How do cul-de-sacs affect livability in city neighbourhoods?

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Date of submission:
28th January 2022

Submission volume:
III

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Problem statement: "The relationship between neighbourhood-level street pattern and livability."
Type of study: "Case study on the city of Groningen"
Problem question: "How does the presence of cul-de-sacs in neighbourhoods affect livability for residents of the city of Groningen, The Netherlands?"

Abstract

Creating livable neighbourhoods is a difficult endeavour, and choosing which street layouts to use is just one of the many considerations that have to be made. This study looks at the connection between the prevalence of cul-de-sacs and livability on a neighbourhood level to identify emergent patterns. Particularly, the number of cul-de-sacs per neighbourhood is taken as the metric of study, and this is compared with a calculated "livability score" using a multinomial logistic regression model. Data from Leefbaarometer allows for the use of a calculated livability score per neighbourhood, and OpenStreetMap data is used for the number of cul-de-sacs. Results show a significant relationship between the variables, but little variation in livability with number of cul-de-sacs. The study presents a new empirical model for studying neighbourhood level prevalence of cul-de-sacs, and advocates for renewed focus on the importance of street layout in city planning when designing new neighbourhoods.

1. Introduction

The problem of creating livable space has been set to planners for decades, and multiple approaches exist in that domain. People can and do live in wildly varying conditions, and are resilient to the many challenges which their environments present. Despite this, many planners in the past have sought to create the perfect city. From Ebenezer Howard's garden city (1902), to Le Corbusier's Plan Voisin (1925), the quest to design utopian cities has been the goal of many planners throughout history. Of course, this goal and the approach it entails does not take into account many aspects of the real, physical world which bounds what can and cannot be designed. Path dependencies guide city planning, and designing from the ground up is rare. However, in some circumstances, new neighbourhoods, suburbs, and city districts get the chance to be designed anew, changing the spaces where little has been done before. A crucial aspect of new neighbourhood design and city planning as a whole is street layout. The way in which planners choose to layout streets in new neighbourhoods has an impact on livability, as does any intervention in the physical urban environment (Ruth & Franklin, 2014).

The effects of humans' interventions in the physical realm have long been studied, and urban planners often seek to find the best method of intervention in any given context. The choice between street design options is seemingly endless, but two categories often seem to be the main topics of conversation. They are the grid pattern neighbourhood and the cul-de-sac neighbourhood (Cozens & Hillier, 2008). This paper does not set out to definitively conclude that one form of street design is better than the other, or even that one leads to higher livability. This paper is solely focused on observation and review. As an abstraction of the reality of the urban plan, the number of cul-de-sacs per neighbourhood is taken as the metric of study. This study is looking at one half of the dichotomous issue of grid vs. cul-de-sac street design in the hopes that further in-depth research can focus on the relationship between grid pattern neighbourhoods and livability, as shall be touched upon later in this paper.

Much of the previous research done on cul-de-sacs comes from, and is based on findings and government intervention in Australia, Canada, and The United States (Davison, 2006; Beavon et al., 1994; Brown & Werner, 1985; Cozens & Hillier, 2008). This leaves a gap in the literature, where little has been written about the many cul-de-sacs which exist in European cities. In the existing literature on the subject there is also some, but little, discussion on the direct association between the cul-de-sac street design and neighbourhood livability. Most literature focuses on crime rate (Kim et al., 2017), burglary rate (Johnson & Bowers, 2009), or housing prices (Asabere, 1990). This has partly to do with the design and prevalence of cul-de-sacs in places like the USA. Cul-de-sacs in Europe, such as those which appear in Groningen, The Netherlands - the subject of this research - are usually dissimilar in design to those found in the US and Canada. As classified by Hochschild (2015), there are two different types of cul-de-sac: the bulb cul-de-sac and the dead-end cul-de-sac. There is also what he refers to as a through street, as can be seen in Figure 1 below. The findings of Hochschild's research show clear differences in terms of attitudinal social cohesion between the different types of street design, which has its own implications for neighbourhood livability. Namely, Hochschild found that residents of bulb cul-de-sacs "experience the highest level of social and behavioural cohesion" (p.1) as compared to dead-end cul-de-sacs and through streets. For the purpose of this paper, this classification is also useful when identifying the difference between Northern American and European cul-de-sacs, as those observed in Groningen in particular could mostly be classified as dead-end cul-de-sacs. This still leaves a gap where the cul-de-sac street design's effect on neighbourhood livability as a whole, in a European context, can be explored.

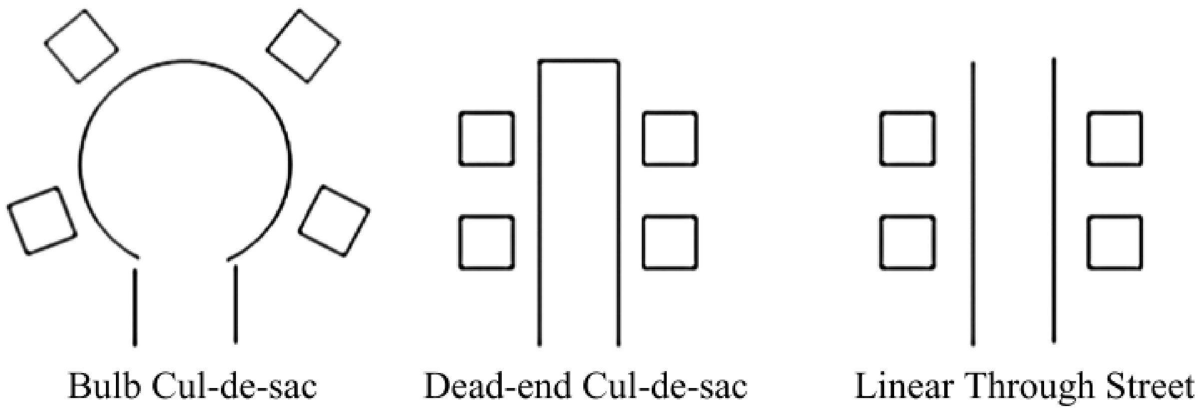


Figure 1. The three types of residential street, as identified and classified by Hochschild (2015).

Other research has identified street patterns such as the grid, modified grid, cul-de-sac, and leaking cul-de-sac (Cozens & Hillier, 2008). This spectrum of street patterns has been made into a more dichotomous distinction between its two extremes for the purposes of this study. Although the research is helpful in analysing street patterns in Europe, their primary subject was the US cul-de-sac present in many suburbs. Cozens & Hillier also call for more holistic planning, pushing aside desire for a one-size-fits-all solution to a very nuanced topic such as town planning, which is also why the aim of this study is not to definitively conclude in favour of one or another street pattern. They found that research on the matter of street layout was inconclusive on matters related to livability such as walkability, social interaction, traffic behaviour, and sustainability (Cozens & Hillier, 2008).

Ruth and Franklin (2014) identify two main components of livability; those being 1) the needs and wants of the people who live or may live in a city, and 2) a city's physical environment. Street layout and neighbourhood design are interlinked, and fall concretely under the umbrella of the physical environment and make-up of the city, which is the main focus of this study. Previous research such as that done by Kim et al. (2017) suggest that longer cul-de-sac street pattern designs lead to lower vulnerability to crime by decreasing connectivity, accessibility, and permeability, which has implications for livability, and that home buyers prefer houses situated on cul-de-sacs (Morrow-Jones et al., 2004).

This paper is an exploratory case study, focusing on the link between the presence of cul-de-sacs on the neighbourhood level and neighbourhood livability. The main objective of this paper is to compare the livability of neighbourhoods within the city of Groningen, according to a quantitative, calculable metric, with an aspect of the street design of those different neighbourhoods. This is done using a quantitative research design, based on previous literature on the effects of cul-de-sacs on livability and its many aspects, with the use of secondary data, GIS mapping, and statistical analysis.

The number of cul-de-sacs per neighbourhood is used as the primary independent variable in this study to represent neighbourhood level street layout. Cul-de-sacs are more easily identifiable and discretely countable. This paper hopes to add to the discussion on street layout by introducing a methodology for testing neighbourhood level street patterns and their effect on livability empirically.

The city of Groningen, The Netherlands was used as a case study for this research. Case study research can be used to test theories, create practical knowledge, and synthesize hypotheses (Flyvbjerg, 2006). Groningen is a university city, with a population of over 200,000 people (CBS, 2018). Students make up a substantial portion of the population and the streets are crawling with cyclists. It is by no means a representative city. Both in terms of demographics and transportation it differs significantly from other cities in Europe. These factors should also be taken into account when interpreting the results of the analysis undertaken in this paper. Despite not being entirely generalizable to other European cities, a study of the city of Groningen could be used in the analysis of other cities in the Netherlands, where similar cultural and demographic contexts can be found, and also in other compact cities. As can be seen in Figure 3, the wider city of Groningen is not very large, and with a population of over 200,000, is very densely populated. Compact cities are characterized by high density, a relatively large proportion of travel done by foot or bicycle, by a mix of transport and land use, and also by the location of trip attractors by effective public transport (Breheny, 1992). All of these apply also to the city of Groningen.

Using all of this information, and attempting to test the theories set forth by the literature on the topic using a quantitative case study approach, the hypothesis of this analysis is that there is a significant positive relationship between the number of cul-de-sacs in a neighbourhood and the livability of that neighbourhood.

2. Methodology

A quantitative GIS analysis of the effect of cul-de-sacs on livability is used in this study. A multinomial logistic regression is used with livability as the dependent variable, the number of cul-de-sacs per neighbourhood as the main independent variable, and total population per neighbourhood, area of each neighbourhood in square metres, and the total number of roads per neighbourhood, taken as covariate. We would expect neighbourhoods with a larger area, more roads, and larger populations to have proportionately more cul-de-sacs. These additional data are thus used in the analysis to account for discrepancies between neighbourhoods. They are used respectively to account for differences in population, physical size, and number of roads, between neighbourhoods. However, because a stepwise regression model is used in this analysis, any covariates which come back as being insignificant in describing the phenomenon of livability are removed from the model.

Operationalizing street layout as "number of cul-de-sacs" does not create a wholly representative statistic. Despite this, a focused view here allows for easier interpretations to be made with the results of the analysis. The number of cul-de-sacs per neighbourhood is calculated using the cul-de-sac mask tool in ArcGIS Pro, which generates a new layer with each road end point in the streetmap data. With this layer, as well as a layer with the neighbourhoods themselves, a new field can be calculated, showing the number of cul-de-sacs identified by the mask tool within each neighbourhood boundary. This is the data which is ultimately used in the regression model as an independent variable against livability. Figure 2 shows a visualization of the distribution of cul-de-sacs throughout the city of Groningen, which is highly irregular. The density peak, in the Eemspoort industrial area in the south-east of the city, shows how location dependent the presence and quantity of cul-de-sacs in the city are. Particularly, as is touched upon later, the relatively new neighbourhoods, built in the 1960s, 70s, and 80s, and those neighbourhoods directly outside the city centre in the north, seem to be the areas where roads end in cul-de-sacs the least.

A quantitative analysis was chosen because in order to carry out meaningful and representative qualitative data collection, a large sample size of the population from each of the 112 neighbourhoods of the city of Groningen would have to have been done. This level of data collection is far more extensive and costly than is possible within the scope of this paper. As well as this, it would have been unwise to carry out any in-person data collection due to the ongoing COVID-19 pandemic.

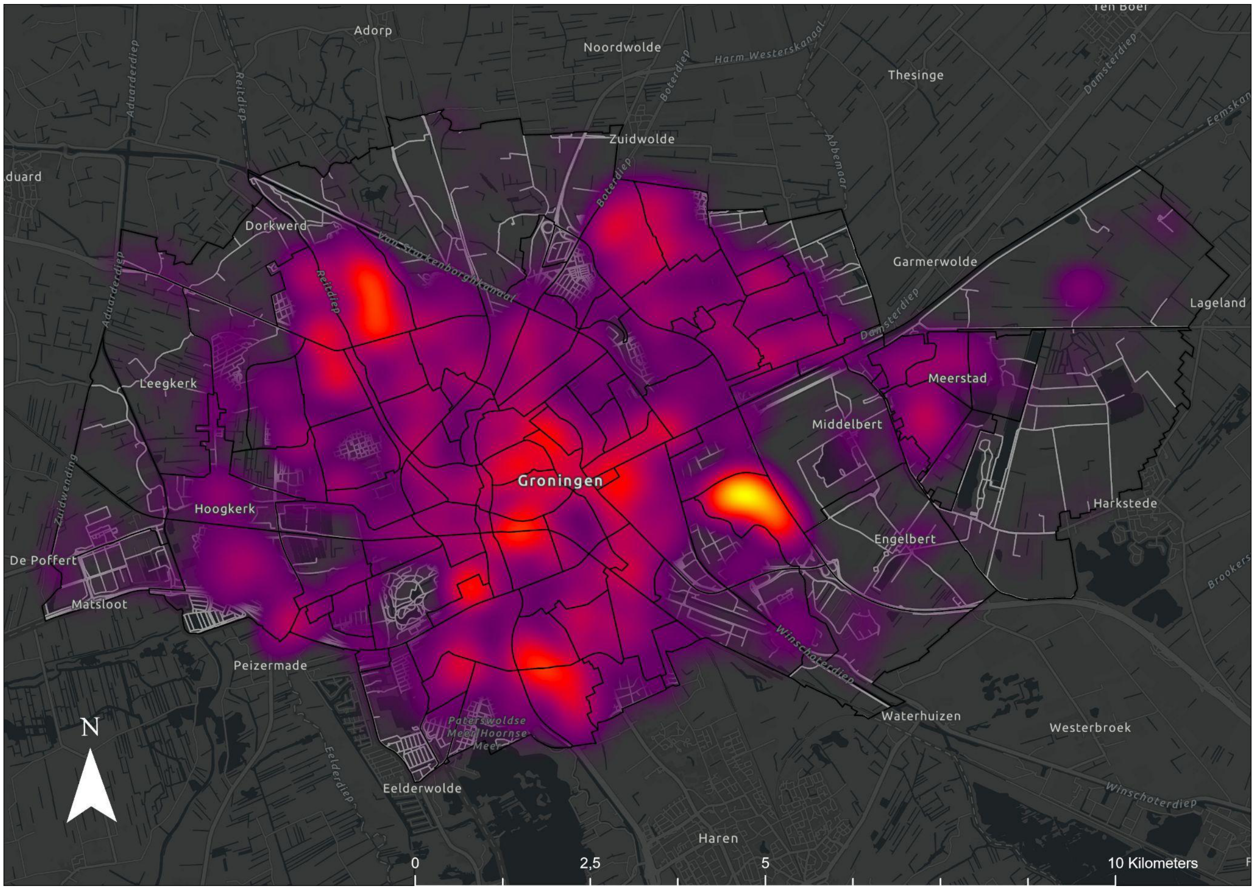


Figure 2. A heat map of cul-de-sacs in the city of Groningen, 2018, from OpenStreetMap data. Legend: 

3. Data

The data used in this analysis are secondary, sourced from Leefbaarometer, OpenStreetMap (OSM), and the Centraal Bureau van de Statistiek (CBS) (see Appendix).

'Leefbaarometer' is a dataset which describes livability for the areas in which people live throughout The Netherlands. It shows the calculated "livability score" of each designated area. Datasets are available at different scalar levels ranging from $100m^2$ parcels of land to entire '*gemeenten*' or 'municipalities'. For the primary purposes of this paper, Leefbaarometer data on the '*buurt*' scale is used. *Buurt(en)/*neighbourhood(s) are sections of municipalities, and this scale of data is used in the analysis for two central reasons. Firstly, as can be seen in Figure 2, these *buurten* are the closest to what we might associate with the classical notion of a neighbourhood. And secondly, due to their quantity in the city of Groningen (n=112), they are the most useful for meaningful statistical analysis. The most recent available Leefbaarometer data is from the year 2018, meaning all of the other data used in this analysis are also from the year 2018 such that they are concurrent with one another.

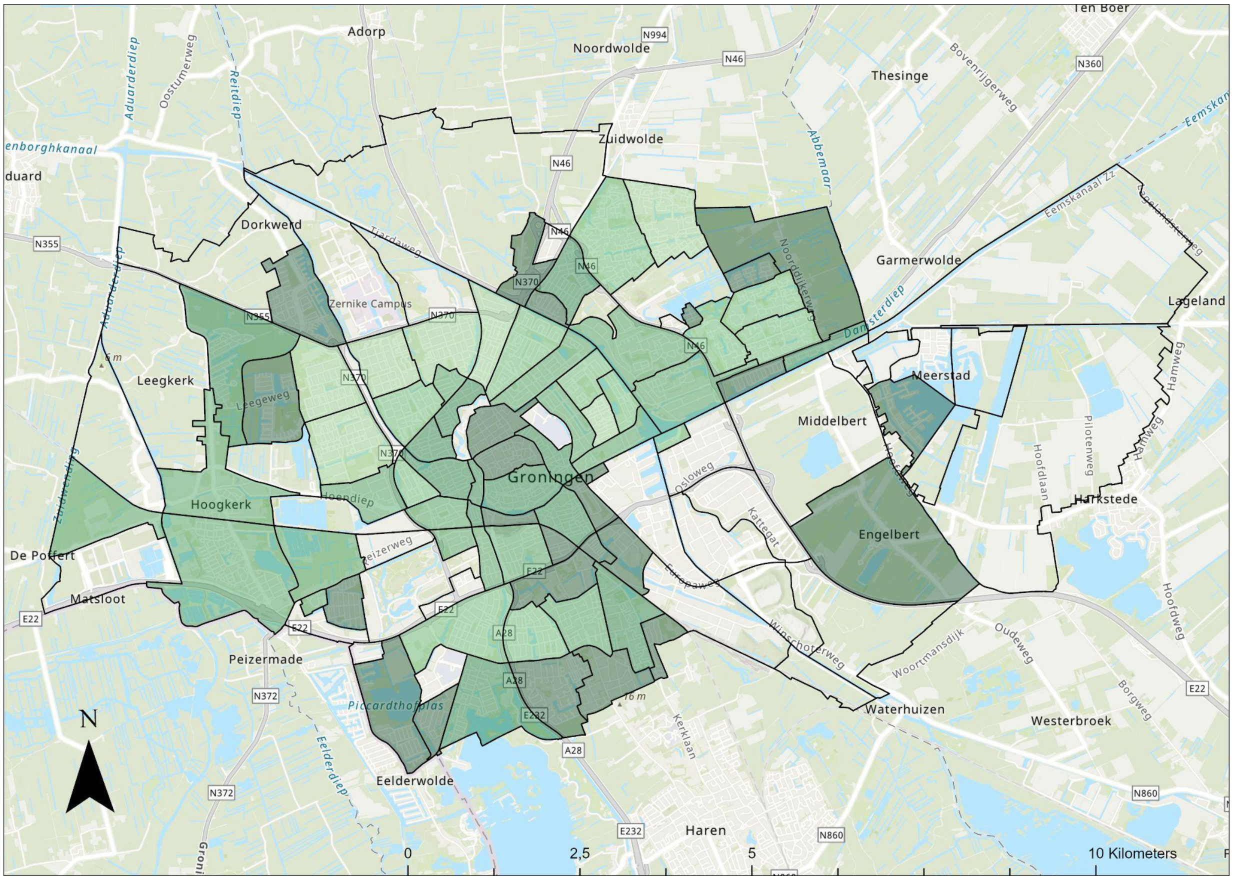


Figure 3. Livability data for each of the [74] available neighbourhoods of the city of Groningen, 2018, where darker green indicates greater livability according to the Leefbaarometer score, and no colour indicates no available data.

OpenStreetMap (OSM) data is a road map dataset which contains roads, motorways, footpaths, cyclepaths, pedestrian areas, and more. This was used in order to find and count the cul-de-sacs in car-accessible/-usable roads within the city of Groningen and its neighbourhoods.

Central Bureau van de Statistiek (CBS) data was used for data such as the total population of each neighbourhood, the total area in square metres of each neighbourhood, as well as for geospatial data on the official municipality and neighbourhood borders.

The data provided and calculated by Leefbaarometer is an objective, calculable measure that reflects a subjective phenomenon - livability. The livability "score" given to each $100m^2$ plot, neighbourhood, and region in The Netherlands, is calculated based on over 100 different indicators, which are split into five categories: housing, residents, services, safety, and physical environment. Each of these categories is given a certain weight in the calculation of the final score. These weights have been assigned by regression analysis. This study uses the Leefbaarometer data from 2018, unchanged, with the aim of both utilizing the data, as well as assessing its concurrency with the literature on the effects of cul-de-sac street design on livability.

Leefbaarometer data does not include and cannot release the data and indicators which are used to calculate the category figures and final score. This leaves much to be desired in terms of analysis, but the literature review and its relevance in the calculation of scores are still considered. The final score of any given area ranges from 1 to 9, as per the calculations made by Leefbaarometer; from 1, meaning very unsatisfactory, to 9, meaning excellent or outstanding. This rating scale is not and cannot be altered for the sake of this analysis. The ratings between 1 and 9 are given as a direct result of the calculations during the analysis process on behalf of Leefbaarometer and reflected in their regression results. The graduated colours on the map in Figure 2, show the difference in livability between different neighbourhoods within Groningen with lighter green being lower on the Leefbaarometer livability scale and darker green being higher on the Leefbaarometer livability scale.

The number of cul-de-sacs per neighbourhood is not a perfect metric, and does not take into account many pieces of information that could be deemed appropriate and relevant, such as angle between intersecting streets, length of cul-de-sacs, type of land use that the cul-de-sac gives access to, etc. As well as this, the cul-de-sac mask tool is also not a perfect tool, and did create some anomalies in the data. Although most of the road endpoints according to the OSM data are correctly identified (Figure 6), some of them have been labelled as road end points, and thus cul-de-sacs, even though describing them as cul-de-sacs might be misleading.

4. Results

Of the 112 neighbourhoods in the city of Groningen, only 74 of them could be used in the regression model due to a lack of Leefbaarometer data. This lack of Leefbaarometer data is mainly caused by a low or non-existent population in these neighbourhoods. During the analysis, using the cul-de-sac mask tool, ArcGIS identified 2,444 cul-de-sacs in the 112 neighbourhoods of Groningen, with a mean of 21.8, and a median of 13 cul-de-sacs per neighbourhood. The median acts as a more representative value here, as there are outliers in the data which bring up the mean, some of which happen to be neighbourhoods with no or very small populations e.g. Eemspoort or Zernike Campus. These neighbourhoods, as well as other outliers in this category also have low or non-existent populations, meaning that there is no Leefbaarometer data available for them.

Due to the fact that the Leefbaarometer final score data is a discrete numerical ranked variable, a multinomial logistic regression was used in this analysis. This was done as opposed to ordinal logistic regression because the dependent variable data did not meet the assumption of proportional odds. In the multinomial logistic regression with the Leefbaarometer score as the dependent variable and number of cul-de-sacs, total population, area, and number of roads, each per neighbourhood as independent variable and covariates, the model came back as being significant at a 95% level of confidence in explaining the variation in the livability score of each neighbourhood.

Figure 4. Model fitting information from multinomial logistic regression, with model significant to a 95% level of confidence.

Model Fitting Information

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	226,159			
Final	184,446	41,714	8	,000

Figure 5. Multinomial regression model parameter estimates table, where 'LB_score' is Leefbaarometer/livability score, 'No_culs' is number of cul-de-sacs and 'Pop_total' is total population, per neighbourhood.

Parameter Estimates

LB_score[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp (B)	
								Lower Bound	Upper Bound
6	Intercept	2,196	1,395	2,477	1	,116			
	No_culs	,038	,037	1,051	1	,305	1,039	,966	1,118
	Pop_total	-,001	,000	3,427	1	,064	,999	,999	1,000
7	Intercept	3,436	1,343	6,548	1	,010			
	No_culs	,029	,038	,568	1	,451	1,029	,955	1,110
	Pop_total	-,001	,000	5,931	1	,015	,999	,998	1,000
8	Intercept	2,891	1,361	4,516	1	,034			
	No_culs	-,077	,050	2,374	1	,123	,926	,839	1,021
	Pop_total	,000	,000	,127	1	,722	1,000	,999	1,001
9	Intercept	4,387	1,340	10,713	1	,001			
	No_culs	,066	,040	2,735	1	,098	1,068	,988	1,155
	Pop_total	-,002	,000	14,713	1	,000	,998	,998	,999

a. The reference category is: 5.

The multinomial logistic regression with livability as the dependent variable and number of cul-de-sacs per neighbourhood as the main independent variable was statistically significant to a 95% level of confidence (Figure 5), meaning we reject the null hypothesis that "all of the coefficients in the model are equal to zero". Because of the fact that the Leefbaarometer score is an objective measure of a subjective phenomenon and that the data used to calculate this score are not openly available, the results and implications of this analysis are limited.

In a separate regression model, with number of cul-de-sacs as the only independent variable against livability, the test came back as being insignificant, meaning that the inclusion of the population data is crucial to the analysis. It is likely an interaction effect which has caused a significant result in this scenario.

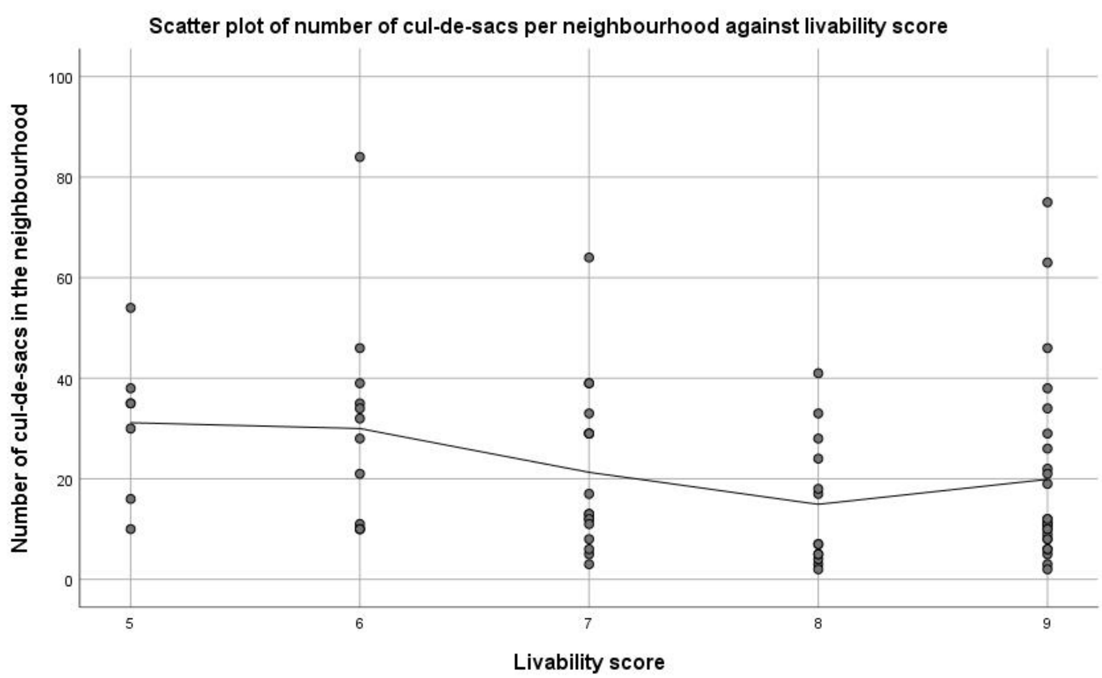
Figure 5 shows that the number of cul-de-sacs and population per neighbourhood are the only statistically significant variables in the model with both the number of cul-de-sacs and population. It also shows that although the model is significant, it isn't exactly clear whether increasing numbers of cul-de-sacs in neighbourhoods increases the odds of that neighbourhood also being more livable, compared to neighbourhoods with a livability score of 5. This is shown in the fluctuating B and Exp(B) values. Coefficient B going from positive to negative across the different groups shows inconsistency, and the Exp(B) values indicate that even though it fluctuates, the odds of this change having an effect on the outcome variable - livability - is incredibly small.

Figure 6. The neighbourhoods in Groningen with a Leefbaarometer/livability score of 5, the lowest in the city, 2018. Left to right, top to bottom: Beijum-Oost (n=54), Bloemenbuurt (n=10), De Hoogte (n=16), Paddepoel-Noord (n=35), Selwerd (n=35), Vinkhuizen-Noord (n=38), and Vinkhuizen (n=30), where n is the number of cul-de-sacs, indicated by the red dots.

The above map (Figure 6) shows the 7 neighbourhoods in the city of Groningen that have a livability score of 5, which is the lowest score on the 1-9 scale that appears in the city. These are all relatively newly developed neighbourhoods, with most being built in the 1960s, 70s, and 80s. A rapid expansion in the city during that time also led to more conventional grid pattern development, as we can see in Figure 6. Except for Bloemenbuurt, all of the 7 neighbourhoods have more cul-de-sacs than the median per neighbourhood in the city as a whole. Of these neighbourhoods, all of them except for Beijum-Oost are in the area immediately surrounding the city centre, and all seven are relatively new additions to the city. Looking at each of these neighbourhoods, Beijum-Oost also seems to be the only one whose street pattern is not based on the grid pattern described by Cozens & Hillier (2008).

Alongside the regression results, looking at a scatter plot plotting livability score against number of cul-de-sacs per neighbourhood (Figure 7), we see that there seems to be a slight negative "correlation" between the two variables. Of course, the slope of this interpolation/mean line, as well as any notion of "correlation" is meaningless here due to the livability score being an ordinal/categorical variable. However, one important takeaway from this scatter plot is that there are simply not enough cases for each livability score (5-9) to allow for a more representative data analysis.

Figure 7. Scatterplot of number of cul-de-sacs per neighbourhood per livability/Leefbaarometer score, Groningen, 2018, where the dots represent individual neighbourhoods, and the mean value line shows a slight downward trend across categories. Neighbourhoods with a livability score of 8 or 9 have on average fewer cul-de-sacs in them than those with a score of 5, 6, or 7, accounting for total population.



5. Reflection

As touched upon in the methodology section of this paper, the number of cul-de-sacs per neighbourhood is far from a comprehensive measure of street layout. When compared to the grid shape street pattern, however, which cannot easily be quantified beyond looking for angles between streets, the number of cul-de-sacs per neighbourhood is a more approachable measure. Using grid street data to then assign a "grid score" to each neighbourhood could have been done, but did not seem as realistic and reliable a metric as simply counting the number of cul-de-sacs per neighbourhood.

Limitations with the Leefbaarometer data and lack of access to its indicators mean that further in-depth analysis of the underlying drivers of the livability score is not possible. It is unknown exactly what culmination of indicators are being used to come to the final livability score. Therefore, it is not impossible that street layout metrics are already included. Thought must also be given to the use of administrative boundaries as guidelines for "neighbourhoods". Although *buurten* are neighbourhoods, using strict, defined boundaries on any map may lead to misleading results. Neighbourhoods aren't wholly uniform throughout, and using a score to define livability within governmentally designated neighbourhood boundaries is unlikely to capture all of the possible differences within neighbourhoods, or account for overlap between them. However, this level of study was chosen because even given these limitations, it was the most usable and relevant to the theory of past literature.

Due to the use of secondary data for this analysis, many ethical problems which could otherwise pose a problem to the research were largely avoided. This, combined with the fact that the analysis was carried out with only publicly available data sources means that issues of privacy were also avoided. The ongoing COVID-19 pandemic made quantitative, desk-driven research a more realistic option as people were encouraged to limit their interactions with others. This was the primary reason for carrying out the type of analysis as seen above. The results of the analysis showed the importance of nuance and context in the field of planning in the physical realm and how vital multidisciplinary action is. As simplistic and possibly reductive a form of analysis this was, it was used as a starter, to take a focused view of the complex problem of optimal neighbourhood design, in the possible hopes of showing how a simpler view can also be valuable.

6. Conclusion

Literature on the topic of cul-de-sac street design and livability suggests that cul-de-sacs are a preferable street design to grids due to their ability to increase social cohesion, lead to less crime, and improve livability for families. The regression results in this paper do not convincingly support this claim. This research did not account statistically for many of the other factors which have an effect on livability. This analysis focused solely on the second of the two aspects of livability as put forth by Ruth & Franklin (2014). The analysis therefore assumes a level of equality between neighbourhoods of all other measures: particularly those classed under the first aspect of livability, such as people's needs and wants in those neighbourhoods, as well as demographics, transportation usage, etc.

The limited scope of this paper as well as the small study area and small number of cases may have caused problems for the thoroughness of the quantitative analysis. Beyond this, none of the literature referenced here used as simplistic a technique as the one outlined in this paper. Opting to count the number of cul-de-sacs per neighbourhood in order to gain a sense of how "cul-de-sac-y" each neighbourhood was, was a simplistic view of the topic of town planning and residential neighbourhood design. It does, however, line up somewhat with the findings of Hochschild (2015) which found that it was only bulb cul-de-sacs which had a significant, positive effect on social and behavioural cohesion, which is linked with the first of the two dimensions of livability identified by Ruth & Franklin (2014): the needs and wants of the people who live or may live in a city. Since bulb cul-de-sacs are rare in the European context, cannot really be found anywhere in Groningen, and dead-end cul-de-sacs are the most common forms of cul-de-sacs, the fact that the regression model was significant but did not show a definitive positive relationship does line up with the findings of Hochschild (2015), albeit through omission, or non-observation.

Although studies on the topic of street layout have found evidence of many positive effects, the inconclusive results of this analysis could bring some doubt to their findings. Particularly, this study shows that although factors within cul-de-sacs, such as social cohesion, safety, etc., may have a significant impact on livability, that may not translate to neighbourhood-wide population livability. The findings of this paper should be taken with some caveats. The limited scope, low number of observations, and European, compact city context may be at fault for producing a result incongruent with the findings of research done in other contexts, with more observations, and different research methods.

Due to the fact that counting the number of cul-de-sacs per neighbourhood is in itself an abstraction of the cul-de-sac street pattern, further research could also be done on a more case-by-case basis, looking for contextual clues in individual or collections of individual cul-de-sacs. This would be more inline with the research methods found in the literature cited in this paper. Further research could also apply the research techniques used here in looking at other cities, whilst possibly also taking into account variables which were left out of this analysis.

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Appendix

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