of cities appears to be essential for sustainable development, too much density can have adverse liveability effects (Lehmann, 2016). For instance, densification often results in less available space for green areas, which might outweigh the overall sustainability benefits of densification (Jenks & Jones, 2010).

This paper therefore makes an attempt at investigating the relationship between access to public green space, densification and urban liveability. Predominately, because urban planning is believed to take a central role within the future of urban populations (Lehmann, 2016). Upcoming planning approaches for future urban areas, such as proximity-based planning are therefore relevant to investigate. Also, this paper tries to decrease the established uncertainty about the effects of densification of urban areas, by answering four sub-questions that overall, answer the main research question:

How do public green spaces influence the success of densification in urban areas?

Sub-questions:

***SQ1:** What are the benefits/problems of densification?*

***SQ2:** What is the importance of public green space for urban liveability?*

***SQ3:** What is the relationship between 'access to public green space' and 'urban intensity' and their relationship with urban liveability in the city of Groningen?*

***SQ4:** What is the influence of a balance between 'access to public green space' and 'urban intensity' on urban liveability?*

2. Theoretical framework:

Urban Densification and Sustainability

The concept of urban densification can refer to several meanings, overall urban densification can be defined as increasing "the degree of concentration or compactness of people or development in a city" (Hess, 2014, p.1554). Increasing densities in cities is becoming progressively supported among urban policymakers as it is believed to enhance sustainable development (Boyko & Cooper, 2011). Many academic studies found evidence that urban densification has a positive relationship with the reduction in fossil fuel consumption, due to shorter travel distances that encourage walking, cycling and public transport (Karathodorou et al, 2010; van de Coevering & Schwanen, 2006). Furthermore, denser cities tend to also provide social benefits by reducing social segregation due to the more equal accessibility to important amenities (Burton, 2000; Dempsey et al, 2012). Additionally, the closer proximity between facilities in denser cities is expected to foster more economic innovation because of less institutional barriers (Hansen, 2015).

Urban Densification and Liveability

The establishment of these promising findings on the sustainable benefits of densification of urban areas resulted in numerous initiatives in European, North American, and Asian contexts (Lehmann, 2016; Boyko & Cooper, 2011; Neumann, 2005). However, besides the optimistic view on urban densification, critics became interested in the possible, negative consequences of densification on the liveability in cities (Howley et al, 2009). Notably, favourable urban liveability harmonizes with healthy urban environments, however in essence densification focuses on urban sustainability (Lowe et al, 2015). De Roo and Miller (2000) summarized this concern by addressing the fundamental differences between sustainability and liveability. Sustainability mainly focuses on larger spatial scales, while on the other hand liveability has more attention for urban conditions locally (De Roo & Miller, 2000). Research by Burton (2000) supports this argument by identifying that densification is likely to be beneficial for reduced social segregation and improved public transport, whereas it also results in less domestic living space and increased local crime levels. Furthermore, Dempsey et al (2012) reported that dense neighbourhoods overall have indeed better access to services and facilities, but in return inhabitants experience more local problems such as poor access to quality green space, a feeling of unsafety and less social cohesion. Additionally, Senior et al (2004) identified that people tend to dislike high-density urban areas because they have a common perception here of noise, pollution, and traffic problems. And lastly, denser cities correspond to more concentrated built-up areas, which may result in increasing urban temperatures (Lemonsu et al, 2015). Findings like these suggest that sustainable benefits through densification can only be achieved at the expense of the quality of urban liveability (Howley et al, 2009; Neumann, 2005).

Urban Intensity, Access to Public Green Space and Liveability

However, Lehmann (2016) argued that densification is indeed the future for sustainable urbanism, provided that there needs to be a balance between densification and public open spaces. This paper therefore takes a specific focus on public green spaces as they are expected to generate enhancing liveability effects that can possibly limit the negative consequences of densification on urban liveability to attain a balance (figure 1). For instance, according to Klok et al (2012) a ten percent increase of green space can decrease temperatures with 1.3 degrees in cities. Moreover, natural environments provide more places for people to meet and to recreate, giving more opportunities for social interaction (Jenks & Jones, 2010). Lastly, public green spaces tend to diminish nuisance within urban areas, as it can absorb noise and shield vociferous areas (Kabisch et al, 2015). Implementing green areas can, therefore potentially accomplish a more successful densification process for urban areas.

An important urban form that is often associated with urban densification and access to public green space is the compact city concept (Howley et al, 2009). It is considered as an efficient planning strategy, that focuses on increasing the urban intensity through densification with the deliberation of enough accessibility to public open spaces (Hess, 2014; Jabareen, 2006). Urban intensity refers to the “volume of spatial interactions” within urban areas (Sevtsuk et al, 2013, p.553). According to Guan and Rowe (2016), urban intensity is a useful tool when investigating the sustainability performance of the spatial distributions of different urban forms. These spatial distributions are categorized into four components consisting of density, diversity, connectedness, and compactness (Rowe, 2015).

Density is included, as higher densities cluster urban activities which stimulate the use of slow modes of transport (Guan & Rowe, 2016; Karathodorou et al, 2010). Diversity of urban functions is considered as essential because mixed land use increases the local availability of functions, which generally relates to improved social equity (Guan & Rowe, 2016; Burton, 2000). Moreover, connectedness is related to the accessibility of these functions (Guan & Rowe, 2016). Closer distances increase the connectivity, which equalizes the accessibility opportunities for residents (Guan & Rowe; Bramley & Power, 2009). Lastly, a higher compactness of an urban area implies that the overall built-up footprint is limited, giving more space for the conservation of natural environments (Guan & Rowe, 2016). Urban areas with an overall high urban intensity are considered to be sufficiently densified and are able to ensure the stated sustainability benefits of urban densification (Guan & Rowe, 2016).

On the other hand, the densification process of cities should contain careful decision-making as too much densification can have adverse liveability effects (Lehmann, 2016). In order to ensure quality city-life, densification requires access to public green space (Lehmann, 2016). The European Environment Agency recommends that people should have access to green space within 900 meters, which can be compared to all the green space within a 15-minute walk (Irvine et al, 2010). According to Baycan-Levent & Nijkamp (2004) this should be a proportion of 10-15 percent of the total surface area. The UK government takes this even further and wants to make sure that people in urban areas must have the opportunity to reach natural environments within 300 meters (Irvine et al, 2010). Also, the green space within neighbourhoods is important as it can locally decrease the urban heat island effect, which is the additional, generated temperature due to built-up surfaces (Klok et al, 2012).

Whereas a combination of densification of urban areas and access to public green space seems to be the solution for sustainable urbanism, the complex relationship between both concepts is a constraining factor (figure 1). Increasing urban intensity through densification is namely strongly related to a reduction in the total amount of green space (Fuller et al, 2010). An achievement of a balance between the two, where both forms of benefits are significant is therefore a complex issue.

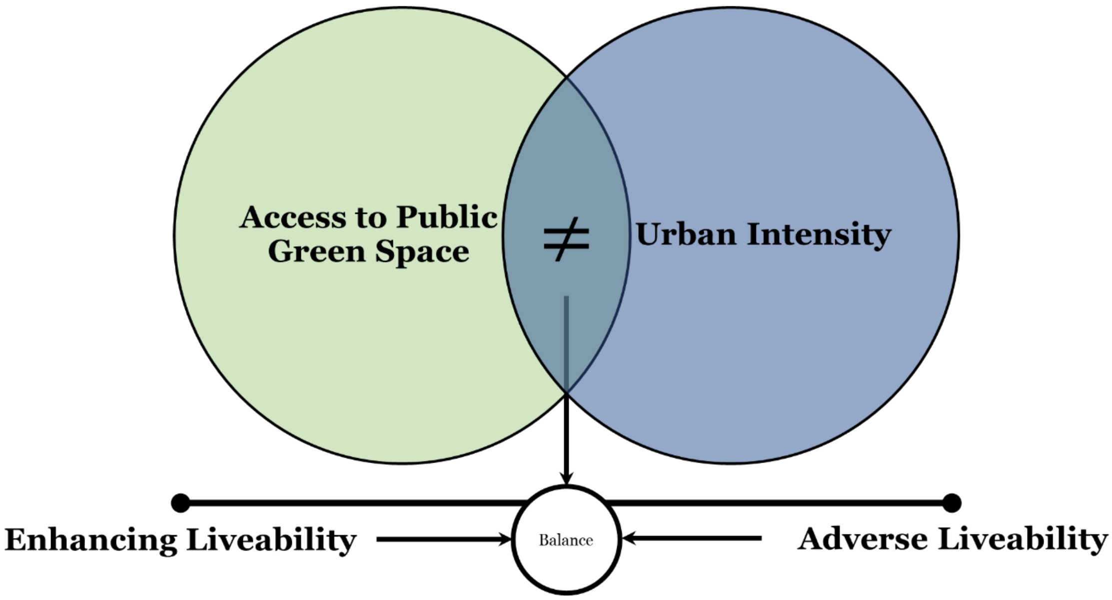


Figure 1: Conceptual model based on the relationships described in the theoretical framework.

3. Methodology:

Case-study Groningen

In anticipation of the main research question, the city of Groningen is selected as a case-study. The selection of the city of Groningen as case-study is based upon its current accelerating urban growth and their strategic compact city approach to accommodate the growing population (Gemeente Groningen, 2018). The municipality of Groningen has densification and access to public green space as high priorities and is therefore expected to be a representative case-study when investigating the influence of public green space on the success of densification (Gemeente Groningen, 2018).

The analysis of this influence will be according to Geographical Information Systems (GIS), with the programme ArcMap. Within ArcMap 15 neighbourhoods of Groningen are selected, 3 out of the city centre and 12 just outside the city centre (figure 2). Throughout the paper, the 12 neighbourhoods just outside the city-centre will be categorized into semi-centre neighbourhoods. The map-layer CBS-Wijk -en Buurtkaart 2018 (Esri, A, 2021) is used, however the boundaries of the neighbourhoods are according to the so-called 'Kompaswijken' in the city of Groningen. Hence, some sub-areas had to be combined into one coherent neighbourhood. The 'Binnenstad' for instance is consisting of the sub-areas 'Binnenstad-Noord', 'Binnenstad-Zuid' and 'Binnenstad-West'.

	Neighbourhood
City-centre	*Hortusbuurtnieuwe-Ebbingekwartier*
	Binnenstad
	Binnenstad-Oost
Semi-centre	*Indische buurt*
	Professorenbuurt
	Oosterpark-Wijk
	Nieuw-Zuid
	Oosterpoort
	Herewegbuurt
	Rivierenbuurt
	Grunobuurt
	Badstraten-Zeeheldenbuurt
	Schildersbuurt
	Oranjebuurt
	Noorderplantsoenbuurt

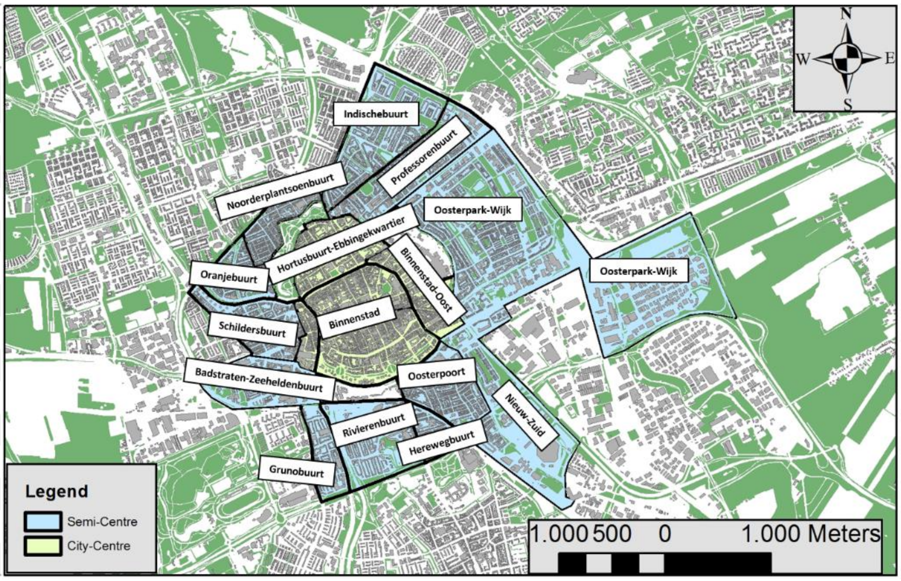


Figure 2: Overview and location of the 15 selected neighbourhoods.

Access to public green space measurement

Subsequently, for every neighbourhood the 'access to public green space' is measured. The map-layer Landuse_Groningen (Arcgis Online, 2021) is used, whereof only public green spaces are selected, excluding cemeteries and agricultural land. The accessibility to these public green spaces is measured in ArcMap according to three variables by using buffers. The first buffer is following the recommendation of the European Environment Agency and uses a radius of 900 meters. The next buffer follows the strict guidance of the UK government and uses a radius of 300 meters. Lastly, the boundaries of the neighbourhoods are used to measure the public green space within a neighbourhood. By using the ‘select by location’ tool within ArcMap the amount of green space in square meters per buffer is measured. To neglect the fact that larger neighbourhoods have consequent larger buffers, and thus have a greater outreach to green space, the absolute amount of green space is divided by the surface area of the buffers, resulting in relative numeric values per buffer. After every neighbourhood obtained the access to green space per buffer, the values of the variables are normalized by the mean (Appendix D). This value represents if a neighbourhood has relatively more or less access to public green space than the mean of all the neighbourhoods together of that specific variable. Ultimately, the ‘normalized by the mean’ values are summed up per neighbourhood, giving every neighbourhood a composite score of the ‘access to public green space’. Here applies that the higher the composite score, the higher the relative performance of ‘access to public green space’ of the neighbourhood.

Urban intensity measurement

In order to identify if the selected neighbourhoods are sufficiently densified to be classified as sustainably built-up urban areas, the urban intensity tool created by Guan and Rowe (2016) is applied. As stated, the measurement of the urban intensity of an urban area consists of four variables. The first variable is density, which is measured with dividing the residential population by the surface area of a neighbourhood. The map-layer ‘CBS Wijk-en Buurtkaart Nederland 2018 (Esri, A, 2021)’ is used to gather the number of residents per selected neighbourhood. This map-layer is reduced to only the 15 selected neighbourhoods to identify the corresponding surface area of the neighbourhoods per number of residents.

Secondly, the diversity of the urban functions per neighbourhood was measured. The map-layer ‘Open Street Map Points of Interest Nederland’ (Esri, B, 2021) was implemented to identify 12 urban functions. These were reduced to 6 urban function categories, including eat & drink facilities, healthcare, education, sport, leisure, and shopping. For every neighbourhood, the number of facilities per category within 900 meters were measured (Appendix B). With these numbers the Shannon’s index per neighbourhood could be measured, representing the diversification of urban functions. The Shannon’s index represents the uncertainty of predicting the type of urban function when a sample is randomly selected of the total urban function population (Ortis-Burgos, 2015). The higher this uncertainty, the higher the diversity of a neighbourhood.

Connectedness is the third variable of urban intensity. In this paper, connectedness is measured by the sum of the accessible fractions within 900 meters of the total available urban functions in Groningen. As an illustration, in the whole city of Groningen there are 664 facilities characterized as eat & drink facilities, 150 as healthcare, 61 as education, 58 as sport, 496 as leisure and 1267 as shopping. Each neighbourhood is connected within 900 meters to a specific fraction of these total number of urban functions (Appendix B), the sum of the fractions per category is considered as the connectedness of a neighbourhood.

The last variable of urban intensity is compactness. For the measurement of the compactness of the neighbourhoods a grid with blocks of 100 by 100 meters is created in ArcMap. The map-layer 'Kadaster ESRI Nederland' (Esri, C, 2021) is used to identify the buildings per neighbourhood. Then the 100 by 100 meter grid is joined with the buildings per neighbourhood. Consequently, each block will represent the amount of built-up area within 100 by 100 meters. The larger the built-up area, the more red the block will be (figure 7 & 8). Lastly, a spatial autocorrelation method is used to determine the Global Moran's I of the neighbourhood. This variable measures if an area is dispersed or clustered, which is ultimately the variable for compactness. The higher the Moran I, the more compact a neighbourhood is. Furthermore, a positive z-score suggests a clustered pattern and a negative z-score suggests a dispersed pattern (Goodchild, 1986).

Finally, every measured urban intensity variable per neighbourhood will again be normalized by the mean. Following the same method as the determination of the 'access to public green space', the normalized by the mean values are added up, representing the urban intensity per neighbourhood. Here, again applies that the higher the composite score, the higher the relative urban intensity performance.

Urban liveability measurement

The outcomes of the analysis are tables including the composite scores of 'access to public green space' and 'urban intensity' per neighbourhood. Subsequently, these composite scores can be statistically tested with the urban liveability indicators. This research uses three urban liveability indicators, consisting of the nuisance score, social cohesion, and heat stress (Appendix 8.3). The data for the nuisance and social cohesion is collected from a questionnaire in 2018 done by IOS Groningen (IOS Groningen, 2018). For the heat stress indicator an urban heat island map from the Dutch institute of public health and the environment is used (RIVM, 2017).

Systematic approach to determine relationships

A systematic approach consisting of three steps is used for finding all the relationships between access to public green space, urban intensity, and urban liveability. All the steps utilize the Spearman's rank correlation test, which is a non-parametric statistical test. A non-parametric test is selected because according to Burt et al (2009) non-parametric tests are advisable when researching with a small sample size, as there is more risk of skewness. The Spearman's rank correlation test produces a coefficient and significance level. The coefficient represents the strength of a positive or negative correlation and the significance level shows if there is enough evidence in the sample to suggest a significant correlation (Table 1).

Correlation Coefficient	Strength correlation
0,00-0,10	*Neglectable*
0,1-0,39	*Weak*
0,40-0,69	*Moderate*
0,70-0,89	*Strong*
0,90-1,00	*Very strong*

Table 1: Associated strengths per value of correlation according to Schober et al (2018).

As a first step of the systematic approach, the relationship between access to public green space and urban intensity is measured. Thereafter, the influence of access to public green space and urban intensity on the urban liveability indicators is identified by statistically comparing the composite scores and the urban liveability indicators. Finally, a graph is composed representing the balance of the neighbourhoods between access to public green space and urban intensity. The range between the two components is calculated and again statistically compared with the urban liveability indicators. Consequently, there can be indicated if the range of the balance influences the urban liveability indicators (figure 3).

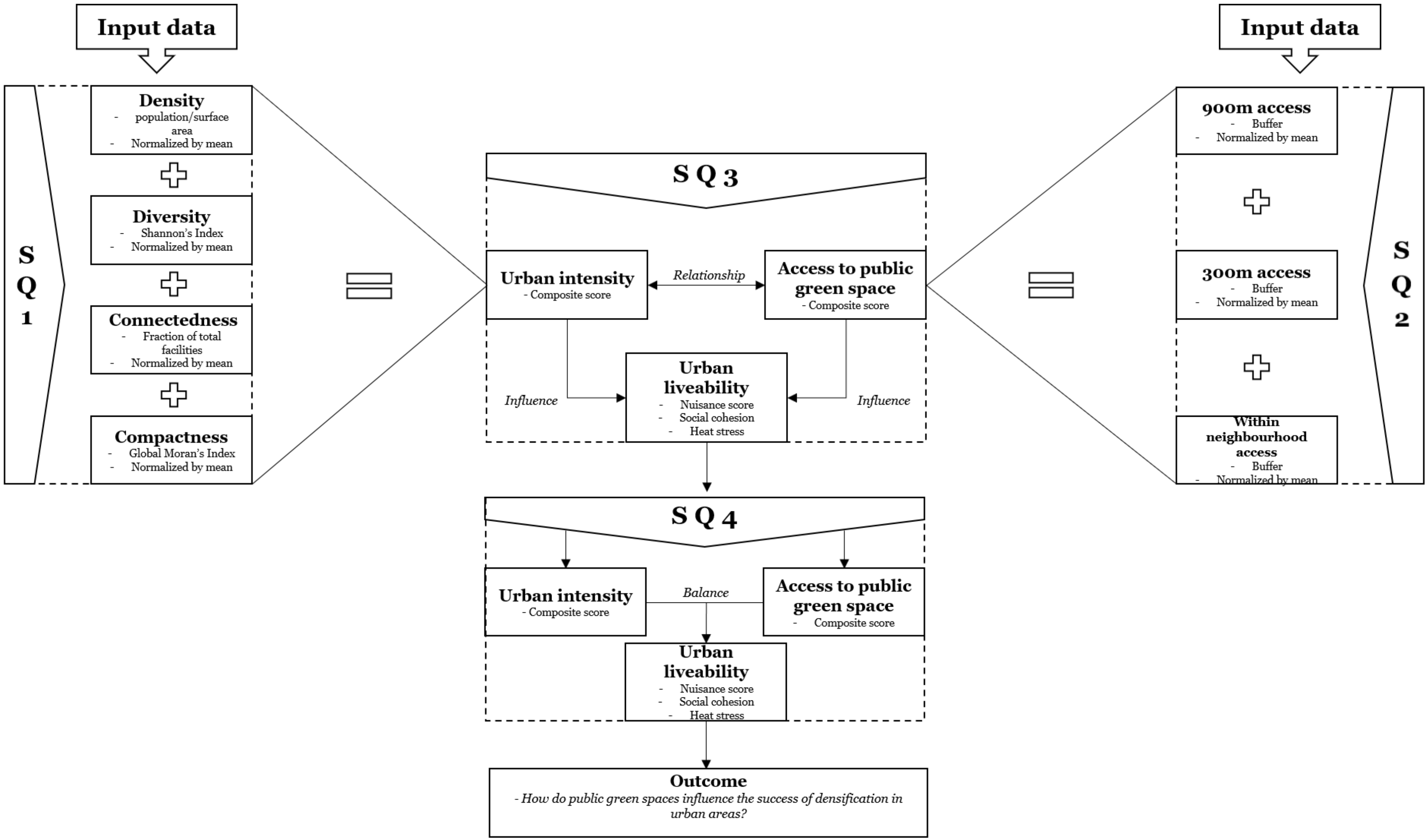


Figure 3: Methodological scheme of the research.

4. Results

4.1 Access to Public Green Space

In this section, the results of the GIS analysis for access to public green space are presented. The outcomes of the three buffers (900m, 300m and within) per neighbourhoods are respectively described and presented in table 2. Subsequently, the neighbourhoods are positioned on a ranking graph, based on their composite performances (figure 6). The highest and lowest composite scoring neighbourhoods are presented on a map.

Access to public green space: within 900 meters

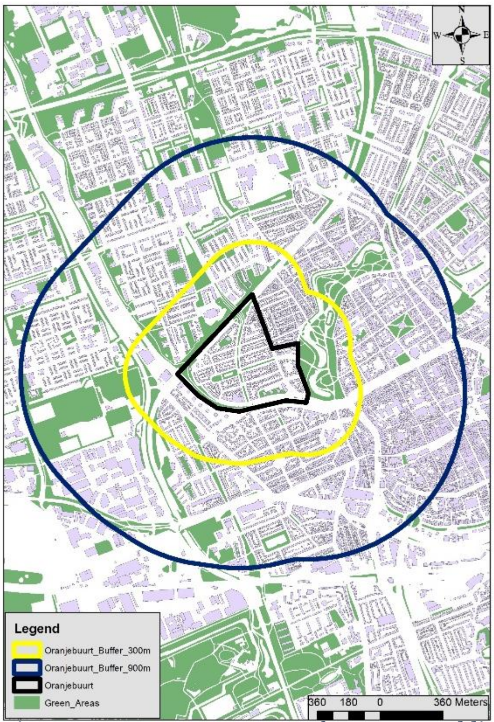
With respect to the public green space for neighbourhoods within the 900-meter buffer, the corresponding mean of the absolute values is 0,145. There are 6 neighbourhoods that relatively have lower access to public green space than the mean. Including all the city-centre neighbourhoods and 3 of semi-centre neighbourhoods. The 'Binnenstad' has relatively the lowest amount of public green space within 900 meters with an absolute proportion of 0,085 and 'Badstraten-Zeeheldenbuurt' obtained the highest amount with 0,206.

Access to public green space: within 300 meters

The mean of access to public green space within 300 meters is 0,130. The relatively negative scores increased from 6 to 8 neighbourhoods, which still includes the whole city-centre and in this situation 5 semi-centre neighbourhoods. The 'Binnenstad', by the same way as with the 900-meter access, has the lowest amount of green space within 300 meters with an absolute proportion of 0,030. The 'Oranjebuurt' has the highest amount of green space within 300 meters, with 0,227.

Access to public green space: within buffer

The overall public green space within neighbourhoods is 0,087. The city-centre again has relatively lower green space than the mean, combined with 5 semi-centre neighbourhoods. The 'Schildersbuurt' has the lowest amount with a proportion of 0,002 and the 'Oranjebuurt' has again the highest amount with a proportion of 0,178 (figure 4 & 5).



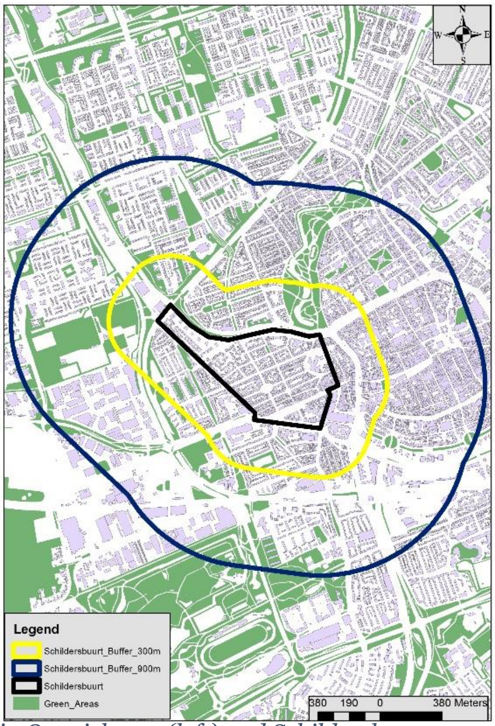


Figure 4 & 5: Measurement of access to public green space in Oranjebuurt (left) and Schildersbuurt (right)

Access to public green space: Composite score

When looking at the composite scores of the neighbourhoods, 8 have a relatively poor access to public green space performance and 7 have a relatively positive performance. In figure 6 the neighbourhoods are ranked according to their composite scores. The 'Schildersbuurt' has relatively the lowest performance, with a composite score of -3,626. And the 'Oranjebuurt' has the relatively highest performance, with a composite score of 1,391 (figure 6).

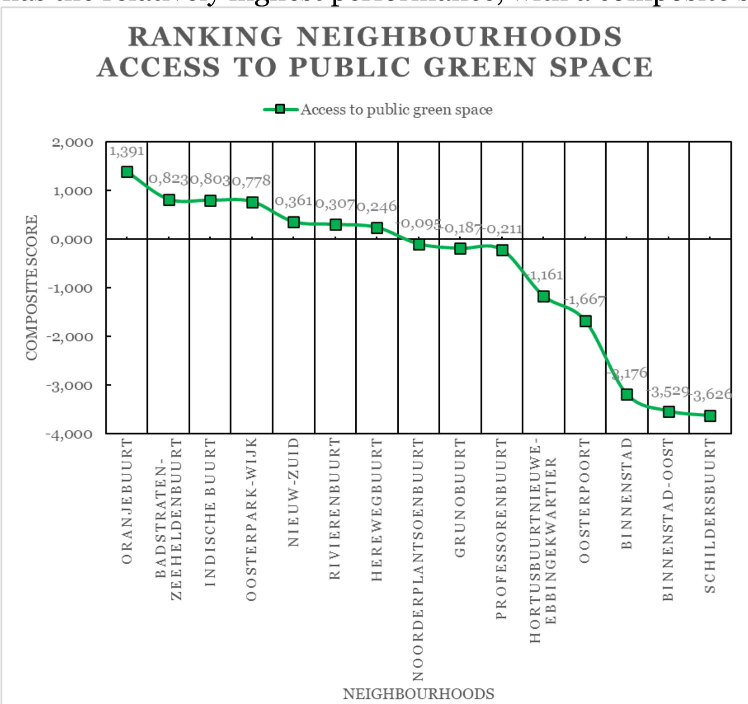


Figure 6: Ranking graph of the neighbourhoods according to the composite scores on access to public green space.

Neighbourhood	900m buffer	300m buffer	Within buffer	Composite score
Hortusbuurtnieuwe-Ebbingekwartier *(Absolute)*	0,091	0,090	0,063	
Normalized by mean	-0,462	-0,371	-0,328	-1,161
Binnenstad *(Absolute)*	0,085	0,030	0,027	
Normalized by mean	-0,535	-1,453	-1,188	-3,176
Binnenstad-Oost *(Absolute)*	0,086	0,035	0,016	
Normalized by mean	-0,517	-1,318	-1,694	-3,529
Indische Buurt *(Absolute)*	0,176	0,122	0,170	
Normalized by mean	0,200	-0,063	0,666	0,803
Professorenbuurt *(Absolute)*	0,156	0,089	0,096	
Normalized by mean	0,078	-0,380	0,090	-0,211
Oosterpark-Wijk *(Absolute)*	0,185	0,127	0,152	
Normalized by mean	0,248	-0,023	0,553	0,778
Nieuw-Zuid *(Absolute)*	0,109	0,122	0,177	
Normalized by mean	-0,280	-0,064	0,706	0,361
Oosterpoort *(Absolute)*	0,093	0,119	0,028	
Normalized by mean	-0,441	-0,090	-1,135	-1,667
Herewegbuurt *(Absolute)*	0,149	0,158	0,089	
Normalized by mean	0,030	0,194	0,021	0,246
Rivierenbuurt *(Absolute)*	0,156	0,166	0,087	
Normalized by mean	0,074	0,241	-0,008	0,307
Grunobuurt *(Absolute)*	0,200	0,179	0,038	
Normalized by mean	0,325	0,319	-0,832	-0,187
Badstraten-Zeeheldenbuurt *(Absolute)*	0,206	0,140	0,130	
Normalized by mean	0,356	0,071	0,396	0,823
Schildersbuurt *(Absolute)*	0,170	0,170	0,002	
Normalized by mean	0,164	0,263	-4,053	-3,626
Oranjebuurt *(Absolute)*	0,164	0,227	0,178	
Normalized by mean	0,124	0,556	0,711	1,391
Noorderplantsoenbuurt *(Absolute)*	0,141	0,179	0,059	
Normalized by mean	-0,025	0,319	-0,389	-0,095
Absolute mean	0,145	0,130	0,087	-0,596

Table 2: Outcome of the access to public green space measurement.

4.2 Urban Intensity

In this section, the results of the GIS analysis for urban intensity are presented. Each urban intensity variable (density, diversity, connectedness, and compactness) is respectively calculated and analysed. The outcomes are presented in table 3. Similar as the previous section the neighbourhoods are ranked according to their composite performance on urban intensity and the highest and lowest scoring neighbourhoods are illustrated on a map.

Urban Intensity: Density

The overall mean of the density variable is 0,0106. The city-centre neighbourhoods do not have the highest density. The 'Noorderplantsoenbuurt', located in the semi-centre has the highest density with a value of 0,0154. The lowest value is also located in the semi-centre, 'Nieuw-Zuid' with a value of 0,0038.

Urban Intensity: Diversity

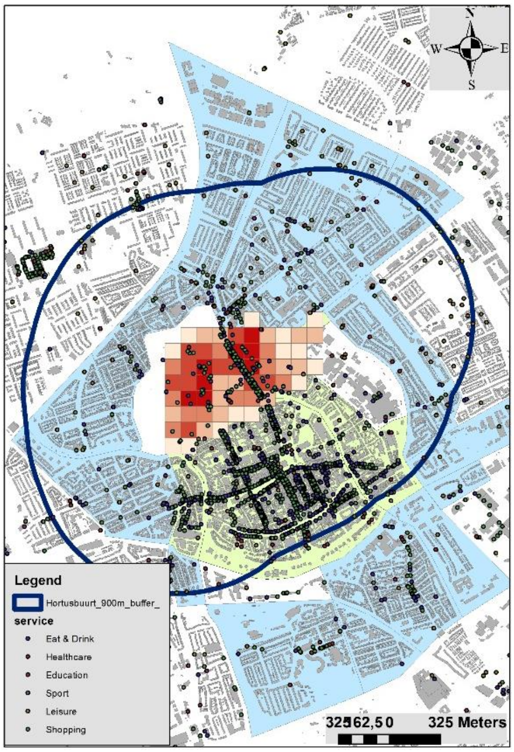
Diversification of the selected urban functions is the highest in the 'Indischebuurt', with a Shannon's index of 1,33. The lowest score is found in the 'Schildersbuurt' with a Shannon's index of 1,05. This means that the 'Indische buurt' has more evenness of urban functions and the 'Schildersbuurt' a more abundance of urban functions. The neighbourhoods altogether have a Shannon index of 1,129.

Urban Intensity: Connectedness

The city-centre area has the highest scores on connectedness within 900 meters. The 'Hortusbuurtbuurt-Ebbingekwartier' is relatively the best connected to the urban functions with a score of 2,814. The 'Grunobuurt' has the lowest score of 1,167, suggesting that this neighbourhood is relatively the poorest connected to the selected urban functions. Overall, the neighbourhoods have a connectedness of 1,794.

Urban Intensity: Compactness

The semi-centre neighbourhood 'Nieuw-Zuid' has the highest performance on compactness, with a score of 0,610. This means that here the built-up area is relatively the most clustered and thus takes up the lowest amount of land-area. The 'Oranjebuurt', on the other hand is relatively the most dispersed neighbourhood, as it has a score of 0,228. However, as every z-score for each neighbourhood is positive, the Global Moran I suggest a clustered pattern (Appendix A). Thus, the selected neighbourhoods all tend the have a clustered building structure.



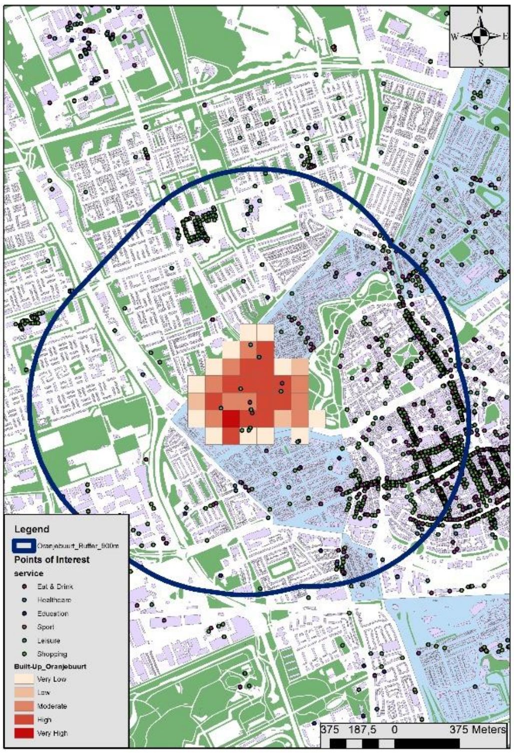


Figure 7 & 8: Measurement of Density, Diversity, Connectedness and Compactness in Hortusbuurt-Ebbingekwartier (left) and Oranjebuurt (right)

Urban Intensity: Composite score

Ultimately, when combining all the outcomes of the variables, the city-centre neighbourhoods have relatively the highest performance on urban intensity. The 'Hortusbuurtnieuwe-Ebbingekwartier is ranked first with a score of 0,657 (figure 9). 9 out of the 12 semi-centre neighbourhoods have a negative composite score on urban intensity. The 'Oranjebuurt' is ranked last as it has a composite score of -0,929 (figure 9).

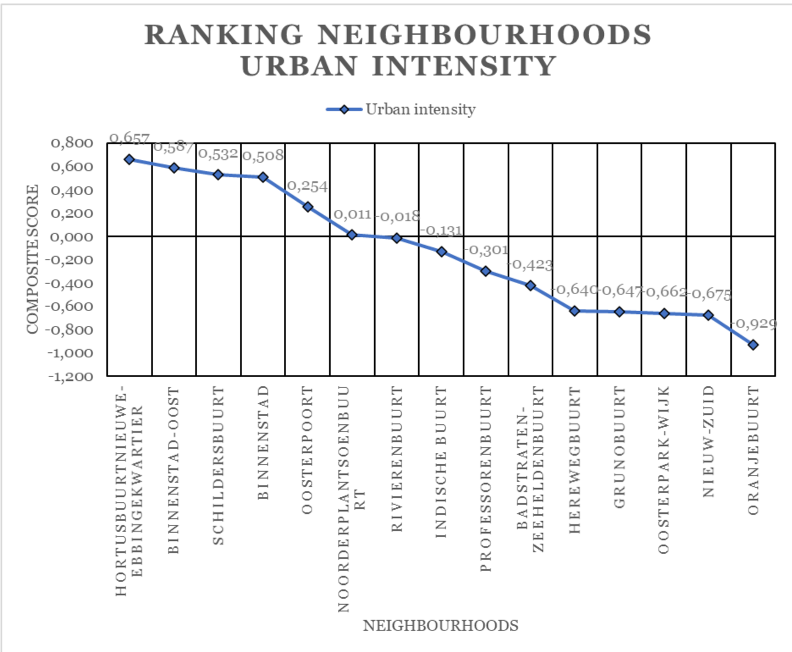


Figure 9: Ranking graph of the neighbourhoods according to the composite scores of urban intensity.

Neighbourhood	Density	Diversity	Connectedness	Compactness	Composite score
Hortusbuurtnieuwe-Ebbingekwartier	0,012	1,120	2,814	0,454	
Normalized by mean	0,149	-0,008	0,450	0,067	0,657
Binnenstad	0,012	1,110	2,600	0,446	
Normalized by mean	0,103	-0,017	0,371	0,051	0,508
Binnenstad-Oost	0,014	1,090	2,292	0,471	
Normalized by mean	0,272	-0,035	0,245	0,105	0,587
Indische buurt	0,012	1,330	1,260	0,407	
Normalized by mean	0,101	0,164	-0,353	-0,042	-0,131
Professorenbuurt	0,011	1,210	1,586	0,326	
Normalized by mean	0,018	0,069	-0,123	-0,264	-0,301
Oosterpark-Wijk	0,004	1,170	2,168	0,411	
Normalized by mean	-0,856	0,035	0,189	-0,031	-0,662
Nieuw-Zuid	0,004	1,130	1,774	0,610	
Normalized by mean	-1,028	0,001	-0,011	0,364	-0,675
Oosterpoort	0,012	1,080	1,779	0,492	
Normalized by mean	0,159	-0,045	-0,008	0,148	0,254
Herewegbuurt	0,010	1,120	1,411	0,299	
Normalized by mean	-0,041	-0,008	-0,240	-0,350	-0,640
Rivierenbuurt	0,008	1,100	1,884	0,534	
Normalized by mean	-0,270	-0,026	0,049	0,230	-0,018
Grunobuurt	0,009	1,140	1,167	0,386	
Normalized by mean	-0,131	0,009	-0,430	-0,095	-0,647
Badstraten-Zeeheldenbuurt	0,010	1,070	1,571	0,362	
Normalized by mean	-0,078	-0,054	-0,133	-0,159	-0,423
Schildersbuurt	0,015	1,050	1,822	0,547	
Normalized by mean	0,335	-0,073	0,015	0,255	0,532
Oranjebuurt	0,010	1,060	1,467	0,228	
Normalized by mean	-0,042	-0,063	-0,201	-0,622	-0,929
Noorderplantsoenbuurt	0,015	1,160	1,316	0,390	
Normalized by mean	0,377	0,027	-0,310	-0,083	0,011
Mean	*0,011*	*1,129*	*1,794*	*0,424*	*-0,125*

Table 3: Outcome urban intensity measurement.

4.3 Relationship Access to Public Green Space and Urban Intensity

Table 4 shows both the 'urban intensity' composites scores and the 'access to public green space' composite scores of every neighbourhood. None of the selected neighbourhoods managed to achieve a positive composite score on both variables. To illustrate, the 'Oranjebuurt' is ranked first with access to public green space but ranked last with urban intensity. Moreover, the "Hortusbuurt-Ebbingekwartier' is ranked first with urban intensity but ranked eleventh with access to public green space.

Neighbourhood	Urban intensity	Access to public green space
Hortusbuurtnieuwe-Ebbingekwartier	0,657	-1,161
Binnenstad	0,508	-3,176
Binnenstad-Oost	0,587	-3,529
Indische buurt	-0,131	0,803
Professorenbuurt	-0,301	-0,211
Oosterpark-Wijk	-0,662	0,778
Nieuw-Zuid	-0,675	0,361
Oosterpoort	0,254	-1,667
Herewegbuurt	-0,640	0,246
Rivierenbuurt	-0,018	0,307
Grunobuurt	-0,647	-0,187
Badstraten-Zeeheldenbuurt	-0,423	0,823
Schildersbuurt	0,532	-3,626
Oranjebuurt	-0,929	1,391
Noorderplantsoenbuurt	0,011	-0,095
Mean	*-0,125*	*-0,596*

Table 4: Composite scores urban intensity and access to public green space.

A Spearman's correlation test was run to determine the relationship between access to public green space and urban intensity. Consequently, the statistical test determined a strong, negative correlation between urban intensity and access to public green space with a value of -0,794 (table 5). Thus, an increase in urban intensity tends to result in a decrease in access to public green space and vice versa.

Relationship	Correlation	Significance level (<0,05)
Urban intensity and access to public green space	*-0,794 (strong)*	*0,000*

Table 5: Outcome Spearman's correlation between urban intensity and access to public green space.

4.4 Relationship Access to Public Green Space and Urban Liveability

This section examines the relationship between access to public green space and urban liveability. Every urban liveability indicator (nuisance score, social cohesion score and heat stress) is statistically tested against access to public green space in the respective order. The strength and significance level of the relationships are indicated in table 6.

Access to Public Green Space and Nuisance

The outcome of the Spearman's correlation test between 'access to public green space' and the 'nuisance score', resulted in a value of -0,711. This indicates a strong, negative relationship between 'access to public green space' and the 'nuisance score'. Consequently, the neighbourhoods with a higher composite score on 'access to public green space' tend to have a lower 'nuisance score'.

Access to Public Green Space and Social Cohesion

Subsequently, 'access to public green space' and 'social cohesion' are statistically tested according to the Spearman's correlation test. Alternatively, the outcome of this test determined a weak, positive relationship between these two variables, with a value of 0,393. However, the correlation is regarded as not significant. Thus, within these selected neighbourhoods there is not enough evidence that an increase in public green space would have a weak influence on the increase of the social cohesion.

Access to Public Green Space and Heat Stress

Lastly, the relationship between 'access to public green space' and 'heat stress' is statistically tested with the Spearman's correlation test. The result is a value of -0,726, which suggests a strong, negative correlation between the two variables. Hence, the additional urban heat stress effect tends to decrease in neighbourhoods that have a positive performance on the access to public green space.

Relationship	**Correlation**	**Significance level (<0,05)**
Access to public green space and nuisance	*-0,711 (strong)*	*0,003*
Access to public green space and social cohesion	*0,393 (weak)*	*0,147*
Access to public green space and heat stress	*-0,726 (strong)*	*0,001*

Table 6: Outcomes Spearman's correlation tests between access to public green space and the urban liveability indicators.

4.5 Relationship Urban Intensity and Urban Liveability

In this section the relationships between urban intensity and the urban liveability indicators (nuisance score, social cohesion score and heat stress) are investigated. The relationships are respectively described and presented in table 7.

Urban Intensity and Nuisance

The Spearman's correlation test found that urban intensity has a strong, positive correlation with the nuisance score in the selected neighbourhoods, with a value of 0,784. Selected neighbourhoods with a higher urban intensity thus tend to have a higher nuisance score than neighbourhoods with a lower urban intensity.

Urban Intensity and Social Cohesion

Within this research urban intensity has a moderate, negative correlation with social cohesion, as the value is -0,561. Consequently, selected neighbourhoods with higher urban intensity might have a lower social cohesion between the residents.

Urban Intensity and Heat Stress

Finally urban intensity has a strong, positive correlation with the heat stress indicator. The value is 0,847, which suggests that neighbourhoods with a higher urban intensity performance experience higher additional heat stress.

Relationship	**Correlation**	**Significance level (<0,05)**
Urban intensity and nuisance	*0,784 (strong)*	*0,001*
Urban intensity and social cohesion	*-0,561 (moderate)*	*0,029*
Urban intensity and heat stress	*0,847 (strong)*	*0,000*

Table 7: Outcomes Spearman's correlation tests between urban intensity and the urban liveability indicators.

4.6 Balance between Access to Public Green Space and Urban Intensity

This section examines the balance between access to public green space and urban intensity of the neighbourhoods. The range between the two composite scores is calculated and presented in figure 10 to indicate how close a neighbourhood is to a balance. Subsequently, this range is statistically tested to the urban liveability indicators to identify the influence of a balance between access to public green space and urban intensity (table 8).

Relationship Range and Urban Liveability indicators

Section 4.3 identified that urban intensity and access to public green space have a strong, negative relationship. Increasing one component will ultimately decrease the other component. Figure 10 illustrates the balance between the urban intensity performance and the access to public green space performance within the 15 selected neighbourhoods. Likewise, the figure shows a similar pattern with large ranges between the two performances. The "Schildersbuurt' has the highest range with a positive performance on urban intensity and the lowest performance on access to public green space. On the other hand, the 'Noorderplantsoenbuurt' and the 'Professorenbuurt' seem to have a small range between the two performances. More specifically, the 'Noorderplantsoenbuurt' has a small, positive performance on urban intensity (0,011) and a small, negative performance on access to public green space (-0,095). The 'Professorenbuurt' has two negative scores but has a small range between them. When taking a rough look at the urban liveability indicators of these neighbourhoods, they seem to be positively influenced (Appendix C).

The spearman's correlation test between range and the urban liveability indicators, resulted in a moderate, positive correlation with nuisance and heat stress. And a weak, negative correlation with social cohesion. Consequently, within the 15 selected neighbourhoods an increase in range between urban intensity and access to public green space results in a moderate, increase in the nuisance score and the additional heat stress effect. On the other hand, the relationship between range and social cohesion is regarded as not significant (table 8).

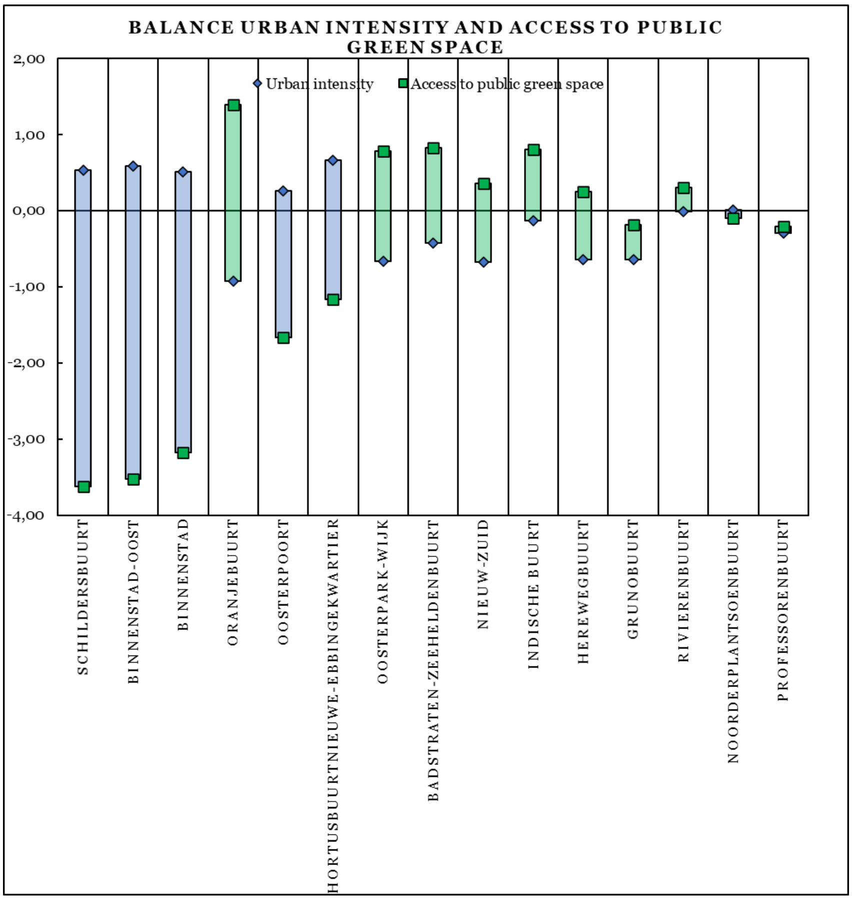


Figure 10: Balance urban intensity and access to public green space per neighbourhood.

Relationship	Correlation	Significance level (<0,05)
Range and nuisance	*0,514 (moderate)*	*0,050*
Range and social cohesion	*-0,334 (weak)*	*0,224*
Range and heat stress	*0,565 (moderate)*	*0,023*

Table 8: Outcomes Spearman's correlation test between range and the urban liveability indicators.

5. Discussion

Relation with established literature

This research focused on to what extent access to public green spaces influences the success of densification in urban areas. The expectation was that a higher degree of access to public green spaces could improve the urban liveability in neighbourhoods and potentially limit the adverse liveability effects of densification. The findings of this research are in line with previous literature as access to public green space tends to have a strong, negative correlation with nuisance and with the urban heat island effect (Kabisch et al, 2015; Klok et al, 2012). Moreover, similar to previous literature, this research indicated that urban intensity has strong, positive correlations with nuisance and with the urban heat island effect (Seniour et al, 2004; Lemonsu et al, 2015). Additionally, the social cohesion of the selected neighbourhoods tends to moderately decrease when the urban intensity increases, which corresponds to the findings of Dempsey et al (2012). Contrarily, this research did not find a significant correlation between access to public green space and the improvement of social cohesion.

Besides the individual performances of access to public green space and urban intensity on the urban liveability indicators, there is also investigated if a balance between the two influences the urban liveability. Firstly, the identified relationship between urban intensity and access to public green space is in line with established literature, as the two have a strong, negative correlation (Fuller et al, 2010). Still, this research found significant results when statistically testing the range between access to public green space and urban intensity with the urban liveability indicators. Namely, the increase of the range moderately increases the nuisance score and the urban heat stress effect. This suggests that a closer range between the two components might moderately decrease the nuisance and heat stress. The influence of the range on the social cohesion remains uncertain as no significant results are found.

In retrospect to the case study, Groningen seems to have quite a balance between access to public green space and urban intensity, since 8 neighbourhoods have a positive performance on access to public green space and 7 on urban intensity. However, when following the literature, Groningen should increase the public green space within the city-centre and within neighbourhoods, as these areas did not achieve the 10-15 percent green space threshold (Baycan-Levent & Nijkamp, 2004)

Deficiencies of the research

This research used a case-study consisting of 15 neighbourhoods located in the city of Groningen. Although, several significant results were found, these cases are not representative for the whole urban population. In hindsight, the results only give a probable indication of what the influence of access to public green space might be on the success of densification. Furthermore, whilst densification within this research is measured according to a proper urban intensity tool, the potential associated sustainability benefits of densification are not included. Also, urban liveability is measured according to three variables. Additional variables are required to implicate a more coherent scenery of urban liveability. Therefore, this paper is unable to indicate if the sustainable benefits of densification can only be achieved at the expense of the quality of urban life and if these benefits might be outweighed by the negative effects on urban liveability.

Alternatively, within this research context there is indicated that increasing urban intensity is related to some negative effects on urban liveability, whereas access to public green space sees enhancing results. Important to note here, is that according to IOS Groningen (2018) the scores on nuisance and social cohesion are not to be regarded as severely unpleasant or adequate exemplary, as every selected neighbourhood has a low-moderate score on nuisance and a moderate-higher score on social cohesion. The results must therefore be interpreted as relatively lowering and relatively improving outcomes of the nuisance and social cohesion scores.

Furthermore, the outcomes of the nuisance and social cohesion scores gathered from IOS Groningen (2018) represent the perception of the residents within the neighbourhoods. This research did not include the cultural and societal background of these residents, which potentially has an underlying influence on the urban liveability results. Therefore, this paper cannot make conclusions about how access to public green space and urban intensity relate to the overall satisfactory of urban citizens.

Lastly, urban intensity within this research is measured according to an almost similar approach as that of Guan and Rowe (2016). Density and connectedness are calculated following a different method. Other methods of measurement could possibly develop into rather different outcomes. Likewise, another approach to the measurement of access to public green space could fundamentally change the outcome of the research.

6. Conclusions

Contributions of the research

Nevertheless, this research contributed evidence that densification can have adverse liveability effects, as urban intensity has strong, positive correlations with nuisance and the urban heat island effect and a moderate, negative correlation with social cohesion. This provides a likelihood that too much urban densification can indeed result in a severe reduction in the quality of urban liveability. This paper, therefore succeeded to diminish, to a certain extent, the uncertainty about the effects of densification on, for at least nuisance, heat stress and social cohesion. Furthermore, there is indicated that access to public green space tends to reduce nuisance and heat stress. This implicates that additional public green space can probably improve the nuisance and heat stress score. Also, this research indicated that a balance between access to public green space and urban intensity can potentially limit the nuisance and heat stress in neighbourhoods.

Although access to public green space individually tends to significantly decrease the amount of nuisance and additional heat stress within this researched case-study, a balance with urban intensity remains challenging. Increasing the accessibility of public green space will improve the urban liveability but thereby decrease the urban intensity. Therefore, implementing more public green space will potentially have a negative influence on densification on its own. However, as indicated in this research increasing urban intensity through densification decreases urban liveability. Hence, access to public green space seems to be evenly essential as densification, within the achievement of sustainable and liveable urbanism.

Overall, the findings mainly support and highlight the importance of public green spaces within cities, as it solely tends to improve some aspects of urban liveability and as it can conceivably be mixed with densification to attain more successful urban results.

Recommendations for future research

Subsequent research on the relationships between public green space, densification and urban liveability should involve a larger case-study with additional urban contexts. The outcomes of different cities can then be compared, which can produce more attested and representative results. Furthermore, considering social factors such as cultural and societal background is recommended as the perception of people, when investigating liveability, can be an underlying influence. These factors can be obtained according to a survey or by having semi-structured interviews with the urban residents. Additionally, the urban liveability should involve more indicators that provide a more coherent view. Examples can be the feeling of safety or the feeling of attachment with a neighbourhood. Subsequently, the influence of urban intensity and access to public green space can be connected to these further aspects of urban liveability.

Next, the sustainability benefits of densification should be involved in a follow-up study. These could be made tangible by calculating the fossil fuel consumption, the degree of social segregation and economic innovation. Consequently, conclusions can be made about if the sustainable benefits are outweighed by the adverse liveability effects of densification.

To conclude, although densification is regarded as a promising policy within current urban planning, it requires meticulous decision-making. On the one hand excessive densification can deteriorate urban liveability and on the other hand deficient densification fails to obtain sustainability benefits. A joint effort between the contributions of this research and the recommendations for subsequent studies could lessen the latent state of densification and provide additional accentuation on the capabilities of public green space. Ultimately, urban planners could assemble reasonable decisions about the degree of densification and public green space within cities, which could potentially conduct, depending on the urban context, an optimal combination between the two.

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8. Appendixes

A. Table outcomes calculation Global Moran I (compactness)

Neighbourhood	Moran's Index	Expected Index	Variance	z-score	p-value
Hortusbuurtnieuwe-Ebbingekwartier	0,453607	-0,017544	0,009945	4,7246	0,000002
Binnenstad	0,446279	-0,008065	0,004351	6,887828	0,000000
Binnenstad-Oost	0,471225	-0,025641	0,015362	4,008803	0,000061
Indische buurt	0,406681	-0,012195	0,006747	5,099683	0,000000
Professorenbuurt	0,32577	-0,013889	0,00779	3,848452	0,000110
Oosterpark-Wijk	0,411159	-0,004149	0,002293	8,67334	0,000000
Nieuw-Zuid	0,61032	-0,011494	0,006522	7,699447	0,000000
Oosterpoort	0,491914	-0,019608	0,01113	4,848527	0,000001
Herewegbuurt	0,298928	-0,052632	0,03092	1,9993	0,045576
Rivierenbuurt	0,534009	-0,018868	0,010764	5,328972	0,000000
Grunobuurt	0,385788	-0,033333	0,017018	3,212769	0,001315
Badstraten-Zeeheldenbuurt	0,361907	-0,023255	0,012649	3,42463	0,000616
Schildersbuurt	0,547384	-0,019608	0,011019	5,401483	0,000000
Oranjebuurt	0,227665	-0,027027	0,014362	2,125257	0,033565
Noorderplantsoenbuurt	0,390413	-0,028571	0,016829	3,229707	0,001239
Mean	*0,42420327*	*-0,021059*	*0,01184673*	*4,700853*	*0,005499*

B. Table for calculation Shannon index and fraction of urban functions (diversity and connectedness)

Neighbourhood	Eat & Drink	Healthcare	Education	Sport	Leisure	Shopping	Total
Hortusbuurt-Ebbingekwartier	499	60	12	12	130	809	1522
Binnenstad	517	70	12	14	119	856	1588
Binnenstad-Oost	481	59	8	11	112	796	1467
Indischebuurt	158	43	8	11	99	271	590
Professorenbuurt	282	48	8	8	112	438	896
Oosterpark-Wijk	365	62	11	16	118	648	1220
Nieuw-Zuid	332	41	7	15	89	567	1051
Herewegbuurt	278	36	8	9	59	440	830
Rivierenbuurt	355	39	15	11	79	626	1125
Grunobuurt	167	26	14	7	51	365	630
Badstraten-Zeeheldenbuurt	292	27	12	11	64	551	957
Schildersbuurt	376	28	10	11	89	679	1193
Oranjebuurt	251	34	9	8	68	557	927
Noorderplantsoenbuurt	222	43	7	5	80	422	779
Mean	*327*	*44*	*10*	*11*	*91*	*573*	*1055*

Equation shannon index = $-\sum\left(\frac{ni}{N} \cdot \ln\left(\frac{ni}{N}\right)\right)$

n = number within an urban function category
N = Total number of urban functions categories
ln = Natural logarithm

Equation connectedness = $\sum\left(\frac{n}{N}\right)$

n = number of facilities of an urban function (within 900m)
N = Total number of facilties of an urban function

C. Table indicating the corresponding urban liveability indicators per neighbourhood

Neighbourhood	Urban intensity	Access to public green space	Nuisance	Social cohesion	Heat stress
Hortusbuurtnieuwe-Ebbingekwartier	0,657	-1,161	3,800	5,900	1,638
Binnenstad	0,508	-3,176	4,400	5,500	1,807
Binnenstad-Oost	0,587	-3,529	3,800	5,900	1,807
Indische buurt	-0,131	0,803	3,600	5,700	1,249
Professorenbuurt	-0,301	-0,211	3,400	6,300	1,349
Oosterpark-Wijk	-0,662	0,778	3,300	6,400	1,215
Nieuw-Zuid	-0,675	0,361	2,200	6,500	1,249
Oosterpoort	0,254	-1,667	3,400	6,500	1,589
Herewegbuurt	-0,640	0,246	3,300	6,200	1,426
Rivierenbuurt	-0,018	0,307	3,300	6,200	1,479
Grunobuurt	-0,647	-0,187	3,300	6,100	1,320
Badstraten-Zeeheldenbuurt	-0,423	0,823	3,300	6,100	1,524
Schildersbuurt	0,532	-3,626	4,000	6,000	1,600
Oranjebuurt	-0,929	1,391	2,900	6,800	1,401
Noorderplantsoenbuurt	0,011	-0,095	2,900	6,800	1,538
Mean	*-0,125*	*-0,596*	*3,393*	*6,193*	*1,480*

D. Formula for ‘normalized by mean’

$$\mathrm{LN}\left[\frac{\text{Absolute value}}{\text{Mean}}\right]$$