The fifteen-minute city: The promotion of active modes by a novel city planning concept

An explorative, statistical research on the fifteen-minute city concept applied to the Rotterdam-The Hague metropolitan region

Master thesis

Harm Jan (Arjan) Freije

15-11-2022

The fifteen-minute city: The promotion of active modes by a novel city planning concept

An explorative, statistical research on the fifteen-minute city concept applied to the Rotterdam-The Hague metropolitan region

Master Thesis in partial fulfilment of the degree of Master of Science at the Delft University of Technology, to be defended publicly on November 29, 2022

Author: Harm Jan (Arjan) Freije MSc

Supervisors:

TU Delft
Prof. dr. G.P. (Bert) van Wee
Dr. C. (Kees) Maat
Dr. J.A. (Jan Anne) Annema

TAUW
Ir. B. (Bart) van Genugten
A. (Aletta) Versluis MSc

Preface

A long journey has come to an end by this final assignment to achieve the Master Transport, Infrastructure & Logistics (TIL). An academic journey that started in September 2014, when I entered Wageningen University and Research, starting my Bachelor Landscape Architecture and Planning. During the last eight years, I grew up from a boy with a love for nature, trains and the landscape to an adult willing to apply his knowledge and capabilities to make this world slightly more beautiful than it currently is. After having finished my master thesis for the Master Environment and Resource Management at VU Amsterdam, I wanted to improve my working process for this second thesis assignment. Therefore, during this period, I choose to do many things besides working on my thesis. Everyday my primary goal was to have a nice day and my secondary (or tertiary or…) goal was to make progress on my thesis. This benefited me and I felt relaxed most of the time. Only not when the focus on my thesis and doing practical things besides my thesis was too much out of balance. During this period I undertook several activities, like volunteering, following courses at VU Amsterdam or working for TAUW. Moreover, I often went some days off and had nice vacations with friends and family. These activities gave me the energy to continue working.

But now the research. Engaging personally in a critical look at a promising sustainable concept where urban planning and transport meet is a great challenge. After nine months, I am still enthusiastic about starting a discussion on the topic. This is related to my inner drive to contribute to a world where infrastructure-oriented mobility decreases and social mobility increases, including stronger relationships with nature. But it is also related to the people who supported me.

First, I'd like to thank you, Kees, for introducing the thesis topic, for helping me to direct me when I needed structure and to challenge me by always being critical. Thank you, Jan Anne, for always questioning 'what do you really want' and by offering a sympathetic ear when my working pace went down. Thank you, Bert, for your helpful feedback, and also for creating a positive deliberation environment at the official meetings. I'm thankful to Bart and Aletta for offering insights in working for the environmental engineering consultancy company TAUW. Moreover, I'd like to thank you for helping me to focus on the practicality of my thesis.

I'd like to thank my friends for the support and distraction you gave. Especially I'd like to thank my study friends as sparring partners when I needed you. Your perspectives and critical comments on my work were very helpful. I'm thankful for my family who supported me throughout this period. Wonderful that you read my work and helped me in the process. Moreover, I could just not have done this research the way I did without my girlfriend. Thank you for your never-ending interest, your loving and caring personality and critical review of my research. Last, I'm grateful to God without whom I wouldn't be able to enjoy the beauty of the world. I'm grateful for the given strength to pursue making this world a better place.

Arjan Freije
Delft, November 2022

Summary

In a world, increasingly faced by climate change and high urbanisation rates, the need for sustainable urban development is urgent. The fifteen-minute city (FMC) is a promising concept that aims to promote sustainable, active modes by urban planning. It is defined as a city where people can "*access all of their basic essentials at distances that would not take them more than 15 minutes by foot or by bicycle*". These basic essentials, in this research referred to as amenities, should be located proximate to induce more trips by active modes. Examples of amenities are work locations, supermarkets, schools and train stations. By optimal resource allocation of amenities, the need for making trips by car is expected to decrease. This frees up space for other functions than car infrastructure and results in a reduction of negative effects of car usage, such as greenhouse gas emissions, nitrogen emissions, noise pollution or traffic accidents. Moreover, travelling by active modes results in health benefits. In theory, this concept has a high potential and policymakers are optimistic. However, a critical look reveals three knowledge gaps in our current understanding of the concept.

First, it is unclear which amenities are part of the 'basic essentials' and what actual effect proximities of individual amenities have on a modal shift from car to active modes. There is little differentiation in both the types of amenities, as well as the travel time to amenities. A job location within 30 minutes by active modes may be acceptable, while 10 minutes by active modes to a supermarket is often perceived as relatively far. Second, to what extent the FMC would actually result in more trips by active mode choice is currently unknown. In practice, people do not always opt for the most proximate amenities as their destination and have several other factors affecting their destination and mode choices. Third, research on the concept has never been applied in polycentric urban areas. This research, applied to the Rotterdam-The Hague metropolitan region (MRDH), is the first in a polycentric urban region and improves our understanding of the concept in perspective to other metropolitan areas. This especially improves our understanding of the potential of the concept for comparative regions globally.

The objectives of this research are…

- …to explore our current understanding of the FMC concept and clarify the concept.
- …to gain knowledge of the relations between the FMC characteristics of an area and the effects on the number of trips by active modes.
- …to understand to what extent a polycentric urban area is an FMC, based on both the proximity of amenities and on the number of trips by active modes.

The main research question and sub-questions of this thesis are:

To what extent could the fifteen-minute city concept contribute to more trips by active modes in polycentric urban areas?

1. *What do a literature review and interviews with policymakers reveal about the characteristics of the fifteen-minute city concept?*
2. *What are the effects of socio-demographic and built environment variables on the probability of making an FMC trip?*
3. *What is the relation between the proximity of individual amenities and the probability of making a trip by active modes?*
4. *What are the effects of the FMC indicators on the probability of making a trip by active modes?*
5. *To what extent does the MRDH fulfil the characteristics of the fifteen-minute city based on both the FMC indicators and choices for active modes?*

The research focuses on relations of the FMC characteristics and other built environment (BE) and socio-demographic variables on the probability of making a trip by active modes. Based on a literature review and interviews with policymakers, it is concluded that there is no straightforward application of the concept. Research and practice reveal a wide range of analysed amenities and different approaches to operationalise the FMC. For statistical analysis, the author made a selection of eleven amenities. These are: sport locations, supermarkets, cafes and restaurants, schools, work locations, transit hubs, general practitioners, financial locations, religious venues, town halls and libraries. These are further analysed to determine their relevance for promoting active modes.

Based on the selected amenities, FMC indicators are defined to indicate the FMC characteristics of the MRDH areas on the postal code 4 level (PC4, areas with similar 4 postal code numbers). The indicators are based on the proximity and level coverage of amenities. The proximity is the shortest distance from a household location to an amenity. The level coverage is the number of amenities accessible for a household within 15 minutes by active modes. Proximity and level coverage of the amenities is retrieved by geographical information systems (GIS) analysis. The mobility and socio-demographic data are retrieved from 'On the road in the Netherlands' (Onderweg in Nederland) pooled data for the years 2017-2019, consisting of 42,890 trips within the MRDH, for 13,422 participants. Locations of amenities and other BE data are retrieved from OpenStreetMap, Voorzieningen voor de samenlevingsatlas and Nationaal Georegister for years ranging from 2019-2022.

A logistic binary regression (LBR) is applied to understand the effects of socio-demographic and BE variables, including the FMC indicators, on the binary choice of a person to make a trip by active modes or not. The values of the variables (β) indicate how strong the effect is. These effects are translated to a percentual increase in the probability of making a trip by active modes. The FMC indicators are constructed to analyse a broad combination of level coverage and proximities. Indicators G-J are specified by individual amenities characteristics. Indicators C' and C'' are not independently applied in a LBR. In total, ten indicators are determined and applied in the LBR, which are the following:

- A: Average most proximate distance to all 11 identified amenities
- B: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs)
- C (binary): Level coverage of all 11 identified amenities is at least 1
- C': Level coverage of all 11 identified amenities (in thousands)
- C'': Level coverage of 4 core amenities (supermarkets, schools, work locations and transit hubs) (in thousands)

- D: Combination of A and C
- E: Combination of A and C’
- F: Combination of B and C’’
- G (binary): Supermarket < 1 km, school < 1 km, transit hub < 5 km and work location < 5 km
- H (binary, high level coverage focus): Level coverages of > 5 supermarkets, > 5 schools, > 5 transit hubs and > 500 restaurants/cafés
- I (binary, recreational focus): Level coverage of > 1 transit hub, > 20 sport locations, > 50 restaurants/cafés and > 1 library
- J (binary, basic and more proximate): FMC indicator A < 1 km, Level coverage of > 2 transit hubs, > 5 supermarkets and > 10 work locations

The results show that car ownership has the strongest effect on the probability of making a trip by active modes. If a person owns a car, this probability is significantly less than if a person, ceteris paribus, has no car. Also, an increase in urbanity has a strong positive effect, especially from weakly urban to moderately urban and from strongly urban to very strongly urban. Moreover, women make more trips by active modes than men. The effects of proximity of individual amenities are less evident. The proximity of supermarkets has a high, positive effect, but proximities of three amenities (schools, work locations and transit hubs) have unexpected negative effects. The proximity of seven other amenities is positively affecting active modes. All proximities and level coverages are positively correlated with the probability of making a trip by active modes. Regarding FMC indicators, those that cover both the proximity and level coverage of the amenities result in higher model validity than those that consider only proximity or level coverage. The effects of FMC indicators that include all amenities are stronger than those that only include four core amenities (supermarkets, schools, transit hubs and work locations). Analysis of indicators G-J shows that the effect is stronger if core amenities such as supermarkets and schools are incorporated by a more proximate threshold within the indicator. These result in more trips by active modes, based on current travel behaviour.

Geographical analysis reveals that about two third of the region has high FMC indicator scores, but only about 30% has a high share of active modes. These PC4 areas are mainly suburbs and are usually located further away from transit hubs. Especially the suburbs of the larger cities have a relatively low share of active modes, although all FMC amenities are within 15 minutes by active modes and the level coverage is high. Moreover, geographical analysis reveals that multiple PC4 areas have a relatively low urbanity level, but a high FMC score. Densification of these areas better promotes sustainable transport than densification of less accessible areas.

To answer the main research question, based on this research, the application of the FMC as sole urban planning strategy is not sufficient to achieve high usage of active modes in a polycentric urban region. The application of the FMC does promote active modes and thus reduces CO_2 emissions and other negative effects of car usage, but other variables, such as car ownership, have considerable effects on car usage and diminish the effect of the FMC concept. Moreover, based on the geographical analysis, a high FMC indicator score does not necessarily result in high numbers of active modes trips. The FMC is effective and benefits future urban developments, but other measures to enhance sustainable, active modes are necessary. These should be directed at discouraging car ownership, improving the quality of cycle paths and densification of built-up areas. Moreover, interaction with other mobility measures should be found, for example mobility hubs or shared cars. Promoting local amenities further improves social ties and reduces the need for a car. Future research can qualitatively differentiate the value of amenities that people would need in an FMC. Personal attitudes that determine mode choice should be incorporated in future research. Moreover, spatial analysis between travel behaviour and BE and socio-demographic variables should be researched more in-depth, for example by differentiation within the distance and motives of the trips by active modes.

Nevertheless, this research demonstrates the benefits of a proximity perspective on urban planning to promote active modes. It is a next step in the substantiation of the effects of the FMC concept with these effects put into perspective to other characteristics. Furthermore, the methodology adds value to gaining insights into a concept which is not applied in practice, but based on current area characteristics and travel behaviour, conclusions can still be drawn about the potential. Additionally, a next step in the practical operationalisation of the FMC concept has been taken in this research. Practically, it is recommended to continue the implementation of the concept in policies, but always in combination with other mobility measures. Within polycentric regions, the concept brings benefits, but connections between suburbs of different cities should be enhanced, both for housing development within current city borders as for new urban developments. The use of active modes will benefit from the implementation of the FMC concept.

Table of content

List of figures

List of tables

List of abbreviations

GHG	Greenhouse gas
FMC	Fifteen-minute city
MRDH	Rotterdam-The Hague metropolitan area
BE	Built environment
GIS	Geographic Information System
KiM	Knowledge Institute for Mobility Policy
LBR	Logistic binary regression
PC4	Postal code 4 area. Area with the same for numbers of the postal code
RQ	Research question
QGIS	Quantum GIS
ODiN	On the road in the Netherlands mobility data
JASP	Jeffrey's Amazing Statistics Program
MAUP	Modifiable Areal Unit Problem
UGCoP	Uncertain Geographic Context Problem
POI	Point of interest
NGR	National Geo Register
OSM	OpenStreetMap

1. Introduction

1.1 Context of the research

The Netherlands has a high pressure on land for housing and other land use types, thereby having a lack of space and a strictly regulated land use tradition (Hamers et al., 2021). New urban developments, such as new towns, and expansion or infill development of existing cities reduce this pressure but bring several other challenges. The shortage of houses in the Netherlands is over almost 300,000 and, in coming years, is likely to increase (BZK, 2021). This spatial pressure can be reduced by a decreased need for infrastructure, currently about 3% of the total land area and about 20% of the total built-up area (CLO, 2020). 50% of the public space is dedicated to cars (KiM, Zijlstra, Witte, & Bakker, 2022). A car needs about seven times as much space as a cyclist on the street, a car parked along the street eight times as much and a car parked in a parking lot sixteen times (Metz, 2014). A shift from car usage to active modes, which are (electric) cycling and walking, can result in extra available space for other purposes than infrastructure.

Besides a search for space, the search for measures to reduce greenhouse gas (GHG) emissions is gaining more and more urgency. Currently, 79% of the total road traffic GHG emissions is caused by passenger traffic (CE Delft, 2019). Simultaneously, alternatives with less negative environmental impacts are needed. For example, the Dutch national government has the objective to increase the number of cycling kilometres between 2017 and 2027 by 20%, which would result in less GHG emissions and 1.3 billion euros of health benefits (Van Ommeren, Lelieveld, Tilburgs, & Ritrovato, 2021). To free up space and reduce GHG emissions, policymakers and scientists are searching for alternative measures that contribute to these goals.

In 2016 researchers developed a concept that aims to promote the use of active modes over cars. This is the so-called fifteen-minute city (FMC). According to the father of the concept, in an FMC, people should be able to "*access all of their basic essentials at distances that would not take them more than 15 minutes by foot or by bicycle*" (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021, pp.105-106). This urban planning concept has gained more attention in light of the COVID-19 pandemic with an increased focus on proximity, which is key in the FMC (Moreno et al., 2021). Especially an increased focus on walking gained more attention (Gaglione, Gargiulo, Zucaro, & Cottrill, 2022). The advantages of the implementation of an FMC are related to an increase in liveability, more urban space and health benefits. According to theory, this is due to an increase in nearby 'basic essentials', in this referred to as 'amenities'. By bringing the locations of amenities closer to households, travel times are reduced. These amenities are a widely divergent group of destinations people may visit regularly; from the grocery store, schools and pharmacies, to cultural venues, universities or job locations. For example, the mayor of Paris made the implementation of the FMC one of her focus points (Cullen, 2021). Also, policymakers in other metropoles shifted attendance to more resilient neighbourhoods through FMC planning (Fabris, Camerin, Semprebon, & Balzarotti, 2020). On a city- or metropolitan regionwide scale, the FMC reconsiders optimal resource allocation (Pozoukidou & Chatziyiannaki, 2021). The idea of scholars and policymakers is that if basic needs are brought closer to homes, the use of active modes will increase and car use will decrease. According to Knowledge Institute for Mobility Policy (KiM) (Zijlstra, Bakker, & Witte, 2022), 1/3rd of the Dutch car drivers perceives their use of a car to reach their destinations as a necessity, instead of a possibility. Moreover, research indicates that over 50% of the Dutch people prefers to commute by active modes (Van den Berg, 2022). In practice, just over 25% of the commuting trips are by active modes (CBS, 2020). Thus, for commuting, but also for other purposes, a modal shift by bringing amenities more proximity seems in theory to have a high potential to reduce car trips.

1.2 Research problems

According to several policymakers (from Paris, Melbourne, Utrecht and more), the application of the FMC in urban policies seems to be promising to reduce the aforementioned problems and optimism in urban visions is key. A critical look at the concept may reveal that the potential is lower than expected. Based on current FMC research, three issues have been identified as a starting point for this thesis research.

First, literature reveals that a wide range of amenities has been analysed for a few cities, but few scholars have analysed the actual or possible effects of these amenities on active modes choice. Some scholars differentiated the relative value between amenities with regard to the FMC, but only based on expert views (Pinto & Akhavan, 2022). Others have reconsidered the original amenities by Moreno et al. (2021) and adjusted these to what authors perceived as the most relevant, but authors' choices for amenities differ considerably and are often unclear (Abdelfattah, Deponte, & Fossa, 2022; Badii et al., 2021; Borghetti et al., 2021; Graells-Garrido, Serra-Burriel, Rowe, Cucchietti, & Reyes, 2021; Z. Li, Zheng, & Zhang, 2019). There is no consensus about which amenities should and which should not be considered and what value they have for the FMC. Moreover, scholars do not differentiate the travel time for different amenities. For example, cultural amenities within at maximum 15 minutes may have a very different effect on the choice for active modes than grocery stores proximate, for which inhabitants may opt for the car as they must carry the groceries. The current average travel time to work of about 30 minutes is another challenging amenity to incorporate, as it is very inelastic (Rodrigue, 2020). There is a need to get a better understanding of the proximity of the different FMC amenities on what effect they actually have on the choice for active modes. Therefore, this research applies statistical and geographical analysis to gain differentiated knowledge about the types of amenities.

Second, the effectiveness of the FMC is scarcely substantiated by statistical research. Scholars often discuss the proximity of amenities and assume that bringing these closer to homes will reduce travel time, but the question is to what extent this results in more trips by active modes. An illustration; on average, Dutch primary schools are located 700 meters from home (CBS, 2017), which is less than 15 minutes by active modes. In practice, an average primary school teacher in Amsterdam, one of the most urbanised regions within the Netherlands, commutes 10 kilometres to school (Municipality of Amsterdam, 2019). This exemplifies that proximity of amenities does not necessarily mean that inhabitants will opt for these. The possibility to choose for proximate amenities is influenced by several other factors. Balletto, Pezzagno, and Richiedei (2021) conclude that the FMC is currently poorly discussed in the academic discourse. Further research on the effect of proximity as part of the FMC concept, in relation to other factors that determine mode choice is needed. This is especially important since the goal of a reduction of the need for cars is achieved better if more insights are gained to what extent proximity plays a role. Most scholars analyse the current situation and assume the potential for the fifteen-minute city, but few focus on the question to what extent the FMC may achieve what it aims to achieve: an increase in urban liveability and available space and a decrease in GHG emissions by a reduced need for car use. Hence, a closer look at the actual effects of the proximity of amenities in relation to other factors is highly relevant to explore the potential of the FMC approach in spatial planning practices.

Third, literature research on the FMC reveals that for several case studies amenities have been mapped, but all of these were conducted for metropolitan regions with one core city. This is done for some Italian cities (Badii et al., 2021; Balletto et al., 2021; Gaglione et al., 2022; Pinto & Akhavan, 2022), Bogotá (Guzman, Arellana, Oviedo, & Aristizábal, 2021), Monterrey (Gaxiola-Beltrán et al., 2021), Zagreb (Majstorović, Ahac, & Ahac, 2022) and Barcelona (Graells-Garrido et al., 2021; Staricco &

Brovarone, 2022). Graells-Garrido et al. (2021) explicitly mention the need to combine quantitative research with statistical data sets for multicity analysis, which allows researchers and urban planners to distinguish specific case study results from visible and measurable subdivisions of cities. According to Zhang, Lu, Zhao, Luo, and Yin (2022), a polycentric urban region, which is a city region with multiple city centres, should be better suitable for or even the result of FMC development. As all scholarly case studies are only conducted on large metropolitan areas with one major core city, little is known about the current functioning and actual future potential of the concept for a polycentric urban region. An analysis of a polycentric region contributes to multicity analysis. Therefore, this research focuses on a polycentric region.

The high demand for housing space, sustainable solutions and a healthier society may be partially reduced by enhancing the FMC concept. The Rotterdam-The Hague metropolitan region (MRDH), a polycentric urban region in the Netherlands with a high housing demand (BPD, 2021), is selected to geographically scope the area. Moreover, this region without a core city is interesting since it consists of a gradation of highly urbanised cities to relatively rural towns proximate to each other. Based on the current characteristics and travel behaviour within the MRDH, this research analyses the potential of the FMC. It explores the possibilities of the application of the FMC concept for future spatial planning. New insights are gained by an analysis of amenities that contribute to a choice for active modes over unsustainable modalities, mainly the car. By the application of logistic binary regression (LBR) the effects of how 'FMC' the region currently is, are compared with socio-demographic and other built environment (BE) variables. Hence, the relations between proximity of amenities and the probability of making a trip by active modes are analysed.

1.3 Basic definitions of FMC variables

For this research, basic FMC definitions are constructed. The FMC variables are measured on PC4 level, an area with the same four numbers in the postal code, the yellow area in the example in Figure 1. In general, these areas are smaller than the areas accessible within 15 minutes by active modes. The following definitions are used in this research:

- An FMC trip is a trip by active modes of maximum 15 minutes.
- An FMC indicator is a constructed characteristic of an area that reveals the FMC quality of that area. It is determined by a combination of the proximity and level coverage of amenities. The proximity is chosen as the FMC definition is based on proximity. Level coverage is chosen, since people not only appreciate proximate amenities, but also variety within proximate amenities (López, Annema, & van Wee, 2022).
- The proximity of an amenity is defined as the shortest distance to an amenity from the centroid of a PC4 area. This is made visible on the left in Figure 1. The proximity is independent of the postal code of the location of the amenity.
- The level coverage is the number of amenities within 15 minutes cycling (on a conventional bike) from the centroid of a PC4 area. The calculation of the level coverage incorporates infrastructural characteristics. This explains why the black isochrone line in Figure 1 has an irregular shape. There may be a river between the household and the transit hub which explains why the transit hub is not counted for the level coverage, but still is relatively proximate. In Figure 1, the proximity of supermarkets (sup) is better than the proximity of schools, while the level coverage is the same. Another example, the level coverage of supermarkets in Figure 1 is 3, while the level coverage of transit hubs is 0. Amenities located outside the PC4 area are also included to determine the proximity and level coverage of inhabitants of that PC4 area.

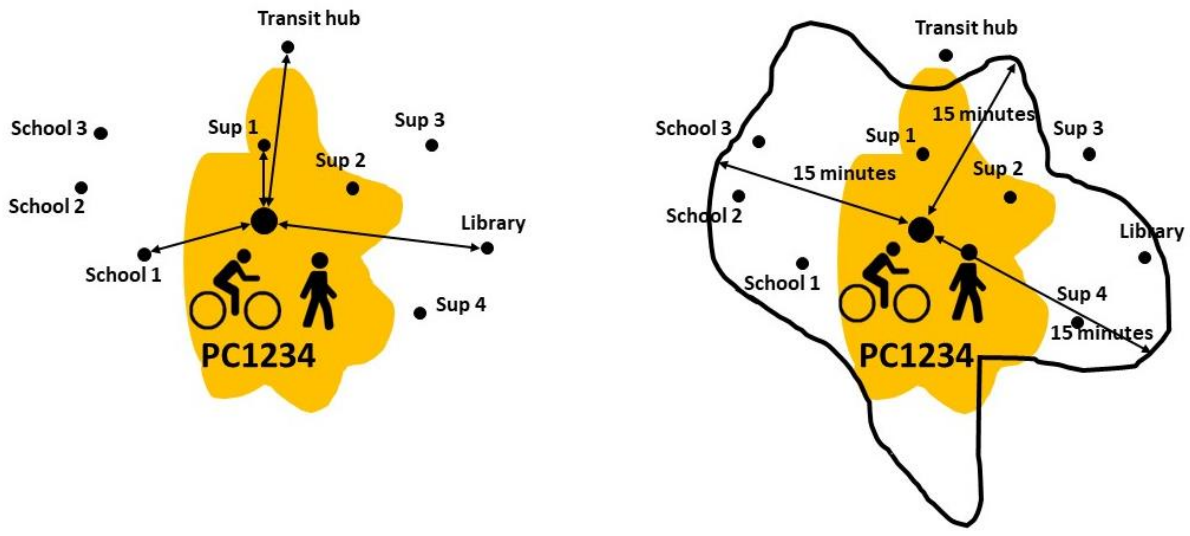

Figure 1: The proximity of (left) and level coverage of amenities (right) for a PC4 area

1.4 Research objective

The objective of this explorative research on the FMC is threefold. The first objective is to clarify the FMC concept, mainly concerning relevant amenities. The second objective is to gain knowledge about the relation between the FMC characteristics of a city and the probability of making a trip by active modes. The third objective is to assess to what extent the MRDH is an FMC. The overall goal is to explore the possible contribution the FMC concept has for promoting sustainable transport in urban areas.

The societal relevance of the research is in the assumed societal benefits related to liveability, the application of the FMC may have. This is worth researching, as with the current housing and climate crisis and an increasing urban population, new urban planning policies are needed to reduce these crises. Scientifically, this research contributes by gaining new insights in the FMC theory, getting an overview of current research on its characteristics and by testing the value of the concept based on current travel behaviour.

1.5 Research questions

To fill the identified knowledge gaps and achieve the objectives of this research, the main research question and related sub-questions are formulated. The main research question (RQ) is:

To what extent could the fifteen-minute city concept contribute to more trips by active modes in polycentric urban areas?

This main research question is answered by a statistical analysis of the effect of the locations of amenities on travel behaviour, compared to socio-demographic and other BE variables. The answer to the main research question is substantiated by the answers to the sub-research questions:

1. What do a literature review and interviews with policymakers reveal about the characteristics of the fifteen-minute city concept?
2. What are the effects of socio-demographic and built environment variables on the probability of making an FMC trip?
3. What is the relation between the proximity of individual amenities and the probability of making a trip by active modes?
4. What are the effects of the FMC indicators on the probability of making a trip by active modes?
5. To what extent does the MRDH fulfil the characteristics of the fifteen-minute city based on both the FMC indicators and choices for active modes?

These research questions guide the research step-by-step. The first research question represents an exploration of our current understanding of the FMC, starting with a literature review. The answer to the second question is a statistical substantiation of the general effects of socio-demographic and BE variables on the probability of making FMC trips. The FMC proximity characteristics are added to answer the third research question. The fourth research question explores the effects of (combinations of) FMC indicators on the probability of making trips by active modes. Thereafter follows a geographical application and analysis of the FMC applied in the case study area to answer the fifth research question. This is based on both the analysed variables, as well on active modes use within the case study area. Finally, the main research question is answered based on the answers to the sub-research questions.

1.6 Scope of the research

This section identifies the research area and scopes the research. The main concepts and the case study area are introduced.

1.6.1 The fifteen-minute city concept

The FMC concept demarcates the focus of this research. Other proximity-oriented concepts such as the 10-minute or 1-minute city are little considered. The core ideas of these concepts are similar to the FMC, but with another travel time. The choice for 15 minutes is based on the perception that this distance is generally acceptable for walking/cycling purposes. Figure 2 displays the relative share of cycling trips compared to trips by car for an increasing travel time. For trips over 15 minutes, the proportion of cycling trips decreases considerably. The FMC has been identified by Moreno but entails many different meanings in research papers and policy documents. Therefore, exact scoping is challenging, but since the concept is relatively new, the number of published papers and policy documents is limited and apprehensible. In current urban planning, accessibility receives more attention than proximity. The difference between those is that accessibility is more location- and infrastructure-oriented whereas proximity focuses more on the vicinity of locations and less on the mobility system itself (Kasraian, Maat, & van Wee, 2019). Moreno (2021) identified six main functions that should be in an FMC, which are living, commerce, entertainment, education, working and healthcare.

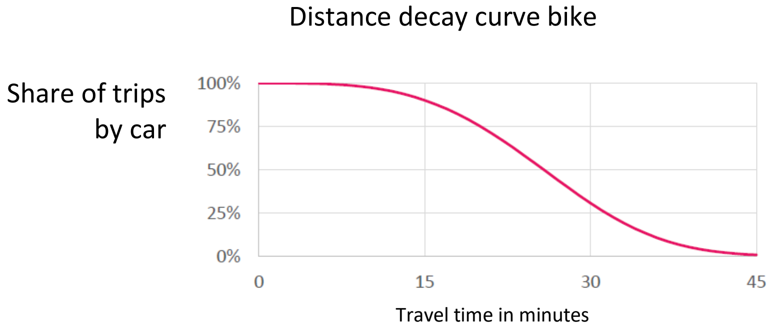

Figure 2: The distance decay curve for bikes in relation to car trips for the MRDH (Goudappel Coffeng, 2018)

1.6.2 The Rotterdam-The Hague metropolitan region

The MRDH consists of 23 municipalities, of which two larger cities and several smaller cities and towns with together 2.4 million inhabitants (MRDH, 2022). Halve of the population lives in Rotterdam and The Hague. Figure 3 shows the region. The polycentricity of the region is visible, as there is not one core city, but two core cities and several proximate other cities. Also, the smaller cities are home to important organisations, such as the TU Delft, the international flower trade exchange or several industries. Especially for the medium-urbanised areas, research on the potential of the FMC could be interesting, as these are more car-dependent than the city centres, but often have a relatively high level of proximate amenities compared to rural areas. Research on a polycentric area has added value as trips within such areas are less bidirectional from core city to suburbs and vice versa, but are much more differentiated. This research gives further insights into the application of the FMC in other polycentric areas.

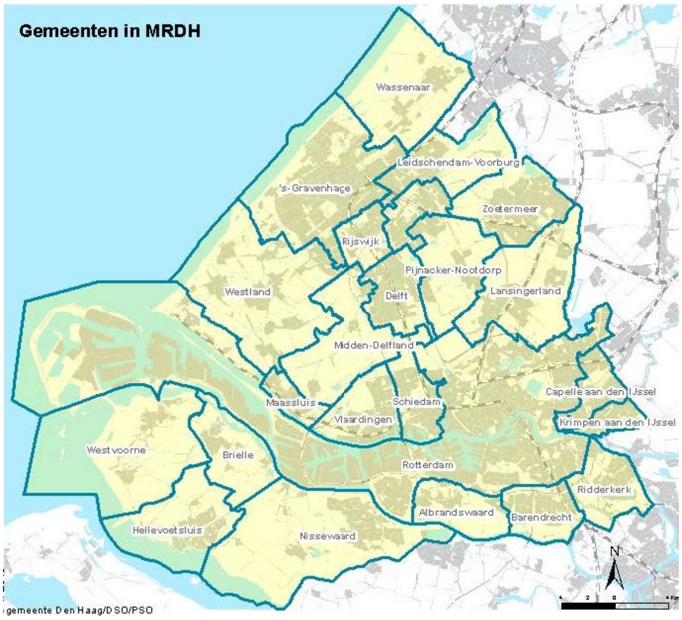

Figure 3: The 23 municipalities that together form the MRDH (MRDH, 2022)

1.6.3 Land use and modal shift

Land use is one of the determinants for mode choices. For example, the urban theorist Jane Jacobs promoted mixed land use as much as possible to achieve liveable, less car-oriented neighbourhoods (Jacobs, 1961). This research scopes to the relation between proximity of amenities and travel behaviour, expressed in the probability to make a trip by active modes. FMC indicators comprise a defined mix of land use by the geographical features of the amenities. Furthermore, the research focuses on active modes and a possible modal shift from car to walking and bicycle (including electric bikes). The FMC is not focused on the choice for public transport, although this mode needs also less space and is more sustainable than the car. Figure 4 displays for different modalities the area that is needed per person. A modal shift results in a land use shift if infrastructure takes up less space.

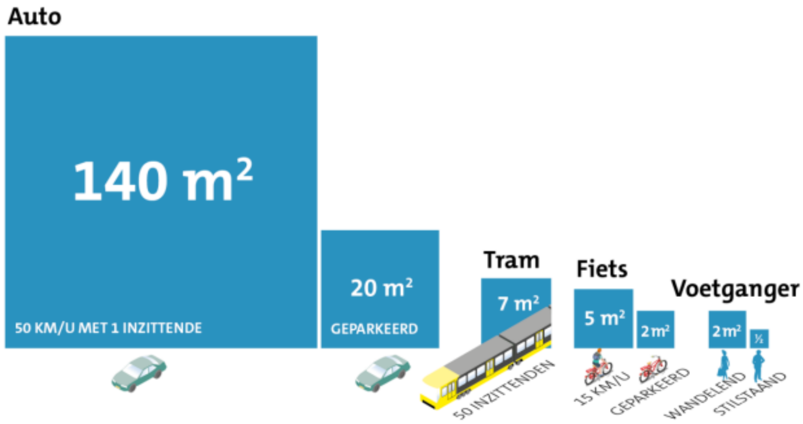

Figure 4: Space needed per person for different modalities (Municipality of Amsterdam, 2017)

It is assumed that by an improvement of the proximity or level coverage, the probability of making a trip by active modes increases. For example, Van de Coevering, Maat, and van Wee (2021) discussed the relation between the proximity of train stations and the effect on car use. According to their research, mode choice is more elastic than usually assumed. Redistribution of amenities to improve the proximity may have more effect than usually assumed. Mode choice is not a choice in itself, but the outcome of a consideration of the preferred way to reach destinations. Improving the proximity by a redistribution of amenities may at first be perceived as difficult and expensive, but can in the longer term reduce infrastructural needs and costs. In theory, the FMC concept has a big potential, but in practice it may result in differentiated effects.

1.7 Structure

The thesis starts with a literature and policy review chapter. The methodology chapter follows thereafter. Within this chapter, the applied data is described. The results of the statistical analysis are in the fourth chapter. Geographical representation and analysis of the case study area are in the same chapter. The fifth chapter contains the conclusion, answers all research questions and discusses the results and practical implications of the research.

2. Literature and policy review

First, a literature review of the FMC has been conducted and the conclusions of what is currently known are discussed. Thereafter, mainly based on interviews, FMC policies are shortly discussed. The goal of this chapter is to clarify the FMC concept and retrieve a set of amenities for statistical analysis.

2.1 Literature review strategy

Through the literature review, insights were gained into what research has been conducted on the FMC and how researchers have approached the FMC. In Scopus, searching for “fifteen-minute city” results in 31 relevant hits since Moreno introduced the concept in 2016. 22 of these have a profound focus on the FMC instead of only slightly referring to the concept. These 22 are summarized in a table, see Appendix 2. In this table, by the uniqueness the most interesting content of a paper that has not been researched or concluded by others is given. Future research recommendations guide this thesis and some of these are executed in this thesis research. By the method of snowballing in the Google Scholar search results, other relevant papers have been found. Also, a search for “fifteen-minute city” on Web of Science revealed one other, relevant paper. These were added to the literature review table in Appendix 2.

2.2 The fifteen-minute city

Moreno's perspective of the FMC has evolved from earlier urban theorists. As part of the neighbourhood approaches, originating in the 1920s (Gaglione et al., 2022), small-scale residential developments with mixed functions and local amenities are given attention (Balletto et al., 2021). In contrast with the zoning approaches, whereby areas are divided into zones with specified functions, the minute-cities, such as the FMC, focus on the human perspective (Bertoni, Dubini, & Monti, 2021). Examples are the 1-minute city (Stockholm), 5-minute city (Vancouver), 10-minute city (Brussels, Utrecht) and 20-minute city (Liverpool) (Beekmans, 2021). All focus on mobility-based urban planning, active modes and reducing travel time by bringing destinations more proximate to residents. The aim of the FMC to "promote more localized mobility patterns" (Graells-Garrido et al., 2021, p.2) is developed by focusing on reducing travel time to a maximum number of minutes.

Moreno further developed his FMC concept by the relations between four domains, visible in Figure 5. According to his theory, the core elements that contribute to a successful FMC are density, diversity, proximity and digitalisation. The focus of this research is on proximity, although density is accounted for by considering the address density of areas. The balance between these four elements and the practical elaboration in urban planning is little developed. By proximity, Moreno considers a 15-minute spatiotemporal radius wherein basic services can readily be accessed (Moreno et al., 2021). He further indicates that proximity is an advanced, but not in itself sufficient dimension for the FMC and interconnectivity with the other dimensions should be considered. Figure 5 conceptually indicates the relations between the transportation system and the socio-economic activities of an area. These features should be discussed in FMC research.

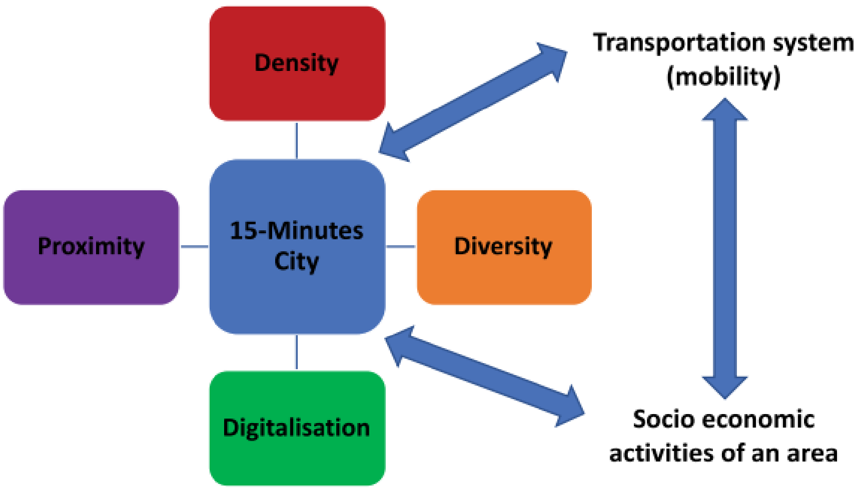

Figure 5: The relations between the FMC and the transportation system and the socio-economic activities of an area (Moreno et al., 2021)

2.3 The fifteen-minute city amenities in literature

The characteristics of the FMC are usually described by a set of amenities. This section explores the mentioned amenities in literature to determine a set of amenities for further analysis.

2.3.1 Selection of amenities

The FMC amenities have been selected in various ways. Although they aim to analyse the same concept and use the same definition as Moreno, none of the selections is similar. First, amenities are selected because scholars are sometimes only interested in one of the functions. For example, Bertoni et al. (2021) have their focus on cultural amenities and thoroughly analyse these. They are not interested in mapping the proximity of other amenities. Second, it is often not mentioned why they have selected their set of amenities. For example, Chen and Crooks (2021) do neither define, nor substantiate their set of amenities. Others, for example Guzman et al. (2021), focus on proximity related to income and select amenities which differ for income groups. Calafiore, Dunning, Nurse, and Singleton (2022) state that they have selected amenities which are generally agreed upon, such as education, healthcare and food-related amenities, but thereby do not explain in detail their specific choices. Moreover, some authors explain they do not select work locations as an amenity, since commuting behaviour has a high uncertainty in the post-COVID-19 situation (Calafiore et al., 2022). Neither of the authors matches the proximity indicators directly to Moreno's functions or aims to analyse all functions identified by Moreno.

2.3.2 Applied methods of analysis

In current FMC research, specific methods reoccur regularly. Most scholars first applied a literature review, but thereafter their substantiation is divergent. No standard methods have been applied and a wide range of amenities have been analysed in various ways to get an understanding of the FMC potential. Most FMC research is desk research (10/22) and case studies (9/22), although several papers also include GIS analysis (8/22). Most scholars refer to Moreno's research and his functions of the FMC, but few differentiate within the value of each function. Elldér, Haugen, and Vilhelmson (2022) applied statistics to determine the relative value of the proximity of amenities. They conclude that the value of the proximity of amenities differs for each urbanity level. By application of principle component analysis, the value of proximate amenities was determined. Li (2022) and Guzman et al. (2021) conducted research on the FMC by the application of a LBR model. Li (2022) focused on the effect of the proximity of grocery stores on the mode and destination choice. Li concludes that this is not a good indicator in perspective to socio-demographic characteristics. The statistical analyses of the effects of the FMC are few. Besides these three studies by Elldér et al. (2022), T. Li (2022) and Guzman et al. (2021), there are no statistical substantiations of the FMC and these are not applied from a comprehensive FMC perspective. This thesis research aims to find FMC indicators that are good predictors for the share of active modes, thereby including socio-demographic characteristics.

2.3.3 The distribution of amenities

A general overview of the characteristics mentioned in the literature review is represented in Figure 6. Out of 22 relevant papers, 12 mention specific sets of amenities that have been analysed. These are discussed and summarized.

A total of 91 indicators are analysed by 12 scholarly papers. These are subdivided by the functions as defined by Moreno. 30 analysed indicators that are directly linked to the division by Moreno, for example 'education' or 'educational activities'. Some amenities are linked to two or more functions. For example, recreational areas are related to both living and entertainment. The most appropriate function is selected and in some cases an indicator is added to 'other', which is about 9% of the total number of amenities. If more amenities are related to the same Moreno function, the amenity is not double counted. The distribution of the analysed amenities is displayed in Table 14.

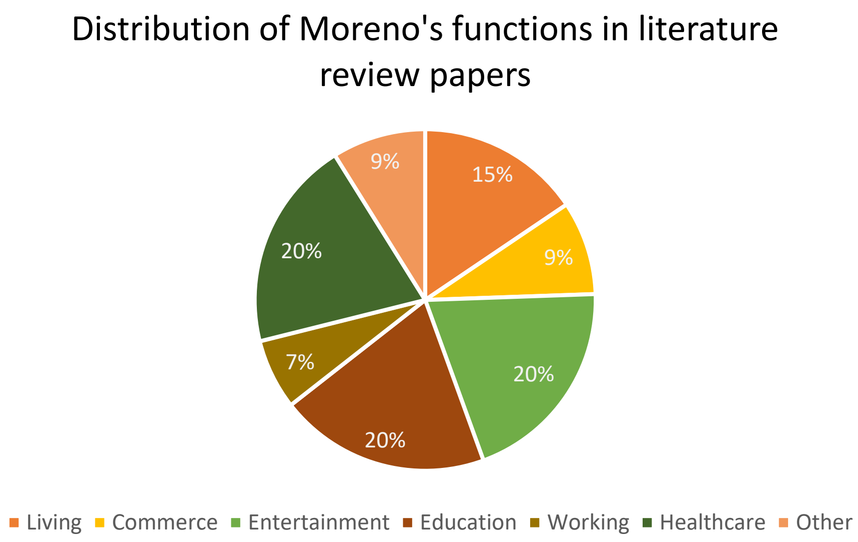

Figure 6: Mentioned amenities divided by Moreno's functions

Figure 6 reveals that entertainment, education and healthcare are analysed most with 20% of the amenities. These 20% corresponds to 9 out of 12 papers. What stands out is that the working function is mapped least with 7%, corresponding to 3 papers, although work location has a significant effect on mode choice for (non-)active modes (Große, Olafsson, Carstensen, & Fertner, 2018). Work locations are rarely considered for FMC analysis. This relates to the difficulty to analyse this amenity compared to more localized amenities, such as a nearby supermarket. Moreover, most FMC research has been published during the COVID-19-pandemic when many people worked from home and this may change commuting behaviour in the long term. Still, since the pandemic seems to have passed, the proximity of work locations is relevant since commuting time increased again and analysis of commuting distance is an important predictor for car ownership (Maat, Timmermans, & Priemus, 2009). Another observation is that the sub-divisions of amenities are rather different. The amenity 'education' is not sub-divided and is almost identically analysed. All papers directly refer to school locations when considering this function. A function like 'living' has a far broader range of amenities that have been analysed, which are all related to living. This indicates that living may be vaguer and widely interpreted. To enhance the living function further practically, the selection of amenities for this function is clarified at the end of this chapter.

None of the scholars aimed to analyse all Moreno's functions, although almost all mention his research. The list of indicators is highly divergent and the authors mainly seem to have selected their own preferred choices. Many Moreno functions have been analysed by divergent amenities, except for education and entertainment.

Appendix 3 displays the number and distribution of amenities. All amenities for this analysis are retrieved from the literature review papers, namely those written by Moreno et al. (2021), Z. Li et al. (2019), Borghetti et al. (2021), Abdelfattah et al. (2022), Graells-Garrido et al. (2021), Badii et al. (2021), Calafiore et al. (2022), Gaglione et al. (2022), Bertoni et al. (2021), Caselli, Carra, Rossetti, and Zazzi (2022), Chen and Crooks (2021) and Guzman et al. (2021).

2.4 Policymakers about the FMC

The FMC concept is mentioned more and more in policy documents around the globe. Cities such as Melbourne, Paris and Utrecht use the concept as the basis for their urban planning and mobility strategies. Moreover, several urbanist and engineering companies discuss the concept as an example of how the city of the future should look like. Utrecht applies a barcode, representing the division of amenities that should be located within 10 minutes for each household. De Graaf (2022), working for the municipality of Utrecht, indicates in an interview that they aim to be more people-oriented, but that the current strategies for mobility are mainly based on production and attraction. The implementation of the FMC benefits from more detailed information about the needs of individual people (De Graaf, 2022). As the barcodes indicate a division of amenities, they steer the urban development, but more as a broad vision, than as a clear roadmap for a selection of amenities. Similar vision-wise approaches are also the case in other cities such as Paris, Melbourne, Milan and Edinburgh. Documents reveal a set of mentioned amenities, but the balance between them and a priority list of the relevance is missing. The question remains to what extent the concept can be more specifically operationalised.

Interviews with policymakers from the municipality of Rotterdam and the MRDH authority, and with a professor in urban design revealed unclarity about the application of the concept. The ideas in themselves are valuable, but the application is very visionary and unpractical. Dijkstra (2022) states that everyone agrees and is enthusiastic if ideas do not become tangible, as is currently the case. If choices for amenities must be made and the concept is operationalised, discussions will rise. For example, Guit and Leurs (2022) mention that an FMC would be ineffective if social ties within (15-minute) neighbourhoods are very loose. In that case, people would still opt to visit sport areas further away or meet friends/family in other cities, often by car. Furthermore, Guit and Leurs (2022) state that the FMC should never become a goal of itself, but always a means to achieve more liveable cities. These are lessons for the practical implementation of the FMC. Interviews with TAUW employees reveal that the current practicality of the concept is questioned. For example, Drenth (2022) mentions that in his view the effect can only be strong if 15-minute neighbourhoods have an individual identity that competes with other urban centres. Otherwise, people will still opt for locations further away with a higher attractiveness and outspoken identity. According to the KiM, proximity of amenities are important factors in explaining car ownership and car use, but there is a lack of suitable data (Zijlstra et al., 2022). The KiM did consider the proximity of stations, which is negatively related with choice for active modes.

Experts indicate that the combination of amenities should always be considered and there is no clear set that is used for several urban contexts (Guit & Leurs, 2022). Most interviewees did consider work locations as a relevant amenity. Four of eight interviewees shared their concerns about the inclusiveness of the FMC whereas lower-educated often have their work in industrial zones which can hardly be brought more proximate, while higher-educated have more flexible work locations that fit better in a mixed neighbourhood. Furthermore, the amenity ‘green’ or ‘sports areas’, are mentioned several times in literature and are related to ‘living’, but could also be perceived as a separate function, for example ‘recreation’ (Angkotta, 2022; Guit & Leurs, 2022).

2.5 Conclusion

Most claims in this section are based on the papers, summarized in Appendix 2. In general, scholars are not very critical on the FMC concept and mainly mention the benefits the FMC concept potentially has. Only three scholars have statistically substantiated their claims about parts of the FMC concept, but not of the proximity to a broad set of amenities as a whole. Also, many seem to have more of an urbanist instead of a sociological perspective, which would focus more on the people on the individual level. Little have a mobility-oriented perspective, whereby authors would focus on the actual effects of the FMC concept on the mobility system. These perspectives are highly relevant for possible FMC policies as the effects of the concept should be perceived in changing travel behaviour.

In most research, the focus is only on walkability and not on cyclability. Cyclability is often mentioned, but analysis remains shallow, although in several metropolitan regions the modal share of the bike is substantial and increasing. The relation with transit is often mentioned, usually as an amenity, for example the location of stations. The relation with shared cars and other new types of mobility (mobility hubs, shared scooters etc.) are rarely mentioned. These can play an important role in further operationalisation of the FMC.

Sometimes, authors refer to the FMC as a place that fulfils most of their needs and sometimes as all of their needs within 15-minutes by bike or walking. This difference indicates that it is debatable what exactly is considered as 'needs'. The effect of the FMC is highest if all basic needs are within 15 minutes as in that case the need for a car for daily purposes is minimized. This may be unrealistic for all inhabitants of a region, but the relation between the number of basic needs within 15 minutes by active modes and car use may exist and may be non-linear. Especially tipping points of proximity of certain amenities causing a far lower car demand are relevant for policymakers. Interviewees indicated their interest in the statistical substantiation of the effect of the FMC.

There is no agreement with regard to specific sets of amenities that must be considered for FMC analysis. Local context matters and partly explains these differences, but the analysed amenities are more divergent than one might expect of a concept so recently developed, although Moreno defined a set of six functions to refer to. The individual interpretations resulted in limited substantiation of the chosen sets of amenities. Moreover, most amenities in literature are poorly or not defined and hard to interpret as a reader. For example, what are 'professional amenities' (Graells-Garrido et al., 2021)? An in-depth understanding of the choice for and meaning of FMC amenities is needed.

The FMC characteristics are more than a selected set of amenities. The focus on people throughout the whole planning process and the most sustainable transport modes, which are active modes, are characterizing the FMC in practice. Mobility systems take a more important role in current planning strategies. Historically, planning developments often demand a mobility system developed following urban development plans. For the FMC, the mobility system is the guiding tool for where and how new development should be developed. Little is known about how a mature FMC will look like, but the priority further shifts to active modes. There is a gradation in amenities mentioned by scholars and in practice. For example, the municipality of Utrecht perceives green, supermarkets and schools proximate as musts, but shares uncertainty about the relevance of other amenities. In this sense, literature findings and policymakers' perspectives are in line with each other.

2.6 Selection of amenities

Based on the results of scholars' opinions of amenities, unclarity of the characteristics of the FMC is stipulated in both research and policy documents. Therefore, a set of amenities is chosen to analyse the concept and make the FMC more tangible. As the amenities determine the characteristics of the FMC, the choice of amenities to in- or exclude in FMC-policies is of utter relevance to get an understanding of these characteristics. A wide range of amenities has been selected and specified. These seem to be the most relevant factors possibly impacting current mode choice. The choice is based on Moreno's functions and specified based on other research and input from expert interviews. All amenities are already researched and the frequencies of these, see Table 14, are a selection criterion for this thesis research. Table 1 displays the selected amenities and the substantiation for this selection. Some amenities, such as cafes, overlap with other amenities, such as restaurants. Therefore, restaurants and cafes together are selected. A short description explains why this amenity was added, mostly based on literature.

Table 1: The selection of amenities for this research analysis

Moreno's function	Amenity	Explanation
Living	Green area	Green area is included since the more green nearby, the more reasonable it is that people will not opt for the car to visit green areas further away
	Sport locations	Sport locations are added since many people conduct sport activities several times a week
Commerce	Supermarkets	Supermarkets are added since people visit these on a regular basis
Entertainment	Restaurants	Several entertainment locations could have been added. For simplicity and since these are often mentioned by scholars, cafes and restaurants are selected
Education	Schools	These are most researched by scholars. The combination of primary and secondary schools is added
Working	Work locations	Job availability is added, although in research this amenity is little considered. The job location is often an important factor people need a car
	Transit hubs	Transit hubs are added since this offers opportunities to reach job locations sustainably and the bicycle-(nearby)train combination is strong
Healthcare	General practitioners	General practitioners are relevant and by many not visited daily, but by some, mainly elderly and infirm people, of high importance to have within walking distance
Other	Financial locations	Financial locations, such as banks and ATMs, offer accessibility to cash and services, although far less than in the past
	Religious venues	Religious venues. By some visited regularly, by others rarely or never, but proximity may play a role in households' mode choice
	Town halls	Town halls, or better specified, governmental buildings, for example to collect a passport or other services. Has been considered by four scholarly papers
	Libraries	Libraries, more and more a meeting place for the neighbourhood where functions are combined and meetings take place

3. Research methodology

This chapter discusses the applied research methods and gives an overview of the data. Figure 7 displays the different steps conducted for this research. The steps are ordered by the research questions.

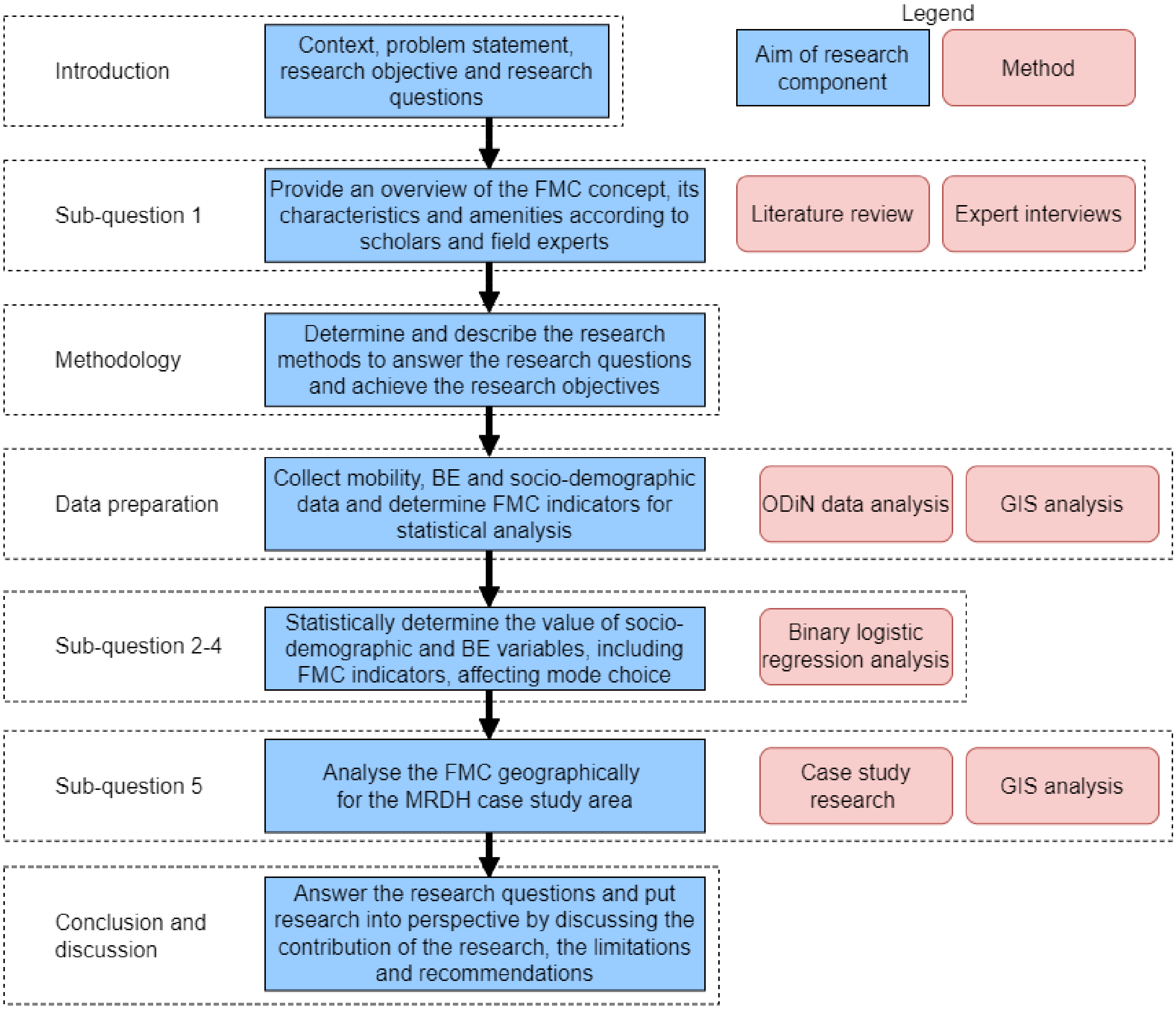

Figure 7: Methodological framework

3.1 Conceptual framework

After the literature review, the conceptual framework is constructed to indicate relations which are relevant to this research. The conceptual framework displays the main relationships between the variables which are used to answer RQ2, 3 and 4, visible in

Figure 8. The choice for making a trip by active modes is assumed to be determined by socio-demographic and BE variables, including FMC indicators. These FMC indicators are specified and based on proximity and level coverage. Currently, the effects of FMC indicators on travel behaviour are unknown. The effects of the FMC indicators in relation to other variables are analysed. More variables, for example travel attitudes, affect mode choice, but are for simplicity left out of this research.

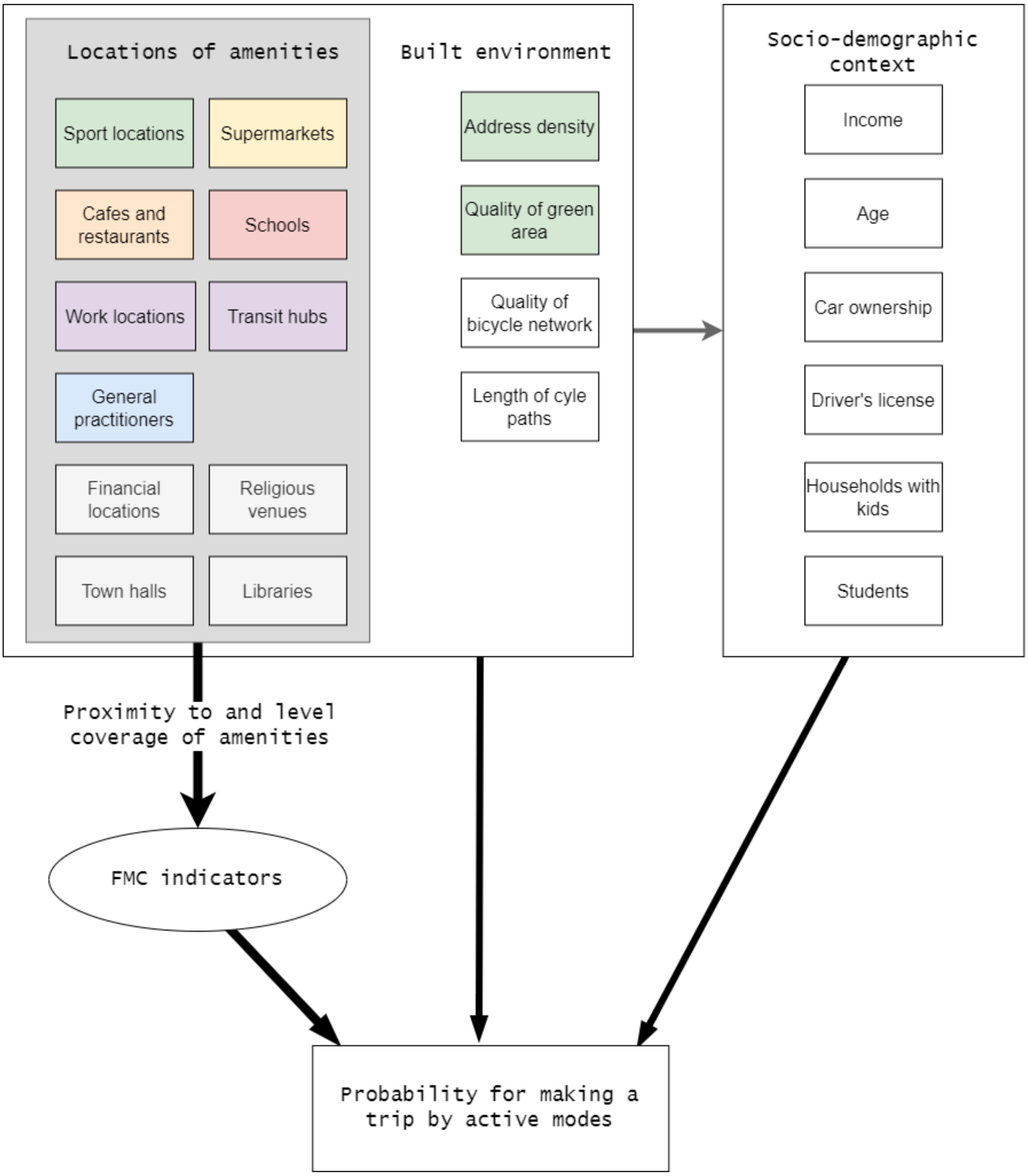

Figure 8: Conceptual framework

The small arrow from the BE to socio-demographic variables represents residential self-selection (Ding, Wang, Tang, Mishra, & Liu, 2018). Residential self-selection reduces the value of BE variables, as people's household location is affected by their personal preferences. For example, a person who loves car driving would probably not choose a living location cars cannot access. These relations are accounted for by correlation analysis, see Appendix 9. The probability of making a trip by active modes is further specified to an FMC trip to answer RQ1. In this case, the FMC indicator is omitted since the FMC characteristic is accounted for by the dependent variable. To answer RQ3 and 4, the dependent variable is a trip by active modes, as displayed in Figure 8. All variables are directly retrieved from available datasets, except for the FMC indicators.

3.2 Literature review

A traditional literature review is conducted to create an overview of the FMC concept, mainly regarding its amenities. The literature research on the FMC needs no further scoping, since the amount of scholarly knowledge is limited. Scopus research gives 31 results since 2016, the year the concept was introduced. These papers are thoroughly analysed. By snowballing extra papers are added to the research. Also, research on similar concepts, such as the 20-minute city, are reviewed. The full literature review is in Appendix 2 and is discussed in chapter 2.

3.3 Expert interviews

To verify the findings from literature and further discuss sets of amenities, interviews are conducted. The interviews give insights into current policy applications and gaps in our current understanding of the FMC. Eight semi-structured interviews with both policy and research experts are conducted. The interviewees have different backgrounds and jobs within the spatial field, but all are working on projects where mobility in relation to land use plays a role. The interviewees are often cited throughout this thesis and the insights gained mainly steer the practical application of the FMC. Appendix 4 contains the list of interviewees and the interview guideline.

3.4 GIS analysis

Geographic Information System (GIS) analysis is applied to calculate the proximity, level coverage and the FMC indicators, based on the amenities data. Figure 9 displays the steps applied in Quantum GIS (QGIS) to process the data. The left series of functions in Figure 9 is the calculation of the number of amenities within 15 minutes for each PC4 area. The right side is the calculation of the proximity. The results, the lowest oval, are the FMC indicators, specific combinations of level coverage and proximity, described in more detail in section 3.5. A detailed GIS analysis is in Appendix 5.

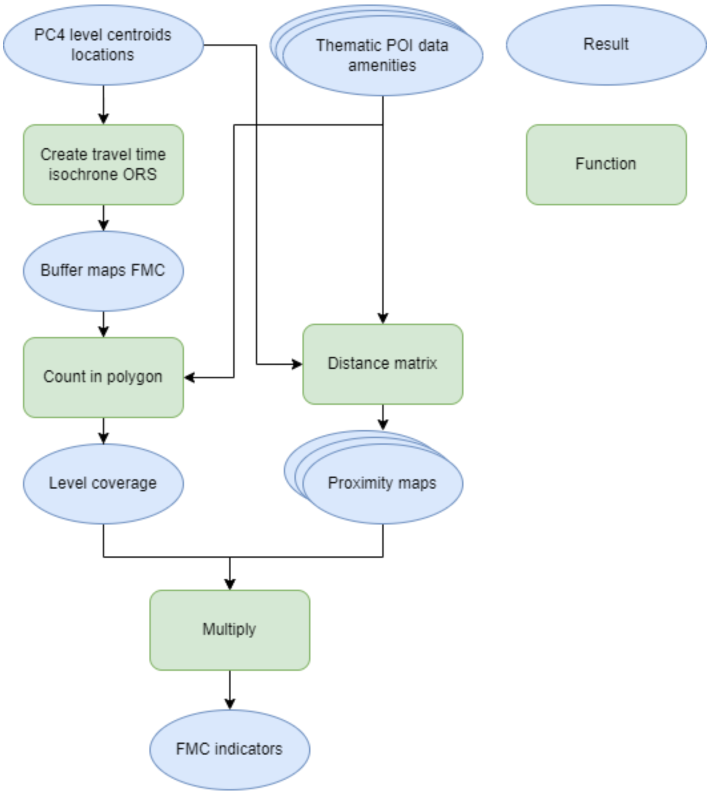

Figure 9: GIS flowchart of steps to retrieve the proximity, the level coverage and FMC indicators

3.5 Fifteen-minute city indicators

The FMC indicators describe the FMC characteristics, based on the proximity and level coverage of amenities. These definitions are explained in section 1.3. Literature research revealed that constructing specific FMC indicators has not been done before. Walkscore (2022) has indicated a proximity walking score for smaller-scale areas, but these are only applied to calculate from one location, not for an FMC analysis of a region. Calculations of the FMC indicators are done in Excell and QGIS. The Moreno dimensions, introduced in section 2.2, partially relate to the FMC indicators. Diversity relates to an FMC indicator by assessing to what extent a PC4 area has a broad selection of amenities proximate. Proximity relates to the distances to amenities and an FMC indicator that considers the average/maximum distance to all amenities. Digitalisation, Moreno's fourth dimension, is not accounted for in this research.

The full list of constructed indicators is in Appendix 6. Only a selection is applied in the statistical models. The proximity distances are in kilometres. Some indicators are binary. This entails that an area gets a score of 1 if the description (for all amenities) is true, otherwise, it is a 0. The amenities are retrieved from section 2.6. Address density and the quality of green area are separately considered in the regression analysis and not included in the FMC indicator. The 11 basic amenities are: *sport locations, supermarkets, restaurants, schools, job locations, transit hubs, general practitioners,* *financial locations, religious venues, town halls and libraries.* See Table 14 in Appendix 5 for the exact properties of each amenity.

The following FMC indicators A-J are statistically researched:

- A: Average most proximate distance to all 11 identified amenities
- B: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs)
- C (binary): Level coverage of all 11 identified amenities is at least 1
- C': Level coverage of all 11 identified amenities (in thousands)
- C'': Level coverage of 4 core amenities (supermarkets, schools, work locations and transit hubs) (in thousands)
- D: Combination of A and C
- E: Combination of A and C'
- F: Combination of B and C''
- G (binary): Supermarket < 1 km, school < 1 km, transit hub < 5 km and work location < 5 km
- H (binary, high level coverage focus): Level coverages of > 5 supermarkets, > 5 schools, > 5 transit hubs and > 500 restaurants/cafés
- I (binary, recreational focus): Level coverage of > 1 transit hub, > 20 sport locations, > 50 restaurants/cafés and > 1 library
- J (binary, basic and more proximate): FMC indicator A < 1 km, Level coverage of > 2 transit hubs, > 5 supermarkets and > 10 work locations

Indicator A is only based on the proximity. This is in line with Moreno's definition, but makes differentiation possible between areas with higher proximity scores.

Indicator B is constructed to analyse if the specification of amenities that are perceived as more relevant, gives other results. Supermarkets, schools and work locations are amenities that many people use regularly. Proximate transit hubs are mainly important amenities to enhance sustainable travel behaviour.

Indicator C is the most strict representation of Moreno's definition of the FMC. This is in line with the image on this research's front page. If all amenities are within 15 minutes, the PC4 area gets a score of 1. Otherwise, it gets a score of 0. A drawback is that there is no differentiation in the number of amenities within 15 minutes. Indicator C' makes quantitative differentiation of the level coverage possible. C'' represents the same for the core amenities.

Indicators D, E and F are constructed to analyse if a combination of proximity and level coverage gives better results. The assumption of this research is that both are relevant for people's mode choice and therefore these are combined.

The specified indicators G-J are used to analyse specific combinations of proximate amenities. These indicators are binary. By specification, travel time and level coverage get different values for each amenity. For example, indicator G differentiates between more proximate supermarkets and schools than transit hubs and work locations. This reveals if more proximate supermarkets and schools have a positive effect on trips by active modes. Other selections could have been made, but this selection covers a broad spectrum. For example, indicator J accounts for 24.7% of the PC4 areas of the region. Descriptive statistics of the FMC indicators are in Appendix 6. The mean scores of the binary indicators display the percentage of PC4 areas to which this indicator applies.

3.6 Logistic binary regression analysis

To analyse the relations between the variables of the conceptual framework, LBR is applied. The variables are assumed to together affect the probability of making an FMC trip (RQ2) or a trip by active modes (RQ3 and 4). The LBR models are run in JASP, Jeffrey's Amazing Statistics Program. LBR is a method to determine the probability of a known binary dependent variable based on independent variables (Harrell, 2015). In this case, it is binary if a trip is made by active modes or not. The main goal is to determine the values of the variables that determine if a person makes a trip by active modes. The weights of the variables, indicated by βs, are unknown and estimated by a maximum likelihood estimation. The probability P that mode choice E (trip by active modes) occurs depends on the weights (β) for variables $X_{1\text{-}k}$:

$$P(E) = \frac{e^{a+\beta X}}{(1+e^{a+\beta X})} \quad (1)$$

Formula (1) is retrieved from Fritz and Berger (2015)

with

$$\beta X = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k \qquad (2)$$

for a total of *k* variables.

The values of the βs contain relevant information to fill the knowledge gaps about the value of different amenities, the FMC indicators and the socio-demographic and other BE variables in comparison to each other. The variables all have a 0-value, which is the standard. For example, the variable 'gender' is either 0 (=male) or 1 (=female). Not all independent variables are binary. The effect of a change of, i.e., X_1 from 0 to 1 on the probability P without altering any other variable determines the value of β_1. β_0 is a constant. The odds ratio describes the percentual effect of the variable. The odds ratio is e^{β}. A positive β indicates an increase, a negative β a decrease and a β of 0 indicates no effect (e^0=1). The model fit of the LBR is assessed by the McFadden R^2 score. In JASP, the pseudo R^2 is calculated and displays a score between 0 and 1. A score of 1 indicates a perfect model. In JASP, the R^2 is adjusted for the number of variables in the model. Formula (3) shows the calculation, retrieved from Smith and McKenna (2013).

$$R^2_{McF} = 1 - \frac{ln(L_M) - k}{ln(L_O)}$$

with:

$L_M = likelihood\ model\ fitted,\ L_0 = likelihood\ null\ model$ and $k = number\ of\ variables$

3.7 Data overview

The other data sources and steps for gaining data are described in this section.

3.7.1 Socio-demographic and other BE data

The colours in the conceptual framework indicate relations with Moreno's six identified functions. For example, green is based on the living function. Detailed amenities data is in Appendix 5. The selection of socio-demographic and other BE data is based on a literature review by Santos, Maoh, Potoglou, and von Brunn (2013) on factors that determine the modal split in medium-sized European cities. As the modal split is the result of mode choices, these factors are assumed to be suitable for this research. These factors are income, car ownership, quality of the bicycle network, age, and if households consist of students or children. Driver's license was added from the ODiN dataset.

Table 2 displays the aggregation level of the applied data for the LBR. Most data are on the individual level, but this was not possible for all data. Data about households describes the type of household an individual is a part of. All individual data in

Table 2 is from ODiN. The quality of green area is from the Mulier research for 2021, the cycle paths data from the Fietsersbond 2019 and the address density from VVS for 2021.

Table 2: Aggregation level of applied data

Variable	Scale
Proximity and level coverage of amenities, FMC indicators, address density	PC4
Urbanity, income, age, car ownership, driver's license, households with children, households with students	Individual
Length of cycle paths, quality of cycle paths, quality of green area	Municipal

The address density (in Dutch: 'omgevingsadressendichtheid') is the density of addresses within a 1-kilometre intersection circle for each 500 by 500 meter household block. The number of households per km^2 is 1.273 times the address density. Urbanity is a similar variable, but with another scale. Figure 10 displays the urbanity distribution. The legend displays the relation between urbanity level and address density.

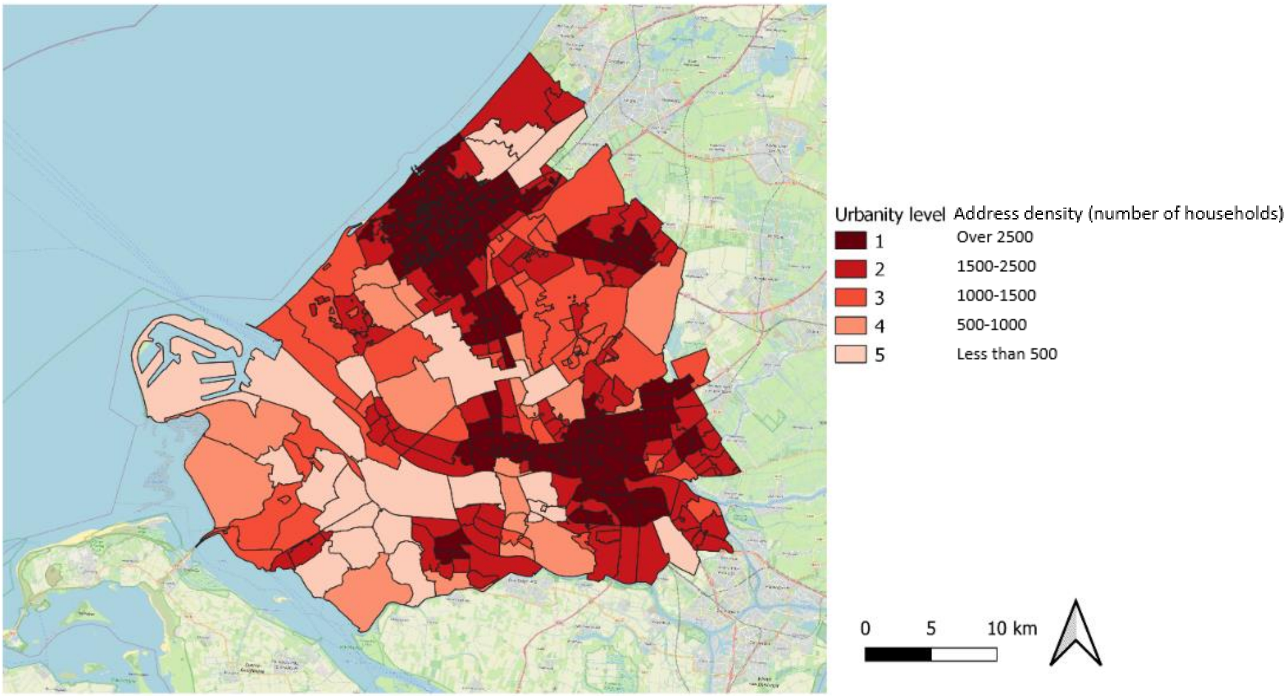

Figure 10: The urbanity level for all PC4 areas within the MRDH region

The income is the total standardised household income, after taxes and welfare, divided into 10 percentiles. Respondents who did not indicate their income are interpreted as average, which is 50%. For simplification and to achieve a more detailed variable analysis the income is also divided into three groups: low (0-40%), middle (40-60%) and high (60-100%). The average income within the MRDH is 64%, which is higher than in the whole country, which is by definition 50%.

The type of cycle network data consists of the length of cycle paths and the quality of cycle paths, rated by the Fietsersbond. Car ownership is the average number of cars per household for each participant. Driver's license is if an ODiN participant did or did not have a driver's license.

The age is in years. For detailed analysis, it is further divided into eight age groups to indicate differences over time as this variable is assumed to be non-linear in relation to the choice for active modes. The division is based on research by Harms, Bertolini, and Te Brömmelstroet (2014) on the differences in bicycle shares for different socio-demographic and BE variables in the Netherlands. Table 3 displays the age groups.

Table 3: Age groups

Age	0-11 years old	12-17 years old	18-29 years old	30-39 years old	40-49 years old	50-64 years old	65-74 years old	≥ 75 years old
Age group	0	1	2	3	4	5	6	7

If a participant is a student is based on if a participant has a student public transport card. Household composition is retrieved from ODiN and subdivided into households with and without children. Households with one or more children, single or double parents, or other households with children are all aggregated to households with children.

3.7.2 Travel behaviour data

The probability of making a trip by active modes is based on ODiN data. This publicly available travel behaviour data 'On the road in the Netherlands' (Onderweg in Nederland, ODiN) reveals information about trip motives, origin and destination and mode choice. The ODiN data is on PC4 level. By data pooling of a selection of the pre-covid years 2017-2019 a sufficiently large dataset is created. All ODiN participants have indicated their travel behaviour for one day. Since the OViN dataset did not contain the PC4 household locations, the PC4 starting point of the trips are assumed to be the household locations. The dataset is cleaned by removing trips without a starting point, trips located outside the MRDH, serial trips (only 1%) and participants who did not undertake a trip and thus did not participate in the mobility system.

In the end, the dataset consists of 42,890 trips divided over 312 PC4 areas. Table 4 displays general information about the ODiN datasets. The dataset of 2017 is called 'Research movement in the Netherlands' (Onderzoek Verplaatsingen in Nederland) (OViN), which is the predecessor of ODiN and has similar data.

Table 4: Overview of general information ODiN datasets

Dataset	Number of trips	Number of participants
OViN 2017	8,864	3,057
ODiN 2018	18,468	5,578
ODiN 2019	15,558	4,787
Total	**42,890**	**13,422**

Table 5 displays the distribution of 8 aggregated modality groups, based on 24 groups from the ODiN research. These groups are applied in the LBR to determine the probability of making a trip by each modality. The simplification of modality groups can be found in Appendix 8. A trip by active modes is made by modality groups 5, 6 and 7. Thus, the total number of trips by active modes is 20,386 of which 13,951 are FMC trips.

Table 5: Distribution of modalities within the MRDH

Simplified modality groups ODiN	Mode	Frequency (number of trips)
1	Car	17,417
2	Train	1165
3	Bus and tram	1451
4	Metro	870
5	Electric bike	1338
6	Conventional bike	10,166
7	Walking	8882
8	Other motorized vehicles	1601

4. Results

This chapter describes and discusses the results of the statistical models. Sections 4.1, 4.2 and 4.3 display the results to answer RQs 2, 3 and 4. Section 4.4 displays the results geographically and answers RQ5. Descriptive statistics, for example average proximities to amenities or average FMC indicators, are in Appendix 7. Appendix 13 gives more information about the travel behaviour data.

4.1 The effects of socio-demographic and built environment variables on the probability of making an FMC trip

These results answer the second RQ, which is:

What are the effects of socio-demographic and built environment variables on the probability of making an FMC trip?

The probability of making an FMC trip in relation to general socio-demographic and BE variables is displayed in Table 6. Model A shows all variables. In model B, the address density variable is divided in the four urbanity levels to gain more insights into urbanity differences. In model C, the age in years is broken down into eight age groups. The McFadden R^2 is the highest for model C.

The constants are significant and describe the probability if all other variables are 0. The reference trip is done by a zero-year-old, low-income male without a car. The interpretation of the constant has little meaning for this research.

The results show that females have about a 20% higher probability of making an FMC trip. For example, the odds ratio of 1.205 in model A means that the probability trip is 20.5% higher for females than for males. This is in line with research by Martín and Páez (2019).

The effect of income is positive but has a small significance. The odds ratio of 0.981 in model A indicates that a person in the higher income group has a 1.9% lower probability than a person with a medium income. This little effect is in line with research by Ton, Duives, Cats, Hoogendoorn-Lanser, and Hoogendoorn (2019). They refer to their own and other research on mode choices and state that the effect of income on active modes choice is usually small or insignificant.

Students have a lower probability (models A and B) or the result is insignificant (model C). This seems counterintuitive as students often have no car, but is explained by a high probability of making a trip by public transport, see Appendix 11. Access and egress trips to a station were often not indicated. Many of these trips are FMC trips, if the station is within 15 minutes by active modes (Schaap, Harms, Kansen, & Wüst, 2015).

Households with children have a higher probability. This is mainly due to the high probability of making FMC trips for children. In general, age has a negative effect (odds ratio 0.992), but model C displays that the relation with the dependent variable is non-linear. Children have a high probability of making an FMC trip, while the elderly (65 and older) also have a high probability. Especially parents of young children (30-39 years) have a low coefficient for making an FMC trip. Since 18% of the participants is below 18, they have a significant influence on the coefficient for households with children.

Car ownership has the strongest, negative effect. The odds ratio of slightly over 0.7 for all three models indicates that if an average person would buy a car, the probability of making an FMC trip decreases by almost 30%. Green quality has a very small and almost insignificant positive effect. If the Mulier green quality score increases by 100%, then the probability of making an FMC trip increases by 0.4%, which is very small. The cycling path characteristics have a higher impact. The quality of cycle paths has a positive effect in all three models, although insignificant in model A. For example for model B, if the quality of cycle paths increases by 10%, the probability of making an FMC trip increases by 4.9%. The length of cycle paths has a very small, but negative effect. If the length increases by 100 kilometres, the probability of making an FMC trip decreases by 0.9% (model A). This seems counterintuitive, but makes sense as the length of cycle paths is larger in rural municipalities, where the share of active modes is lower. Moreover, the effect is very small and therefore of a minor meaning.

The address density has a positive effect of 0.078 (model A) and 0.089 (model C). If broken down in urbanity levels (model B), the effects from weakly urban to moderately urban and from weakly urban to very strongly urban are particularly strong. These effects are in line with research on proximity of amenities by Elldér et al. (2022). Based on the results in model B, if an area is densified from weakly urban to moderately urban (and no other variable changes) the probability of making a trip by active modes would increase by 31.4%.

Table 6: Logistic coefficients for general socio-demographic and BE variables on the probability of making an FMC trip

	Model A		**Model B (urbanity specified)**		**Model C (age groups specified)**	
Variables	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**
Constant	-0.409***	0.665	-0.585***	0.557	-0.852***	0.427
Age	-0.008***	0.992	-0.008***	0.992		
Female	0.187***	1.205	0.188***	1.207	0.209***	1.232
Students	-0.130**	0.878	-0.129**	0.879	0.064	1.066
Children	0.160***	1.174	0.132***	1.141	0.140***	1.151
Income	-0.019	0.981	-0.025*	0.975	0.012	1.012
Car ownership	-0.331***	0.718	-0.351***	0.704	-0.344***	0.709
Green quality	0.004*	1.004	0.003	1.003	0.004*	1.004
Quality of cycle paths	0.169	1.185	0.396**	1.486	0.212*	1.237
Length of cycle paths	-0.009***	0.991	-0.006***	0.994	-0.008***	0.993
Address density	0.078***	1.081			0.089***	1.093
Reference: weakly urban						
Moderately urban			0.273**	1.314		
Strongly urban			0.177	1.194		
Very strongly urban			0.404***	1.497		
Reference: age group ≥ 75 years						
65-74 years					0.064	1.066
50-64 years					-0.134*	0.874
40-49 years					-0.152**	0.859
30-39 years					-0.154**	0.857
18-29 years					-0.055	0.946
12-17 years					0.599***	1.820
≤ 11 years					0.540***	1.716
McFadden R^2	0.026		0.024		0.034	

*** = P <0.001; ** = P<0.01; * = P <0.05

4.2 The value of proximity of amenities on the probability of making a trip by active modes

The results within this section explain the effects of the proximity of individual amenities on the probability of making a trip by active modes. In contrast to section 4.1, the dependent variable is a general trip by active modes instead of an FMC trip. This is because the goal of an FMC is to promote active modes in general, based on proximity of amenities, and not only trips of maximum fifteen minutes. Based on the results, RQ3 can be answered, which is:

What is the relation between the proximity of individual amenities and the probability of making a trip by active modes?

In Table 7, the effects of the individual proximities are displayed. In model A, the address density was removed as this had a distorting effect on the significance of all other variables. In both models, the green quality and cycle path variables were omitted as these were also distorting the results. The proximities to libraries and financial locations were omitted as these were insignificant. The effects of the socio-demographic and BE variables are quite similar to Table 6. The coefficient for car ownership is stronger. The proximities to schools, work locations and transit hubs are contradictory to their correlations with the probability of making a trip by active modes. These correlations are respectively -0.044, -0.010 and -0.024. Therefore, these results have a minor value to determine the relative importance. Gregorich, Strohmaier, Dunkler, and Heinze (2021) recommend summarizing different variables to achieve signs in line with the correlation. This is applied in the next section.

Proximities to restaurants and cafes and religious venues are relatively strong. This may be related to the fact that these are often more proximate in city centres. The proximity of general practitioners has an odd ratio of 0.905. This indicates that if general practitioners are located 1 kilometre less proximate, the probability of making a trip by active modes decreases by 9.5%. To get a better understanding of the relative effects, proximities are considered together in the next section.

For model B, the focus is on the proximity of four core amenities. The address density had no disturbing effect on the proximity variables and was not omitted. The coefficient of the address density is similar to the effect in Table 6. The effect of proximity of supermarkets is relatively strong. An increase in the proximity of supermarkets by 1 kilometre, results in a 24% higher probability of making a trip by active modes.

The McFadden R^2s of both models are higher than the models in Table 6, but still low.

Table 7: Effects of proximity of amenities on the probability of making a trip by active modes

	Model A		**Model B**	
Variables	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**
Constant	0.770***	2.159	0.285***	1.361
Age	-0.007***	0.993	-0.007***	0.993
Female	0.157***	1.170	0.160***	1.174
Students	-0.283***	0.753	-0.287***	0.751
Children	0.128***	1.137	0.138***	1.148
Income	-0.060***	0.942	-0.058***	0.944
Car ownership	-0.363***	0.696	-0.356***	0.701
Address density			0.080***	1.083
Proximity of sport locations	-0.007**	0.993		
Proximity of supermarkets	-0.076	0.927	-0.275***	0.760
Proximity of restaurants and cafes	-0.188***	0.829		
Proximity of schools	0.369***	1.446	0.233***	1.262
Proximity of work locations	0.099***	1.104	0.030	1.030
Proximity of transit hubs	0.016*	1.016	0.020***	1.020
Proximity of general practitioners	-0.100***	0.905		
Proximity of religious venues	-0.297***	0.743		
Proximity of town halls	-0.036**	0.965		
McFadden R^2	0.035		0.034	

*** = P <0.001; ** = P<0.01; * = P <0.05

4.3 The effects of the FMC indicators on the probability of making a trip by active modes

The devised FMC indicators from section 3.5 are modelled in LBR with the same basic variables as section 4.1, model A. Within this section, the FMC indicators effects are analysed and discussed to answer the fourth RQ, which is:

What are the effects of the FMC indicators on the probability of making a trip by active modes?

The effects of the socio-demographic and BE variables are fairly similar to the results in the previous two sections. Address density and length of cycle paths were omitted for most of the models, since these variables had a distorting effect on the other variables. As all socio-demographic and other BE variables are discussed in section 4.1, this section only discusses the FMC indicators. The complete models are in Appendix 12.

Table 8 displays that for some models both a proximity and a level coverage indicator (D, E and F) are applied. The FMC indicators are described in the first column, the coefficient and odds ratios are in the next column. By the R^2s, in the third column, the quality of the model for each FMC indicator is compared.

Table 8: Comparison of the FMC indicators. Effects of each indicator (or combination of two indicators) on the probability of making a trip by active modes

Indicator	**Coefficients**		**Coefficients**		**R^2 model**
	Proximity part value indicator	**Odds ratio**	**Level coverage part value indicator**	**Odds ratio**	
A: Average most proximate distance to all 11 identified amenities	-0.067***	0.935			0.033
B: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs)	-0.036*	0.964			0.029
C (binary): Level coverage of all 11 identified amenities is at least 1			0.033	1.033	0.029
D: Average most proximate distance to all 11 identified amenities and binary level coverage of all 11 identified amenities is at least 1	-0.043**	0.957	0.383***	1.467	0.035
E: Average most proximate distance to all 11 identified amenities and level coverage of all 11 identified amenities (in thousands)	-0.044**	0.957	0.004***	1.004	0.035
F: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs) and level coverage of these core amenities (in thousands)	-0.092***	0.912	-0.122**	0.885	0.029
G (binary): Supermarket < 1 km, school < 1 km, transit hub < 5 km and work location < 5 km	0.158***	1.171			0.029
H (binary, high level coverage focus): Level coverages of > 5 supermarkets, > 5 schools, > 5 transit hubs and > 500 restaurants/cafés	0.144***	1.155			0.033
I (binary, recreational focus): Level coverage of > 1 transit hub, > 20 sport locations, > 50 restaurants/cafés and > 1 library			0.111***	1.117	0.033
J (binary, basic and more proximate): FMC indicator A < 1 km, Level coverage of > 2 transit hubs, > 5 supermarkets and > 10 work locations	0.177***	1.194			0.030

*** = P <0.001; ** = P<0.01; * = P <0.05

Indicator B is the only indicator which is not significant. Most signs are as expected. Proximity indicators A, C-F are negative and level coverage indicators B, D and E are positive. Level coverage indicator F is not as expected. If the level coverage of the core amenities (F) increases one would expect an increase in the probability of making a trip by active modes. This may be caused by a too high correlation between the proximity and level coverage of the core amenities. Moreover, work locations, determining 1/4th of this indicators, are often located further away from households, mainly industrial areas. Indicators G-I have positive signs. If the situation as described by the indicator is the case, then the probability of making a trip by active modes increases by the percentage of the odds ratio. An example of the interpretation for indicator G: if inhabitants have a supermarket and a school within 1 kilometre, and a transit hub and a work location within 5 kilometres, than the probability of making a trip by active modes in comparison to areas where this situation is not the case, is 17.1% higher. This demonstrates a significant effect of the FMC characteristics of an area on trips by active modes.

Indicator A shows that if the average distance to all most proximate amenities increases by 1 kilometre, the probability of making a trip by active modes decreases by 6.5%. In comparison, the effect of the proximity of four core amenities (model C) is smaller. This may be related to the fact that the non-core amenities, such as libraries, restaurants and cafes, are usually more located in city centres. The insignificant FMC indicator of model B is positive, but not strong. This means that if all amenities are within 15 minutes cycling, the probability of making a trip by active modes does not increase much in comparison to other variables, for example car ownership.

Model D and E have a combination of a proximity and level coverage indicator. This benefits the R^2 of the model as these have the highest R^2. Especially the level coverage of amenities has a strong effect, but this is in 1000s of amenities within 15 minutes travel time and has very high scores for city centres. Therefore, it is too far-reaching to conclude that this indicator is more important than others.

Model F focuses on the core amenities by a combination of the proximity and level coverage of the core amenities. Compared to model D, the R^2 is lower, which indicates that model F describes the probability of making a trip by active modes less precise. This is partially caused by the unexpected sign of the level coverage indicator.

A comparison between models G and H shows that the effect of indicator G is stronger than H. The FMC indicator J has the highest coefficient and is an FMC with more proximate amenities and high level coverage. For example, the requirement that there should be 2 transit hubs within 15 minutes reduces the number of PC4 areas for which this is the case. If model J is the case, then the probability is 19.4% higher. For example, if an area has a share of active modes of 20%, but improves in Models G to J differentiated in travel time for different amenities. For example, a comparison between models G and J displays that the effect of a stricter definition (model J) results in a higher coefficient.

In perspective to socio-demographic and other BE variables, the FMC indicators have a medium-strong effect, based on the coefficients. Variables such as car ownership, students and gender (see Appendix 12) have a larger effect, but other variables have lower effects. The effects of the FMC indicators are evident but in itself insufficient to increase the total share of active modes to high percentages. For example, if the number of proximate amenities in a PC4 area increases the score of indicator J from 0 to 1 (as it is binary), trips by active modes are likely to increase by 19.4%. This is a strong relation, but if the active modes share in this area was about 50% (which is already relatively high), the share will increase to around 60%. The effects of the FMC indicator scores on themselves are thus not sufficient to reduce the share of car trips to neighbourhoods with no need for cars.

4.4 Geographical analysis of the FMC indicators

The analysed data on the individual level gives valuable insights if applied on the MRDH level. Thus, this section dives deeper into the geographical analysis of FMC indicators, thereby including mobility data. Three FMC indicators with significant statistical results are geographically represented and discussed. Based on this analysis, the fifth RQ is answered, which is:

To what extent does the MRDH fulfil the characteristics of the fifteen-minute city based on both the FMC indicators and choices for active modes?

The effects of the FMC indicators in section 4.3 were significant, but the question is if this is enough to achieve a city with high shares of active modes as the aggregated result of individual choices for active modes. If areas are in practice an FMC, then not only the FMC indicator should be high, but also the share of active modes. For this analysis, a share of over 50% active modes was determined as sufficiently high for an FMC. FMC indicators B, E and J, two of them with relatively high model R^2s in Table 8, are analysed. Appendix 13 displays the modal share maps of the region. These were used to create Figure 11 and Figure 12.

4.4.1 Geographical analysis of FMC indicator B: all 11 amenities within 15 minutes cycling

First, indicator B is displayed and analysed. Figure 11 shows the areas which are an FMC area, if Moreno's definition is applied most strictly with regards to all basic needs within 15 minutes, considered by indicator B. The orange areas have a high share of active modes and all amenities proximate and are thus in practice FMC areas. This accounts for in total 94 PC4 areas, about 30% of the MRDH. Hence, most PC4 areas are not an FMC. The cores of the large cities do have a high share of active modes and all amenities proximate, but also some PC4 areas in smaller cities, like Spijkenisse, Maassluis and Vlaardingen. Several suburbs are an FMC when only looking at the proximities, but are not based on modal share. This accounts for in total 139 areas. Some of these areas have a high share of public transport, but most are more car-oriented, although all FMC amenities are within 15 minutes by active modes. The application of Moreno's basic FMC definition of having all basic needs within 15 minutes is insufficient to achieve high shares of active modes.

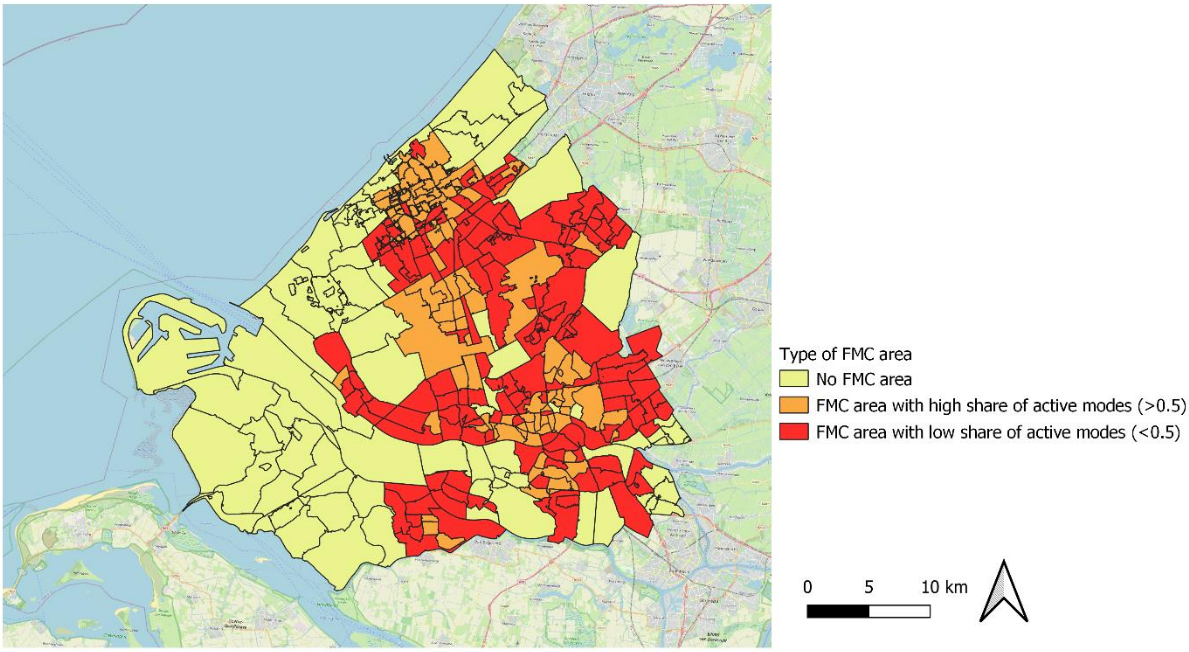

Figure 11: FMC areas based on indicator B in combination with the share of active modes

4.4.2 Geographical analysis of FMC indicator E: combination of average distance to all 11 amenities and average number of amenities within 15 minutes cycling

In Table 8, the highest statistical fits were for indicators D and E. Therefore, indicator E is selected for geographical analysis. This indicator is represented in Figure 12. As the indicator is a combination of proximity and level coverage, the representation is further differentiated. Areas that are within the lowest 50% average distance of all amenities and the highest 50% average number of amenities are perceived as FMC areas. These are highlighted in orange and red in Figure 12. Orange areas have a high share of active modes and are thus also FMC areas with respect to the actual travel behaviour.

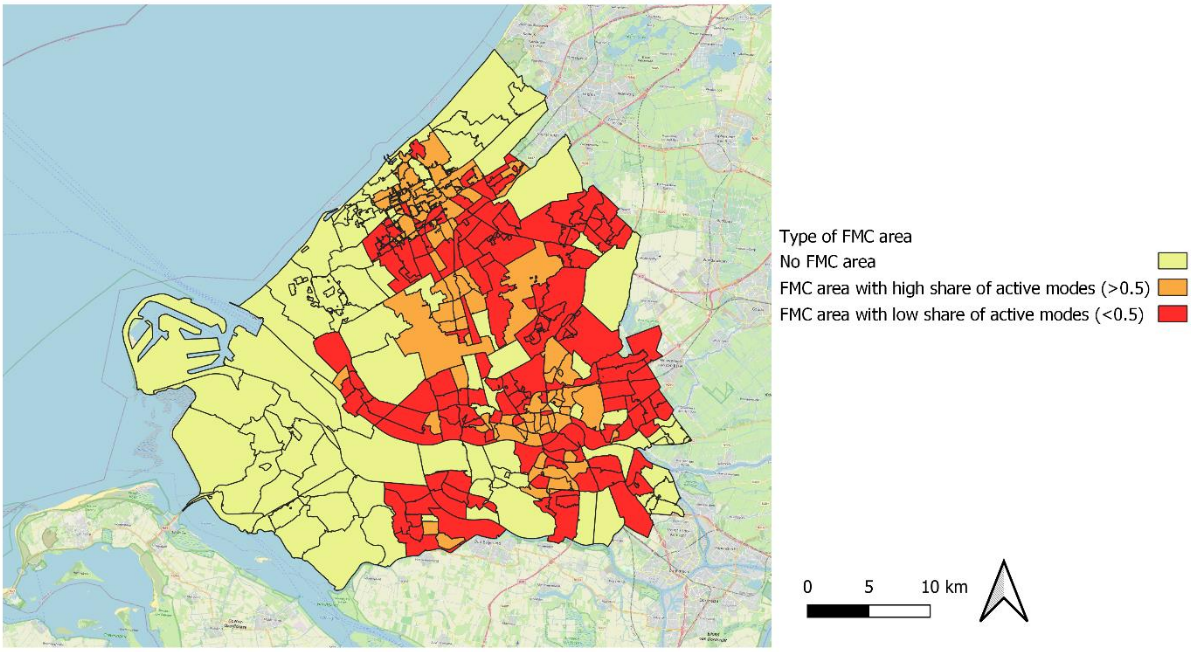

Figure 12: FMC areas based on indicator E in combination with the share of active modes

The number of areas that fulfil indicator E is 10 less than for indicator B. Areas that are only yellow in Figure 12, but not in Figure 11, have a lower number of amenities and are therefore not considered an FMC. These are mainly located in the suburbs of the larger cities. 84 of the 312 areas, about 27%, are orange and 139 are red. To promote active modes within these red areas, other variables than a combination of the proximity and level coverage must be considered, as this high FMC score in itself does not cause a share of active modes (>50%). Although the combination of proximity and level coverage results in a higher model fit and fewer FMC areas, the geographical representation demonstrates that it is not sufficient to explain a high share of active modes.

4.4.3 Geographical analysis of FMC indicator J and urbanity level

The third analysed indicator is FMC indicator J: average distance to all amenities of maximum 1 kilometre, at least 2 transit hubs, 5 supermarkets, 5 schools and over 10 work locations within 15 minutes cycling. If all these proximity and level coverage constraints are fulfilled, the PC4 areas is indicated in green in Figure 13. Based on this definition, 92 of 312 PC4 areas (29%) are an FMC. The comparison with the urbanity level results in green areas with FMC characteristics, but diverging address densities/urbanity levels. Density is one of Moreno's (2021) dimensions and a success factor for the FMC. Lighter green areas have the potential to become denser FMC areas. Some of these areas, such as the area between Delft and Schiedam, are very well protected and cannot easily be developed, but other lighter green areas are more suitable for densification.

Compared to FMC indicators B and E, Figure 13 is a more practical representation and a good starting point for spatial development. The lighter green areas could in future be transformed into higher-density FMC neighbourhoods. The specified amenities are already proximate. Based on the statistical analysis in section 4.1, densification from urbanity level 4 to 3 and from 2 to 1 will be most effective in increasing the probability of making FMC trips. If new housing development is taking place in these lighter green areas, the probability is higher that new inhabitants will make more trips by active modes.

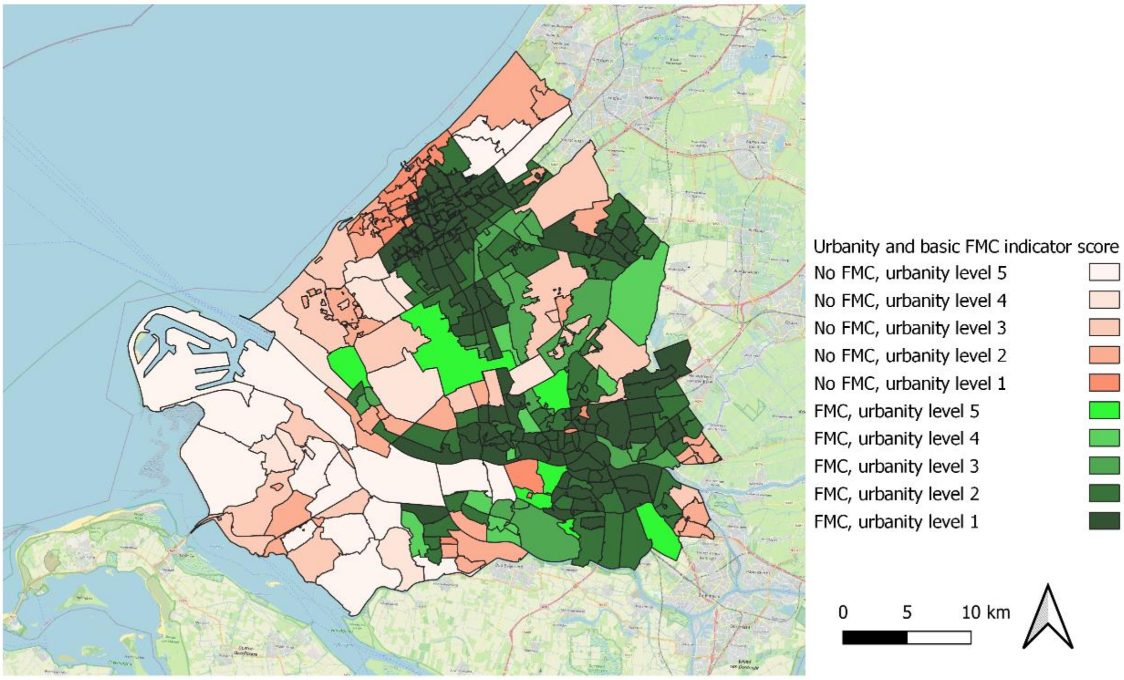

Figure 13: Representation of the urbanity level and FMC indicator J combined

The geographical results do not show differences in the number of participants per PC4 area. Although the data has been pooled over three years, the number of participants for some PC4 areas is very low and differs from 0 to 238. Moreover, the number of inhabitants per area is also widely divergent. Figure 19 in Appendix 13 displays areas with a low number of participants. For the majority of the MRDH the number of participants is sufficient to draw geographical conclusions.

5. Conclusion, discussion and recommendations

In this chapter, the conclusion, discussion and recommendations are presented. Section 5.1 gives the conclusion by answering the main and sub-research questions. Next, section 5.2 discusses the limitations of the research. Thereafter, future research recommendations are shared. Section 5.4 discusses the implications of the research. Section 5.5 gives recommendations for spatial planning practices.

5.1 Conclusion

In this research, an exploration of our current understanding of the FMC is discussed, specified and applied in logistic binary regression models. The results fill the knowledge gaps identified in the introduction. The different research questions are presented and answered. Based on these answers, the main research question is answered in section 5.1.2.

5.1.1 Answers to the sub-research questions

The first objective was to clarify our current understanding of the FMC. This objective is partially achieved by the first research question:

What do a literature review and interviews with policymakers reveal about the characteristics of the fifteen-minute city concept?

The FMC concept is strictly defined and elucidated by Moreno, but gives plenty of space for own interpretation if the concept is geographically applied. The FMC characteristics, both in research as well as in practice, are indistinct. The literature revealed a broad range of amenities as characteristics of the FMC. The choices for these amenities are often moderately underpinned, especially not based on the effect of the amenities, revealed by statistical analysis. Scholars make their own decisions regarding the amenities of the FMC instead of building on Moreno's original functions. There is no standardised FMC research approach and no FMC indicator that comprises the FMC characteristics. The same unclarity accounts for policymakers who indicated that the concept should become more tangible, but, by aiming for this, they often do not substantiate their selection of amenities. The main characteristics of the concept are a set of amenities that should be located proximate to households, but other factors characterise an effective FMC as well, such as local social ties. A set of 11 amenities is selected, based on the original six functions by Moreno and occurrence in current research. These are: sport locations, supermarkets, cafes and restaurants, schools, work locations, transit hubs, general practitioners, financial locations, religious venues, town halls and libraries. An FMC is characterized by proximity and sufficient level coverage within 15 minutes for a set of amenities.

The second objective of this research was to gain knowledge about the relation between the FMC characteristics of an area and the effect on the number of trips by active modes. This is revealed by the probability of making a trip by active modes in a logistic binary regression model. First, the effects of general built environment and socio-demographic characteristics on the probability of making specific FMC trips (trips by active modes of maximum 15 minutes). Thus, the second research question is answered, which is:

What are the effects of socio-demographic and built environment variables on the probability of making an FMC trip?

The socio-demographic and built environment characteristics determine to a minor, but significant extent the probability of making an FMC trip. Especially if a person owns a car has a high impact on the probability of an FMC trip. Related to the urbanity, differences between weakly urban and moderately urban and, particularly, strongly urban and very strongly urban results in more FMC trips, respectively differences of +31.4% and +49,7%. Hence, densification of the built environment results in more sustainable travel behaviour. Another effect is that females make more FMC trips. Related to age, a reduction in FMC trips is especially high for people over 30, but reverses for people over 65 years. Another observed effect is that an increase in the quality of cycle paths has a strong effect on making FMC trips.

The effect of specific FMC amenities on the probability of making trips by active modes is analysed by application of the proximities of these FMC amenities in the logistic binary regression model. Thus, the third research question is answered, which is:

What is the relation between the proximity of individual amenities and the probability of making a trip by active modes?

All correlations between proximities of amenities and trips by active modes are positive. This means that an increase in proximity is correlated with an increase in the number of trips by active modes. The results of the statistical analysis for the proximities are not in line with the correlations. Hence, no direct conclusions can be drawn on amenities for which this was the case, namely the proximities to schools, work locations and transit hubs. For other amenities, relations are stronger. Particularly proximity of supermarkets causes more active modes trips. Moreover, proximity of amenities such as restaurants and cafes, religious venues and general practitioners have also strong effects on trips by active modes. The effects of proximity of town halls and sport locations were weaker. The proximities of amenities have correlations, but these are not too strong to make the results invalid. To conclude, the analysis of relations between proximity of individual amenities and active modes trips reveals that differentiation between the amenities for the FMC results in more sustainable travel behaviour than aggregation. This differentiation is further applied in specific FMC indicators.

To determine the effect of the constructed FMC indicators on the probability of making a trip by active modes, the values of these indicators are estimated in the logistic binary regression model. By this, the fourth research question is answered, which is:

What are the effects of the FMC indicators on the probability of making a trip by active modes?

The FMC indicators are based on the proximity or the level coverage of amenities, or a combination of both. The probability of making trips by active modes increases by a higher score for all FMC indicators, but the effects vary. The results show that considering a broad set of amenities has a stronger effect than only a set of four core amenities (supermarkets, schools, transit hubs and work locations). Moreover, the FMC indicators that combine proximity with level coverage result in a higher validity of the model. Therefore, the level coverage and proximity are suitable complements to analyse the effects of the FMC. The relative effects of the FMC indicators are less strong. Especially car ownership and urbanity explain better the active modes use. Still, the effects of the FMC indicators should not be neglected. Indicators that strictly define the proximity and level coverage of a set of amenities within short distances have a strong influence on trips by active modes. These indicate for example a minimum number of schools within 15 minutes or a maximum proximity of 1 km to a supermarket. The comparison of FMC indicators revealed that the implementation of the indicators is highly relevant to determine the effect. A stricter definition results in stronger effects in the promotion of active modes.

The third objective of understanding to what extent the MRDH is an FMC, is the answer to the fifth research question, which is:

To what extent does the MRDH fulfil the characteristics of the fifteen-minute city based on both the FMC indicators and choices for active modes?

Between 27% and 30% of the MRDH PC4 areas (postal code four numbers) have FMC characteristics, based on both the FMC indicators, as well on the use of active modes. Three FMC indicators are analysed geographically. The FMC characteristics of the MRDH are far less if based on the combination of FMC indicators and actual mode choice, than only based on the FMC indicators. This implies that the FMC indicator on itself is not a good predictor for a high share of active modes. Related to the geographical distribution, areas with a high FMC indicator and a high share of active modes are not always highly urbanised. These areas offer opportunities for further densification thereby also aiming for the promotion of active modes. In addition, suburbs of cities have a high FMC indicator score, but a relatively low share of active modes. Thus, the statistical results of the moderate effect of the FMC are geographically reflected. Only an analysis of the proximity of amenities is not sufficient to characterize the MRDH as an FMC.

5.1.2 Answer to the main research question

Substantiated by the answers to the sub-research questions, the main research question is answered, which is:

To what extent could the fifteen-minute city concept contribute to more trips by active modes in polycentric urban areas?

Current travel behaviour in the MRDH shows that the FMC characteristics of an area have a positive effect on the choice for active modes. The application of the FMC in urban planning would likely increase the share of active modes. However, other factors are also strong and the choice for active modes is only to a small extent determined by the proximity of amenities. Especially car ownership has a strong negative effect on choosing active modes. If an area is being developed as an FMC, but car ownership is not discouraged, then the effects are relatively small. In polycentric urban areas like the MRDH, the need for travelling by car from suburbs to other cities is high and distances are often too long to consider active modes. Moreover, although public transport connections between city centres in polycentric areas are often of high quality, this is less the case for trips from one suburb to another. This research demonstrates that using strictly defined FMC indicators the promotion of active modes. If there is political commitment to focus strongly on proximity, the concept is beneficial.

To conclude, the FMC concept contributes to more trips by active modes in polycentric areas, but the positive effects are far stronger in combination with other measures that promote active modes or discourage more unsustainable and space-occupying transport modes.

5.2 Limitations

This section discusses the limitations of the research. Based on these limitations, future research recommendations are given in section 5.3. Several limitations are considered beforehand, but could not be handled due to a limited time frame and limited data availability. This section discusses how limitations are dealt with.

The conceptual framework of this research (Figure 8) assumes the relationship between socio-demographic, BE variables and mode choice. Attitudes were omitted for simplicity. In reality, attitudes have a strong impact on mode choice (Ababio-Donkor, Saleh, & Fonzone, 2020; Ding, Chen, Duan, Lu, & Cui, 2017). The low McFadden R^2s, measuring the validity of the statistical models, indicate that the results only partially explain the reality. Besides missing information about attitudes, the information about personal considerations at the moment was not researched. Variables like if it is raining, if a person had an exhaustive workout the evening before, if a person is stressed or not, etc., affect mode choice to a large extent (Martins Silva Ramos, 2021). Still, if a participant has no car, the probability of making a trip by car is reduced to almost 0 as this research shows. In that case, the considerations at the moment are less relevant. The analysed effects are significant and explain mode choice well enough to draw conclusions.

Related to the conceptual framework, complex relations between the variables could have been explored more in-depth. As the goal of the research is mainly to focus on the FMC characteristics and the FMC indicator explaining mode choice, other complexities are paid little attention. The conceptual framework explains the approach and incorporates the residential self-selection effect, sufficient for this statistical analysis. Including more variables would increase the probability of having correlated variables. In this research variables are omitted to achieve significant results, more variables would only complicate this research. Research aimed at specific attitudes could be separately executed.

High correlations between variables result in the multicollinearity problem. Though the correlations between socio-demographic and BE variables were often below 0.5 (see Appendix 9, Table 19), the correlations between proximity, level coverage and FMC indicators often were not (see other tables in Appendix 9). This explains the incorrect and counterintuitive outcomes for some variables in section 4.2. The FMC indicators reduce the issue, as these are the aggregated proximities and level coverages of a set of amenities

The Modifiable Areal Unit Problem (MAUP) often occurs in spatial analysis (Wong, 2004). Case study areas are divided into aggregated zones. The choice for the zones determines the results of the analysis. In this research, the MRDH was divided into PC4 areas. The effect of proximate amenities just outside the MRDH, but within 15 minutes, is not considered. Moreover, only trips within the MRDH are considered. Therefore, especially for PC4 areas at the edge of the area, the results are slightly less valuable. For the calculations of the proximity and level coverage on itself, the MAUP has been dealt with as the calculations are not limited by the boundaries of each PC4 area.

Since the effects of area-based attributes are analysed on individual behaviours (in this case mode choice), the Uncertain Geographic Context Problem (UGCoP) pops up (Kwan, 2012). The geographical context of mode choice in the timing and duration of the trip is not fully known. The individuals choosing their modes are positioned in a geographical and cultural context that cannot be fully covered by the parameters of the model.

5.3 Future research recommendations

The explorative nature of this research brings as a side result various starting points for future research. These starting points are introduced in this section.

If not all amenities are proximate, other innovative mobility measures could increase people´s accessibility. For example, mobility hubs and shared cars can complement an FMC. The interaction between these mobility solutions and the FMC should be further researched.

Current research, based on ODiN data, has some drawbacks. First, this data could improve by adding personal attitudes about mode choice preference. Moreover, daily features, like the weather or the mood of participants, contribute to our understanding of mode choices. Social factors should not be neglected in future research. Second, the number of participants in rural areas is relatively low. In future, a higher number of participants improves the validity, especially for geographical analysis on the PC4 level.

Related to the method, differentiation in time, trip length or purpose of the active modes trips improves the validity and is recommended in future research. Furthermore, more data on the individual level improves the validity. This was not possible with the available data, but could be gathered if the focus area is smaller.

The focus of this research was mainly on Moreno's FMC dimension of proximity. Density and diversity were also mentioned, but gained less attention. Future research could focus on the functions of the other dimensions of the FMC. For example, the dimension of digitalisation is a rising topic with increasing home delivery, digital social connections and hybrid working. This reduces the need to have some amenities proximate, such as offices, libraries or town halls. One effect of Covid-19 is longer travel distances to work, since people work more from home (Buitelaar et al., 2021). This may reduce the local ties and need for proximate amenities. Uncertainty of looser ties with local surroundings should be further researched as this has a significant effect on the potential of the FMC.

This research gives insights into the relations between FMC characteristics and trips by active modes. The next step would be to further quantify the change the implementation of the FMC brings. This change can be expressed in CO2-equivalents, but also in m^2s extra space. Especially the area savings are relevant to initiate more land development projects.

5.4 Practical implications of the FMC

This section discusses the implications of the research.

The goal of the FMC is to promote active modes by bringing amenities more proximate. This research has revealed that currently, the proximity of amenities, measured by an FMC indicator, has a positive effect on the probability of making trips by active modes. Therefore, policies that implement the FMC concept in urban planning are better substantiated by the results of this research. However, there are some drawbacks to the full implementation of the concept. First, the application of the concept would be insufficient to result in high shares of active modes in all areas with high FMC indicators. If policymakers aim for higher shares of active modes, other measures that stimulate active modes should also be implemented. The FMC is not the one answer to solve the problems related to car use in cities. Second, the effect of the FMC is relatively small compared to car ownership. To achieve more sustainable transport trips, measures that discourage car ownership should be implemented. Examples are designing less car-oriented neighbourhoods, increased taxes for buying a (second) car or higher parking fees. To achieve this, integral policy and design are needed. This entails a clear vision from the scale of how a neighbourhood should be, until how the cities of the MRDH (or another metropolitan area) should be connected to achieve the highest number of trips by active modes.

This research has contributed to multicity analysis and showcases that the FMC concept has added value for polycentric urban areas. The approach of the concept is more locally oriented than inhabitants of polycentric urban areas often are. Trips are often from city to city, especially in a polycentric urban area and these trips are harder to achieve high shares of active modes. For example, consider a person living in Rotterdam-South working in Zoetermeer. This is a long distance by active modes and public transport has no good connections. Densification of suburbs increases the added value of future transit connections as more people would use these. Thus, several connected FMC neighbourhoods would reduce the need for cars. The proximity of transit hubs was considered and is positively correlated to trips by active modes, but there was no differentiation for the type of transit hubs. Within the FMC concept, transit plays a minor role and is only considered as a nearby station. Some interviewees perceived the FMC as the successor of transit-oriented development. The focus on transit should not be reduced by the implementation of the FMC. A robust public transport system that includes suburbs should be developed to stimulate sustainable mobility for future housing developments.

The geographical analysis revealed areas with a high FMC score, but a low urbanity level. Several of them are located between larger cities. In some sense, it is a 'waste of proximity' to have low address densities in these areas, particularly in perspective to new urban developments at the edge of the city. This is often caused by historical reasons, for example harbour areas which were once at the edge of the city are now located near the city centre. Currently, several of these areas are redeveloped for housing, but substantiated by the FMC concept and the need to induce sustainable travel behaviour, this redevelopment is better substantiated.

The potential of the FMC is higher if more people are open to live in a neighbourhood with all amenities proximate, which is more effective if car access is reduced. Research by Andringa (2022) shows that the willingness to live in areas with reduced car access is higher if accessibility to amenities is sufficient. Related, residential self-selection may be a minor problem, as people often think they have to buy (second) a car and will not do that if they move to an area with sufficient proximate amenities. This is already the case within the MRDH, based on differences in car ownership between strongly urban and rural areas.

The need for trips by car is high if people perceive this. Benefits, like you will not get wet when it rains, are difficult to weigh against drawbacks, for example that there are more traffic jams with bad weather. The perception of proximity is important and the FMC will work best if the benefits of proximity are stipulated. Drawbacks of cars are perceived less, as a high percentage of the costs are external (CE Delft, 2022). Health benefits of cycling are also external, but positive (CE Delft, 2022). To achieve higher societal benefits, caused by a modal shift, perceptions should be influenced by nudging. The FMC is an appealing idea of a more liveable city.

Related to ethical aspects, the implementation of the FMC concept may increase existing social segregation, for example, based on income. All amenities proximate and a reduced need for a car is lower if the car is not needed for work, which is more often the case for office work than for practically oriented work. Based on the results, the effect of income is currently slightly negative (higher income causes lower use of active modes), but there is a risk of increased segregation if level coverage differences between neighbourhoods increase. A focus on a basic FMC standard for everyone reduces the risk of segregation. Further implementation of the FMC can also increase segregation if only applied in some neighbourhoods. More proximate amenities will probably cause rising housing prices which will result in less affordable houses. To alleviate this effect, FMC neighbourhoods should be developed with sufficient percentages of affordable housing.

5.5 Recommendations for spatial planning practices

For spatial planning practice, the following recommendations are proposed:

- Give proximity of amenities priority earlier in the spatial development process of new neighbourhoods. Do not only focus on proximity, but also on the level coverage. The effect of the promotion of active modes is highest if a broad combination of amenities is proximate and offers people choice. If housing areas are once developed with insufficient proximate amenities, people will buy a (second) car and once they have a (second) car they choose significantly less for sustainable, active modes.
- Consider the hierarchy of modalities in urban design, from neighbourhood scale to regional scale. The effect of having a broad range of amenities proximate has little effect if car infrastructure has priority. Car ownership has a strong negative impact on making trips by active modes. Simultaneously, the quality of cycle paths has a strong positive impact on active modes use. People without a car opt more for sustainable transport, gain health benefits and claim less public space. Urban design should encourage the choice for active modes.
- Focus on densifying weakly urban to moderately urban and strongly urban to very strongly urban neighbourhoods. This densification has the most impact on the promotion of sustainable transport. Especially in areas with a high FMC indicator score will densification achieve the most benefits.
- Improve the quality of cycle paths. Based on the statistical analysis, this variable has a significant effect on the number of trips by active modes. This effect is stronger than, for example, the green quality of neighbourhoods. Though it is not an explicit characteristic of current transit-oriented development or FMC development, the quality of cycle paths should not be ignored in urban developments, not only on the neighbourhood level, but also on a higher scale.
- If not all amenities are proximate, other measures can reduce the need to buy a car. For example, mobility hubs offer possibilities to use a shared car to reach amenities which are located just too far for citizens to choose for active modes. The area a person can access within 15 minutes increases significantly if a mobility hub is proximate, but simultaneously the number of cars in a neighbourhood is likely to drop.
- The FMC approaches a city mainly from an urbanist perspective. The social aspects, to connect people, do not automatically follow from having a sufficient level of amenities proximate. Creating social ties between people on an FMC scale should be encouraged. If people feel no connection within their neighbourhood, town or city, they will not opt for proximate amenities, but travel to further destinations for their basic needs, which is more often by less sustainable transport modes. This may not be that important for a proximate supermarket, but is for cultural venues, libraries, cafes and restaurants and such (Guit & Leurs, 2022). Social connections should already be encouraged during the (re)development of housing areas to create neighbourhoods with strong social ties.

Bibliography

Ababio-Donkor, A., Saleh, W., & Fonzone, A. (2020). Understanding transport mode choice for commuting: the role of affect. *Transportation planning and technology, 43*(4), 385-403.

Abdelfattah, L., Deponte, D., & Fossa, G. (2022). The 15-minute city: interpreting the model to bring out urban resiliencies. *Transportation Research Procedia, 60*, 330-337.

Andringa, G. (2022). Preferences of potential residents for car-reduced neighbourhoods.

Angkotta, Y. (2022, April 6, 2022) *Interview 15-minutenstad/Interviewer: A. Freije*. TAUW, Utrecht.

Badii, C., Bellini, P., Cenni, D., Chiordi, S., Mitolo, N., Nesi, P., & Paolucci, M. (2021). *Computing 15MinCityIndexes on the Basis of Open Data and Services.* Paper presented at the International Conference on Computational Science and Its Applications.

Balletto, G., Pezzagno, M., & Richiedei, A. (2021). *15-Minute City in Urban Regeneration Perspective: Two Methodological Approaches Compared to Support Decisions.* Paper presented at the International Conference on Computational Science and Its Applications.

Beekmans, J. (2021). Welcome to the ×-Minute City. Retrieved from https://popupcity.net/observations/welcome-to-the-x-minute-city/

Bertoni, A., Dubini, P., & Monti, A. (2021). Bringing Back in the Spatial Dimension in the Assessment of Cultural and Creative Industries and Its Relationship with a City’s Sustainability: The Case of Milan. *Sustainability, 13*(19), 10878.

Borghetti, F., Longo, M., Mazzoncini, R., Somaschini, C., Cesarini, L., & Contestabile, L. (2021). relationship between railway stations and the territory: case study in lombardy–italy for 15-min station. *International Journal of Transport Development and Integration, 5*(4), 367-378.

BPD. (2021). Top 40 'meest verhitte' gemeenten op Nederlandse woningmarkt. Retrieved from https://www.bpd.nl/actueel/persberichten/top-40-meest-verhitte-gemeenten-op-nederlandse-woningmarkt/

Buitelaar, E., Bastiaanssen, J., Hilbers, H., t Hoen, M., Husby, T., Christian, L., . . . Weterings, A. (2021). Thuiswerken en de gevolgen voor wonen, werken en mobiliteit: Op zoek naar trends, trendbreuken en kansen als gevolg van corona.

BZK. (2021). Het statistisch woningtekort nader uitgelegd. Retrieved from https://www.woningmarktbeleid.nl/onderwerpen/berekening-woningbouwopgave

Calafiore, A., Dunning, R., Nurse, A., & Singleton, A. (2022). The 20-minute city: An equity analysis of Liverpool City Region. *Transportation Research Part D: Transport and Environment, 102*, 103111.

Caselli, B., Carra, M., Rossetti, S., & Zazzi, M. (2022). Exploring the 15-minute neighbourhoods. An evaluation based on the walkability performance to public facilities. *Transportation Research Procedia, 60*, 346-353.

CBS. (2017). Afstand tot dichtstbijzijnde basisschool. Retrieved from https://www.cbs.nl/nl-nl/achtergrond/2017/34/afstand-tot-dichtstbijzijnde-basisschool

CBS. (2020). Hoeveel reisden inwoners van Nederland van en naar het werk? Retrieved from https://www.cbs.nl/nl-nl/visualisaties/verkeer-en-vervoer/personen/van-en-naar-werk#:~:text=Vooral%20met%20de%20auto%20van,auto%20afgelegd%2C%20meestal%20als%20bestuurder.

CE Delft. (2019). Uitstoot broeikasgassen in Nederland. *Een analyse van de sectoren en bedrijven met de meeste uitstoot*.

CE Delft. (2022). *External Costs of Transport in Europe*. Retrieved from Delft: https://ce.nl/publicaties/external-costs-of-transport-in-europe/

Chen, Q., & Crooks, A. T. (2021). *Delineating a'15-minute city' an agent-based modeling approach to estimate the size of local communities.* Paper presented at the Proceedings of the 4th ACM SIGSPATIAL International Workshop on GeoSpatial Simulation.

Clerici Maestosi, P., Andreucci, M. B., & Civiero, P. (2021). Sustainable urban areas for 2030 in a Post-COVID-19 scenario: Focus on innovative research and funding frameworks to boost transition towards 100 positive energy districts and 100 climate-neutral cities. *Energies, 14*(1), 216.

CLO. (2020). Kaart bodemgebruik van Nederland, 2015. Retrieved from https://www.clo.nl/indicatoren/nl0061-bodemgebruikskaart-voor-nederland#:~:text=Bodemgebruik%20in%20Nederland%20is%20vooral,bouwterrein%20en%20overig%20bebouwd%20terrein).

Cullen, R. (2021). The plan to transform Paris into a '15-minute city'. Retrieved from https://newseu.cgtn.com/news/2021-11-08/The-plan-to-transform-Paris-into-a-15-minute-city--150iEWb5Hu8/index.html

De Graaf, L. (2022, April 6, 2022) *Interview (10-/)15-minutenstad/Interviewer: A. Freije*. Delft.

Dijkstra, R. (2022, April 7, 2022) *Interview 15-minutenstad/Interviewer: A. Freije*. Delft.

Ding, C., Chen, Y., Duan, J., Lu, Y., & Cui, J. (2017). Exploring the influence of attitudes to walking and cycling on commute mode choice using a hybrid choice model. *Journal of advanced transportation, 2017*.

Ding, C., Wang, Y., Tang, T., Mishra, S., & Liu, C. (2018). Joint analysis of the spatial impacts of built environment on car ownership and travel mode choice. *Transportation Research Part D: Transport and Environment, 60*, 28-40.

Drenth, A. (2022, April 12, 2022) *Kennismaken en verdiepen op 15-minutenstad/Interviewer: A. Freije*.

Elldér, E., Haugen, K., & Vilhelmson, B. (2022). When local access matters: A detailed analysis of place, neighbourhood amenities and travel choice. *Urban Studies, 59*(1), 120-139.

Fabris, L. M. F., Camerin, F., Semprebon, G., & Balzarotti, R. (2020). New Healthy Settlements Responding to Pandemic Outbreaks. Approaches from and for the Global City.

Fritz, M., & Berger, P. (2015). Chapter 11-will anybody buy? Logistic regression. *Improving the user experience through practical data analytics, Morgan Kaufmann*, 271-304.

Gaglione, F., Gargiulo, C., Zucaro, F., & Cottrill, C. (2022). Urban accessibility in a 15-minute city: a measure in the city of Naples, Italy. *Transportation Research Procedia, 60*, 378-385.

Gaxiola-Beltrán, A. L., Narezo-Balzaretti, J., Ramírez-Moreno, M. A., Pérez-Henríquez, B. L., Ramírez-Mendoza, R. A., Krajzewicz, D., & Lozoya-Santos, J. d.-J. (2021). Assessing Urban Accessibility in Monterrey, Mexico: A Transferable Approach to Evaluate Access to Main Destinations at the Metropolitan and Local Levels. *Applied Sciences, 11*(16), 7519.

Gerritsen, M. (2022, April 12, 2022) *M.e.r., mobiliteit en 15-minutenstad/Interviewer: A. Freije*.

Goudappel Coffeng. (2018). *Fiets in de MRDH*. Retrieved from https://docplayer.nl/106338640-1-aanleiding-bijlage-1-bereikbaarheidskaarten-toplocaties-bijlage-2-effecten-van-fietsmaatregelen-bij-30-min-en-afstandsvervalcurve-2.html

Graells-Garrido, E., Serra-Burriel, F., Rowe, F., Cucchietti, F. M., & Reyes, P. (2021). A city of cities: Measuring how 15-minutes urban accessibility shapes human mobility in Barcelona. *PloS one, 16*(5), e0250080.

Gregorich, M., Strohmaier, S., Dunkler, D., & Heinze, G. (2021). Regression with highly correlated predictors: variable omission is not the solution. *International journal of environmental research and public health, 18*(8), 4259.

Große, J., Olafsson, A. S., Carstensen, T. A., & Fertner, C. (2018). Exploring the role of daily "modality styles" and urban structure in holidays and longer weekend trips: Travel behaviour of urban and peri-urban residents in Greater Copenhagen. *Journal of Transport geography, 69*, 138-149.

Guit, M., & Leurs, K. (2022, May 30, 2022) *Interview 15-minutenstad/Interviewer: A. Freije*. Municipality of Rotterdam, Rotterdam.

Guzman, L. A., Arellana, J., Oviedo, D., & Aristizábal, C. A. M. (2021). COVID-19, activity and mobility patterns in Bogotá. Are we ready for a '15-minute city'? *Travel Behaviour and Society, 24*, 245-256.

Hamers, D., Kuiper, R., van der Wouden, R., van Dam, F., van Gaalen, F., van Hoorn, A., . . . Evers, D. (2021). Grote opgaven in een beperkte ruimte: Ruimtelijke keuzes voor een toekomstbestendige leefomgeving.

Harms, L., Bertolini, L., & Te Brömmelstroet, M. (2014). Spatial and social variations in cycling patterns in a mature cycling country exploring differences and trends. *Journal of Transport & Health, 1*(4), 232-242.

Harrell, F. E. (2015). Binary logistic regression. In *Regression modeling strategies* (pp. 219-274): Springer.
Jacobs, J. (1961). Jane jacobs. *The Death and Life of Great American Cities*.
Kaal, H. L., Vanderveen, G. N., & McConnell, W. (2008). Een postcodegebied is de buurt niet—Het gebruik van buurtvragen in (criminologisch) surveyonderzoek. *Sociologie, 4*(4), 371-394.
Kasraian, D., Maat, K., & van Wee, B. (2019). The impact of urban proximity, transport accessibility and policy on urban growth: A longitudinal analysis over five decades. *Environment and Planning B: Urban Analytics and City Science, 46*(6), 1000-1017.
KiM, Zijlstra, T., Witte, J.-J., & Bakker, S. (2022). *De maatschappelijke effecten van het wijdverbreide autobezit in Nederland*. Retrieved from
Kissfazekas, K. (2022). Circle of paradigms? Or '15-minute'neighbourhoods from the 1950s. *Cities, 123*, 103587.
Kwan, M.-P. (2012). The uncertain geographic context problem. *Annals of the Association of American Geographers, 102*(5), 958-968.
Li, T. (2022). Modeling the Efficacy of the 15-Minute City Using Large-Scale Mobility Data from the Perspective of Accessibility and User Choice: A Case Study on the Urban Food Environment. In: Massachusetts Institute of Technology.
Li, Z., Zheng, J., & Zhang, Y. (2019). Study on the layout of 15-minute community-life circle in third-tier cities based on POI: Baoding City of Hebei Province. *Engineering, 11*(9), 592-603.
López, M. d. M. P., Annema, J. A., & van Wee, B. (2022). The added value of having multiple options to travel to. An explorative study. *Journal of Transport geography, 98*, 103258.
Maat, K., Timmermans, H., & Priemus, H. (2009). Built environment and car travel. Analyses of interdependencies. 185.
Majstorović, I., Ahac, M., & Ahac, S. (2022). The City of Zagreb Lower Town Urban mobility development program. *Transportation Research Procedia, 60*, 362-369.
Martín, B., & Páez, A. (2019). Individual and geographic variations in the propensity to travel by active modes in Vitoria-Gasteiz, Spain. *Journal of Transport geography, 76*, 103-113.
Martins Silva Ramos, É. (2021). *Psychology for sustainable shared mobility: An investigation of the use of private cars and carsharing services*.
Metz, F. (2014). Eén reizigerskilometer minder met de auto: wat levert dat op?
Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4*(1), 93-111.
Moro, A. (2022). Co-design of public spaces for pedestrian use and soft-mobility in the perspective of communities reappropriation and activation. *Transportation Research Procedia, 60*, 36-43.
MRDH. (2022). Gemeenten. Retrieved from https://mrdh.nl/wie-zijn/gemeenten
Municipality of Amsterdam. (2017). Meerjarenplan Fiets 2017-2022. Retrieved from https://www.amsterdam.nl/bestuur-organisatie/volg-beleid/verkeer-vervoer/meerjarenplan-fiets/
Municipality of Amsterdam. (2019). *Woon-werkstromen van Amsterdams onderwijspersoneel po, so en vo*. Amsterdam Retrieved from https://static.amsterdam.nl/woon-werkstromen-docenten/assets/2019-factsheet-woon-werk-afstanden-amsterdams-onderwijspersoneel.pdf
Pinto, F., & Akhavan, M. (2022). Scenarios for a Post-Pandemic City: urban planning strategies and challenges of making "Milan 15-minutes city". *Transportation Research Procedia, 60*, 370-377.
Pozoukidou, G., & Chatziyiannaki, Z. (2021). 15-Minute City: Decomposing the new urban planning eutopia. *Sustainability, 13*(2), 928.
Rijkswaterstaat. (2021). *Integrale Mobiliteitsanalyse*. Retrieved from https://zoek.officielebekendmakingen.nl/blg-990632.pdf
Rodrigue, J.-P. (2020). *The geography of transport systems*: Routledge.
Salih, N. M. M., & Hussein, S. H. (2021). Cities after pandemic: enabling social distancing as a new design standard to achieve urban immunity. *Acta Scientiarum Polonorum Administratio Locorum, 20*(4), 345-360.

Santos, G., Maoh, H., Potoglou, D., & von Brunn, T. (2013). Factors influencing modal split of commuting journeys in medium-size European cities. *Journal of Transport geography, 30*, 127-137.
Schaap, T. W., Harms, L. W. J., Kansen, M., & Wüst, H. (2015). *Fietsen en lopen: de smeerolie van onze mobiliteit*: Kennisinstituut voor Mobiliteitsbeleid| KiM.
Smith, T. J., & McKenna, C. M. (2013). A comparison of logistic regression pseudo R2 indices. *Multiple Linear Regression Viewpoints, 39*(2), 17-26.
Staricco, L., & Brovarone, E. V. (2022). Livable neighborhoods for sustainable cities: Insights from Barcelona. *Transportation Research Procedia, 60*, 354-361.
Ton, D., Duives, D. C., Cats, O., Hoogendoorn-Lanser, S., & Hoogendoorn, S. P. (2019). Cycling or walking? Determinants of mode choice in the Netherlands. *Transportation research part A: policy and practice, 123*, 7-23.
Van de Coevering, P., Maat, C., & van Wee, G. (2021). Begrijpen aan welke knoppen je kunt draaien bij ruimte en mobiliteit: Nieuwe studie wijst op belang van attitudes op relatie tussen de gebouwde omgeving en mobiliteit. *Verkeerskunde: vaktijdschrift over verkeer en vervoer*.
Van den Berg, I. (2022, May 17, 2022). Voornemens die voornemens blijven: Nederlanders verkiezen auto boven fiets voor woon-werkverkeer. *Metro*. Retrieved from https://www.metronieuws.nl/onderweg/2022/05/nederlanders-verkiezen-auto-fiets-woon-werkverkeer-onderzoek/
Van Ommeren, K., Lelieveld, M., Tilburgs, L., & Ritrovato, M. (2021). *De maatschappelijke voordelen van stimuleren van actieve mobiliteit na Covid 19.* Retrieved from https://open-pilot.overheid.nl/repository/ronl-394eff8d-8e91-4ed9-a078-b96bb652416b/1/pdf/Effecten%20post%20covid%20beleidsscenarios.pdf
Walkscore. (2022). Live Where You Love. Retrieved from https://www.walkscore.com/
Wong, D. W. (2004). The modifiable areal unit problem (MAUP). In *WorldMinds: geographical perspectives on 100 problems* (pp. 571-575): Springer.
Zhang, W., Lu, D., Zhao, Y., Luo, X., & Yin, J. (2022). Incorporating polycentric development and neighborhood life-circle planning for reducing driving in Beijing: Nonlinear and threshold analysis. *Cities, 121*, 103488.
Zijlstra, T., Bakker, S., & Witte, J.-J. (2022). *Het wijdverbreide autobezit in Nederland*. Retrieved from https://www.kimnet.nl/publicaties/publicaties/2022/02/22/het-wijdverbreide-autobezit-in-nederland
Zuid-Holland, P. (2022). Zuid-Holland doet breed woonbod aan minister De Jonge. Retrieved from https://www.zuid-holland.nl/actueel/nieuws/juni-2022/zuid-holland-doet-breed-woonbod-minister-jonge/

Contact data

Name	Function	Mail
Harm Jan (Arjan) Freije	Student TIL	arjan-freije@tudelft.nl
Prof. dr. G.P. (Bert) van Wee	Professor in Transport Policy	g.p.vanwee@tudelft.nl
Dr. C. (Kees) Maat	Associate professor Transport and Planning	c.maat@tudelft.nl
Dr. J.A. (Jan Anne) Annema	Assistant professor Transport Policy Analysis	j.a.annema@tudelft.nl
Bart van Genugten	Project manager	bart.vangenugten@tauw.com
Aletta Versluis	1st project employee	aletta.versluis@tauw.com

Appendices

Appendix 1: Paper

The paper can be found on the next pages

The fifteen-minute city: The promotion of active modes by a novel city planning concept

An explorative, statistical research on the fifteen-minute city concept applied to the Rotterdam-The Hague metropolitan region

H.J. (Arjan) Freije, Delft University of Technology, November 2022

Abstract

The fifteen-minute city (FMC) concept aims to reduce greenhouse gas emissions, improve urban liveability and free up space by promoting a modal shift from car to active modes. According to theory, the proximity of all basic needs should have a maximum travel time of 15 minutes by bike or foot to achieve the FMC goals. However, basic needs are poorly specified and discussed, the effectiveness of the FMC concept is unknown and difficult to measure by current indicators. Therefore, this paper clarifies the FMC concept. It statistically analyses the effect on the promotion of active modes by logistic binary regression, applied to the Rotterdam-The Hague metropolitan region. It introduces FMC indicators to measure and geographically analyse urban regions. It reveals a set of amenities that characterises the FMC. Further, it demonstrates that the FMC concept has a positive effect on the probability of making trips by active modes, but also demonstrates the effects of other relevant variables, such as car ownership or the quality of cycle paths. Moreover, an FMC indicator that combines both the proximity of amenities and the number of amenities within 15 minutes predicts the effect of the FMC concept best. The FMC concept is beneficial to promote active modes, but to be most effective, active modes should also be stimulated via other measures, including the improvement of the quality of cycle paths and discouragement of car ownership for areas with all FMC amenities in close proximity.

Keywords: fifteen-minute city, proximity, Rotterdam-The Hague metropolitan region, mobility, spatial planning, logistic binary regression

1. Introduction

In 2016, Moreno et al. (2021) developed the FMC concept, defined as a city where residents should be able to *"access all of their basic essentials at distances that would not take them more than 15 minutes by foot or by bicycle"* (Moreno et al., 2021, pp.105-106). Key within the concept is the effect of proximity on mode choice. Moreno et al. (2021) assume that if a set of functions is available within 15 minutes, the need for a car drastically reduces. These functions are *living, commerce, entertainment, education, working and healthcare.* With current urbanisation rates and a search for more sustainable urban planning concepts, the need for urban policies that reduce car traffic is high. In theory, more proximate locations of basic needs, from now on 'amenities', promote the use of active modes. In practice, citizens often do not opt for the most proximate amenities (Municipality of Amsterdam, 2019). Destination choice relates also to more specific characteristics, such as the choice within amenities (López et al., 2022), personal preferences (Ababio-Donkor et al., 2020) or socio-demographic characteristics. Based on current FMC research, three knowledge gaps have been identified:

1) The knowledge about the effect of proximity of individual amenities on trips by active modes is limited. The question is what the effects are of which amenities for what proximity.
2) Knowledge about the actual effect of the FMC on active mode choice is

limited. No statistical research on the relationship between how 'FMC' an area is (concerning the proximity of amenities within 15 minutes) and the effect on mode choice has been conducted.

3) Research on the FMC has only been conducted for metropolitan regions with one core city. The value of the concept for polycentric urban regions is unknown.

To resolve these issues, this research answers the main research question, which is: *To what extent could the fifteen-minute city concept contribute to more trips by active modes in polycentric urban areas?* This paper clarifies the FMC concept, mainly concerning relevant amenities. It increases our understanding of the relation between the FMC characteristics of a city and active mode choice. This is done by a logistic binary regression (LBR) analysis of socio-demographic and built environment (BE), including FMC indicators that display how 'FMC' an area is. The underlying question is what determines if a person makes a trip by active modes or not.

Furthermore, the study applies the FMC concept to the Rotterdam-The Hague metropolitan region (MRDH) to explore the contribution the concept has to polycentric urban areas. This Dutch polycentric region consists of 23 municipalities and has 2.4 million inhabitants (MRDH, 2022). In the coming years, 10,000s of extra houses need to be built in this densely populated province (Zuid-Holland, 2022), while simultaneously transport should become more sustainable and the current network is already congested. Therefore, this region is selected for analysis.

2. Literature overview

A literature review reveals what is currently known about the FMC. The results are complemented by expert interviews. Since 2016, 31 papers have been published in Scopus, of which 22 focus specifically on the FMC concept. Via snowballing, the list is complemented. Scholars often show optimism about the concept. They assume positive effects on active mode choice, but seldomly use statistics to underpin their conclusions. Only Elldér et al. (2022), T. Li (2022) and Guzman et al. (2021) use regressions to reveal the effects of the proximity of some amenities. They zoomed in on specific relations, such as between the urbanity level and proximity (Elldér et al., 2022) or grocery stores and mode choice (T. Li, 2022). Other scholars focused on mapping proximity to a set of amenities, but seldomly based on Moreno's (2021) functions (see Appendix 3). Moreover, the focus is mainly on walkability, instead on cyclability. The full literature review overview is in Appendix 2.

Expert interviews revealed that in practice the choice for amenities is not well-substantiated (De Graaf, 2022). The concept is currently mainly applied in visions for decades in the future. Moreover, the broader context is little concerned with current FMC applications, for example related to social ties within FMC neighbourhoods (Guit & Leurs, 2022). Furthermore, the sustainability benefits of the concept are hard to incorporate into calculations (Gerritsen, 2022). There is an explicit need to gain knowledge of how to operationalise the FMC. Based on the literature review and expert interviews, a choice for amenities to analyse for the FMC indicators is made, displayed in Table 9. These FMC indicators and the methodology are discussed in section 3.2.

Table 9: The choice of amenities to determine FMC indicators

Moreno's function	Amenity	Explanation
Living	Green area Sport locations	Green area is included since the more green nearby, the more reasonable it is that people will not opt for the car to visit green areas further away Sport locations are added since many people conduct sport activities several times a week
Commerce	Supermarkets	Supermarkets are added since people visit these on a regular basis
Entertainment	Restaurants	Several entertainment locations could have been added. For simplicity and since these are often mentioned by scholars, cafes and restaurants are selected
Education	Schools	These are most researched by scholars. The combination of primary and secondary schools is added
Working	Work locations Transit hubs	Job availability is added, although in research this amenity is little considered. The job location is often an important factor people need a car Transit hubs are added since this offers opportunities to reach job locations sustainably and the bicycle-(nearby)train combination is strong
Healthcare	General practitioners	General practitioners are relevant and by many not visited on a daily basis, but by some, mainly elderly and infirm people, of high importance to have within walking distance
Other	Financial locations Religious venues Town halls Libraries	Financial locations, such as banks and ATMs, offer accessibility to cash and services, although far less than in the past Religious venues. By some visited regularly, by others rarely or never, but proximity may play a role in households' mode choice Town halls, or better specified, governmental buildings, for example to collect a passport or other services. Has been considered by four scholarly papers Libraries, more and more a meeting place of the neighbourhood where functions are combined and meetings take place

3. Methodology

The relations between the main concepts have guided the statistical analysis of this research (Figure 16). This chapter discusses the different steps taken to achieve the results.

3.1 Variables of the conceptual framework

The probability of making a trip by active modes is assumed to be determined by built environment (BE) and socio-demographic variables. Locations of amenities, which are also BE variables, determine FMC indicators. These FMC indicators are based on the proximity and level coverage of amenities. The proximity is the shortest distance between a household and the most proximate location of one amenity type, calculated on the postal

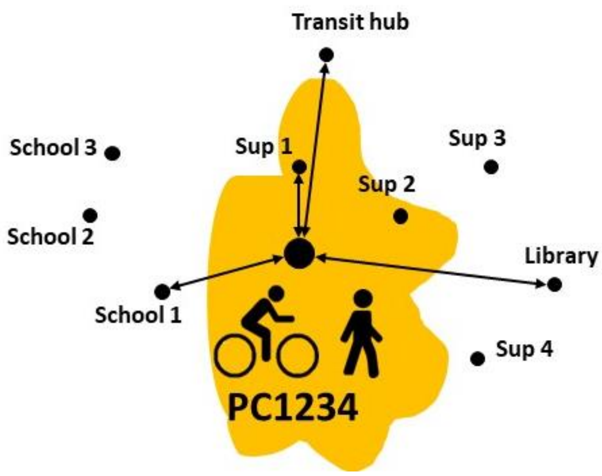

Figure 14: Proximity of amenities for a random PC4 area

code 4 level, based on the centroid location of the area (PC4). In Figure 14 the proximity of supermarkets (sup 1) is shorter than of schools or a library.

The level coverage is the number of amenities within 15 minutes from the centroid of a PC4 area, displayed in Figure 15. In this example, the level coverage of supermarkets and schools is the same. The area accessible within 15 minutes is calculated by GIS. The location data of amenities is loaded and analysed in QGIS. Details about the applied GIS method is in Appendix 5.

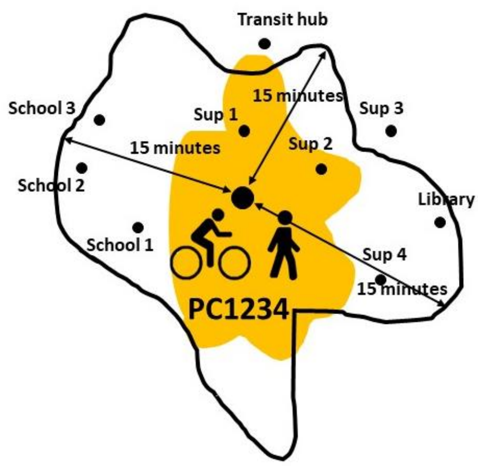

Figure 15: Level coverage of amenities for a random PC4 area

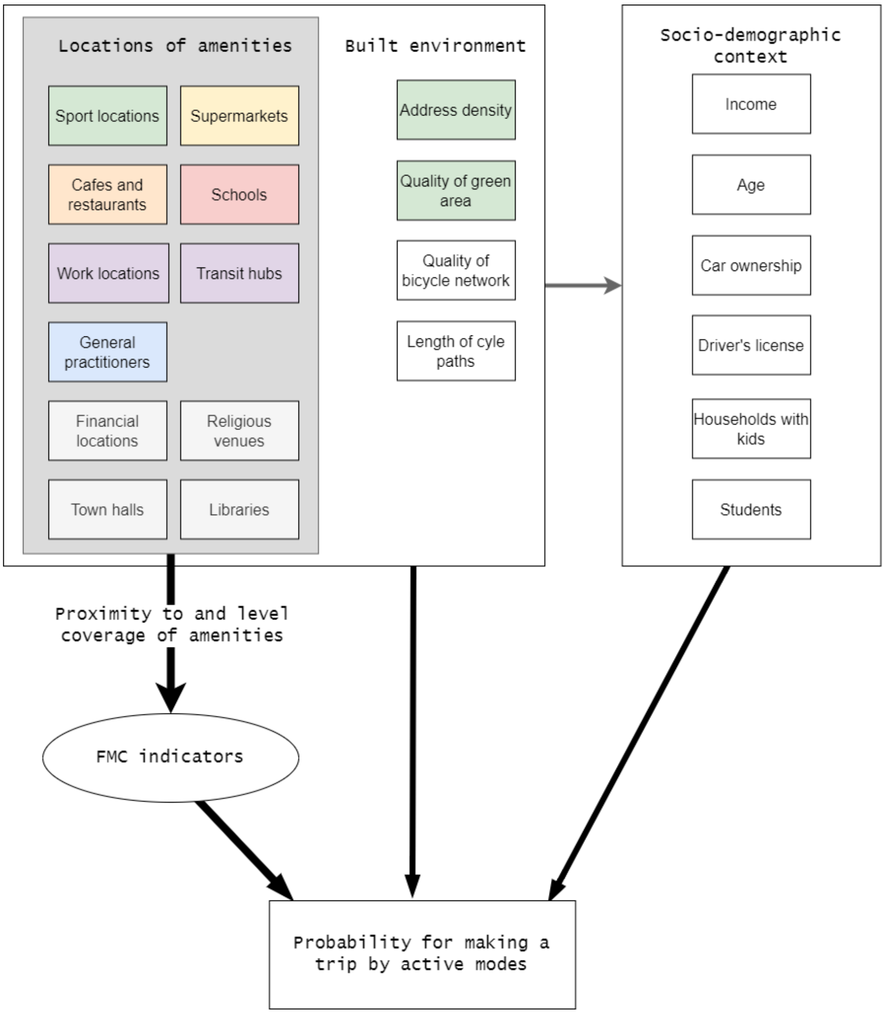

Figure 16: Conceptual framework

3.2 FMC indicators

Based on combinations of proximity and level coverage, FMC indicators are formulated. The following were applied in the LBR:

A: Average most proximate distance to all 11 identified amenities
B: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs)
C (binary): Level coverage of all 11 identified amenities is at least 1
C': Level coverage of all 11 identified amenities (in thousands)
C'': Level coverage of 4 core amenities (supermarkets, schools, work locations and transit hubs) (in thousands)
D: Combination of A and C
E: Combination of A and C'
F: Combination of B and C''
G (binary): Supermarket < 1 km, school < 1 km, transit hub < 5 km and work location < 5 km

H (binary, high level coverage focus): Level coverages of > 5 supermarkets, > 5 schools, > 5 transit hubs and > 500 restaurants/cafés
I (binary, recreational focus): Level coverage of > 1 transit hub, > 20 sport locations, > 50 restaurants/cafés and > 1 library
J (binary, basic and more proximate): FMC indicator A < 1 km, Level coverage of > 2 transit hubs, > 5 supermarkets and > 10 work locations

3.3 Logistic binary regression

The LBR is applied to determine the value of variables that affect the choice for trips by active modes. Each participant that undertook a trip that was or was not made by active modes. This is assumed to be dependent on the set of variables displayed in Figure 16. The weights of the variables, indicated by βs, are unknown and estimated by a maximum likelihood estimation. The probability P that mode choice E occurs depends on the weights (β) for variables $X_{1\text{-}k}$:

$$P(E) = \frac{e^{a+\beta X}}{(1+e^{a+\beta X})} \quad (1)$$

Formula (1) is retrieved from Fritz and Berger (2015)

With

$$\beta X = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k \quad (2)$$

for a total of *k* variables.

To determine the percentual effect of each variable, the odds ratio is calculated by e^{β}. A positive β indicates an increase, a negative β a decrease and a β of 0 indicates no effect (e^0=1). The quality of the LBR is assessed by the McFadden R^2 score.

3.4 Data overview

Travel behaviour data is retrieved from 2017-2019 'Onderweg in Nederland' pooled data sets, consisting of 42,890 trips within the MRDH, divided into 8 modality groups. The active modes group consists of walking, electric bike and conventional bike trips. The choice for socio-demographic and BE data is based on research by Santos et al. (2013). Most data are applied on the individual level, while the amenities, cycling infrastructure and green quality data are on the PC4 or municipal level. The LBR is applied to each individual.

4. Results

Before the effects of the FMC indicators are displayed, the effects of the BE and socio-demographic variables are displayed. Thus, the effects of the FMC indicators are put into perspective.

4.1 Socio-demographic and BE effects

First, the effects of making a trip by active modes, independent of FMC variables, are displayed in Table 10. The urbanity is further divided to indicate the effects of each urbanity level. The effects of car ownership and quality of cycle paths are strong. If a participant owns a car, the probability is 29,6% that person

Table 10: The values of the socio-demographic and BE variables for the probability of making a trip by active modes

	Values (with urbanity specified)	
Variables	**Coefficient**	**Odds ratio**
Constant	-0.585***	0.557
Age	-0.008***	0.992
Female	0.188***	1.207
Students	-0.129**	0.879
Children	0.132***	1.141
Income	-0.025*	0.975
Car ownership	-0.351***	0.704
Green quality	0.003	1.003
Quality of cycle paths	0.396**	1.486
Length of cycle paths	-0.006***	0.994
Reference: weakly urban		
Moderately urban	0.273**	1.314
Strongly urban	0.177	1.194
Very strongly urban	0.404***	1.497
McFadden R^2	0.024	

*** = P <0.001; ** = P<0.01; * = P <0.05

makes a trip by active modes. Furthermore, the results reveal that densification from weakly urban to moderately urban and from strongly urban to very strongly urban have the highest impact on promoting active modes. Females have a higher probability of making trips by active modes.

4.2 Proximities effects

Secondly, the effects of proximities of individual amenities are analysed, see Table 11. The values of the socio-demographic and BE variables are relatively similar to those in Table 10. The effects of the proximities are mostly negative, which indicates that if the distance (in km) to an amenity increases, the probability of making a trip by active modes decreases. The values of schools, work locations and transit hubs contrast with the correlations with trips by active modes (see Appendix 9). Therefore, these have a low validity. The higher adjusted McFadden R^2 than in Table 10 reveals that proximity data improves our understanding of why people make a trip by active modes. Still, the added value is low and aggregation of proximities in combination with level coverages in FMC indicators improves our understanding.

Table 11: The values of the socio-demographic, BE and individual proximity variables for the probability of making a trip by active modes

	Values	
Variables	**Coefficient**	**Odds ratio**
Constant	0.770***	2.159
Age	-0.007***	0.993
Female	0.157***	1.170
Students	-0.283***	0.753
Children	0.128***	1.137
Income	-0.060***	0.942
Car ownership	-0.363***	0.696
Proximity of sport locations	-0.007**	0.993
Proximity of supermarkets	-0.076	0.927
Proximity of restaurants and cafes	-0.188***	0.829
Proximity of schools	0.369***	1.446
Proximity of work locations	0.099***	1.104
Proximity of transit hubs	0.016*	1.016
Proximity of general practitioners	-0.100***	0.905
Proximity of religious venues	-0.297***	0.743
Proximity of town halls	-0.036**	0.965
McFadden R^2	0.035	

*** = P <0.001; ** = P<0.01; * = P <0.05

4.3 FMC indicators effects and comparison

Thirdly, the FMC indicators are analysed in relation to the socio-demographic and BE indicators, as in the conceptual framework. Only the FMC indicator variables and the R^2s are displayed in Table 12 as the other variables were relatively similar to the first and second LBR results. Moreover, this, comparison of indicators is more appropriate. The urbanity/address density has often been omitted as these distort the results.

The signs are as expected, except for indicator F. The effect of, i.e., indicator G is that if inhabitants have a supermarket and a school within 1 kilometre, and a transit hub and a work location within 5 kilometres, than the probability of making a trip by active modes in comparison to areas where this situation is not the case, is 17.1% higher. This effect is stronger than, among others, indicator A. Hence, a choice for a stricter indicator has a higher result in promoting the share of active modes, if the FMC is operationalised in urban planning. The $R^2$2 of the models are low, but D and E are higher than others. The results in Table 12 display that the indicators that combine proximity and level coverage have a higher validity. Moreover, the R^2 improves if the FMC indicators are more precisely defined. In perspective to the values of socio-demographic and BE variables in Table 10 and Table 11.

Table 12: Comparison of the FMC indicators

Indicator	Coefficient(s)				R^2 model
	Proximity part value indicator	Odds ratio	Level coverage part value indicator	Odds ratio	
A: Average most proximate distance to all 11 identified amenities	-0.067***	0.935			0.033
B: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs)	-0.036*	0.964			0.029
C (binary): Level coverage of all 11 identified amenities is at least 1			0.033	1.033	0.029
D: Average most proximate distance to all 11 identified amenities and binary level coverage of all 11 identified amenities is at least 1	-0.043**	0.957	0.383***	1.467	0.035
E: Average most proximate distance to all 11 identified amenities and level coverage of all 11 identified amenities (in thousands)	-0.044**	0.957	0.004***	1.004	0.035
F: Average most proximate distance to 4 core amenities (supermarkets, schools, work locations and transit hubs) and level coverage of these core amenities (in thousands)	-0.092***	0.912	-0.122**	0.885	0.029
G (binary): Supermarket < 1 km, school < 1 km, transit hub < 5 km and work location < 5 km	0.158***	1.171			0.029
H (binary, high level coverage focus): Level coverages of > 5 supermarkets, > 5 schools, > 5 transit hubs and > 500 restaurants/cafés	0.144***	1.155			0.033
I (binary, recreational focus): Level coverage of > 1 transit hub, > 20 sport locations, > 50 restaurants/cafés and > 1 library			0.111***	1.117	0.033
J (binary, basic and more proximate): FMC indicator A < 1 km, Level coverage of > 2 transit hubs, > 5 supermarkets and > 10 work locations	0.177***	1.194			0.030

*** = P <0.001; ** = P<0.01; * = P <0.05

the binary FMC indicators have a medium value. Variables such as car ownership, students or gender have a larger effect. Non-binary FMC indicators are more difficult to compare, as these have different units, but the comparison between FMC indicators reciprocally reveals that the effects of considering core amenities is smaller than a wide group of amenities. An example of this is a comparison between indicators D and F.

4.4 Geographical application and analysis of FMC indicators

Geographical application reveals areas that are not only an FMC based on the indicator, but also based on the share of active modes. These areas are functioning as FMC if the share of active modes is high, in this case above a threshold of 50% of all trips. In Figure 16, based on indicator E (with a high R^2), the FMC areas are mainly the inner cities, 84 of 312 areas in orange. Especially suburbs are an FMC based on the indicator, but are not in practice, based on the share by active modes. This reveals that FMC areas do not necessarily result in high shares of active modes.

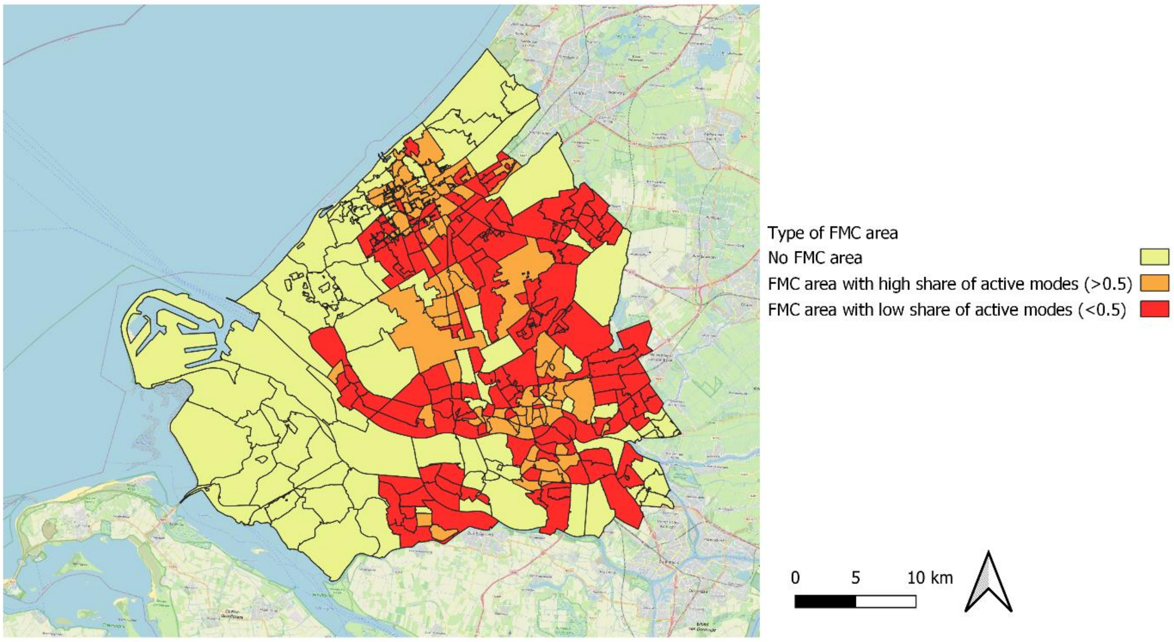

Figure 16: FMC areas based on indicator E combined with the share of active modes

The geographical representation of FMC indicator J in combination with the urbanity levels in Figure 17 reveals that some FMC areas have a low urbanity level, indicated in light green. These areas have decent FMC qualities, but relatively few inhabitants benefit from this proximity. Further densification of these areas results in lower shares of car traffic than densification of areas which have few proximate amenities. Not all these light green areas are suitable, for example Midden-Delfland (centrally green area) is a protected landscape. Other areas have traditional harbour functions and are now relatively close to inner city amenities. The light green areas have a high potential to be further developed into FMC-oriented neighbourhoods.

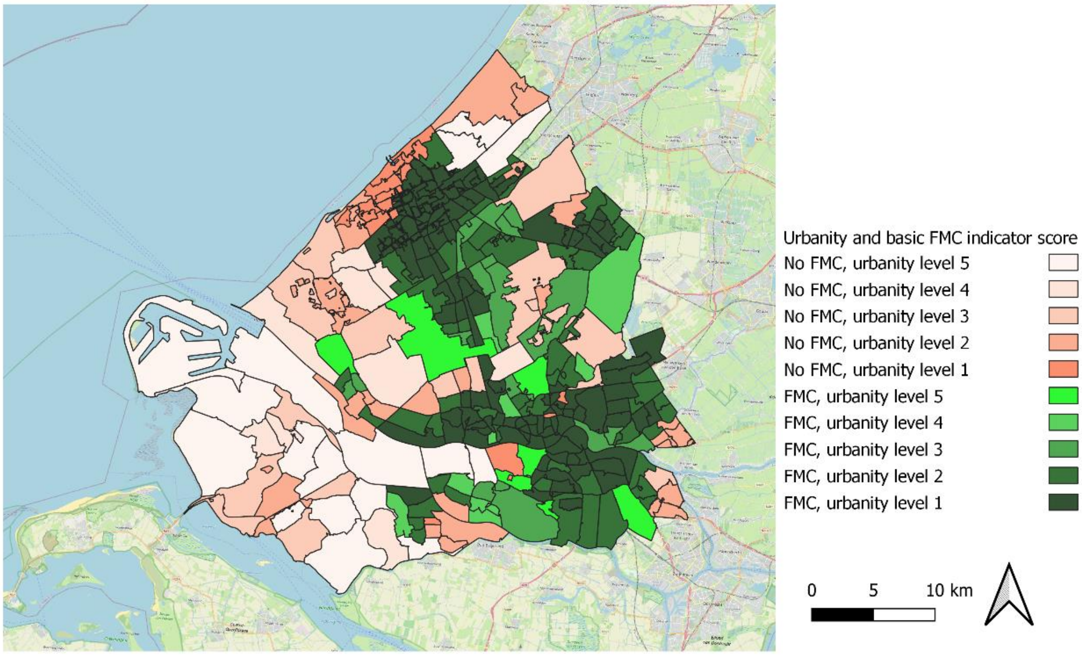

Figure 17: Urbanity level in combination with FMC indicator J

5. Conclusion

This research indicates that the FMC concept has a positive effect on the promotion of active modes. The extent is significant, but limited in relation to other factors, for example car ownership or the quality of cycle paths. Moreover, if an area is an FMC, based on only the proximity and level coverage, does not imply that the share of active modes is high. To have a more sustainable impact, the concept should be applied in combination with other measures. The effect of the concept on the promotion of active modes for polycentric areas is likely to be less than in large metropoles with one core city, as especially suburbs of the different cities within the case study region have relatively low shares of active modes. Trips are often made between suburbs, instead of to city centres or from city centres to city centre. Depending on the FMC indicator definition, the effect of a higher proximity and level coverage of amenities nearby households, shows that also in a polycentric region FMC indicators are suitable predictors for trips by active modes.

6. Discussion

This FMC research has an explorative nature and reveals that the operationalisation of the FMC gives challenges. Based on the low R^2s, the meaning of the results is statistically low, but does have added value. The results indicate that the concept has beneficial effects on the promotion of active modes. This implies that policies to stimulate sustainable transportation through the implementation of the FMC concept, can be substantiated by this research. In an age with a rising threat of climate crisis, this concept is part of the solution and should be further stimulated. It is recommended to calculate the costs of the FMC and consider subsidy schemes to stimulate a sufficient level of amenities, early in the process of housing development, both within cities and for new urban areas. Moreover, it is recommended not to fully focus on FMC development, but link this concept with current policies, such as transit-oriented development or urban infill. Also, other measures to promote sustainable transport enhance the effect of the concept. For example, the creation of mobility hubs and shared cars can address the need for a car in some areas where almost all amenities are proximate except for one or two.

This research did not reveal detailed specific differences between amenities. The value of proximity of each independent amenity can in future be explored by qualitative research that indicates what citizens prefer to have most proximate. Based on these results, the amenities can be weighed, which improves the validity of the FMC research. Simultaneously, individual proximity data (instead of postal code 4 data) results in higher validity. This research has revealed that the concept is promising, based on the application of statistical analysis in a polycentric urban region, and is a step forward towards an increased focus on the promotion of active modes by the built environment.

Bibliography

Ababio-Donkor, A., Saleh, W., & Fonzone, A. (2020). Understanding transport mode choice for commuting: the role of affect. *Transportation planning and technology, 43*(4), 385-403.

Elldér, E., Haugen, K., & Vilhelmson, B. (2022). When local access matters: A detailed analysis of place, neighbourhood amenities and travel choice. *Urban Studies, 59*(1), 120-139.

Fritz, M., & Berger, P. (2015). Chapter 11-will anybody buy? Logistic regression. *Improving the user experience through practical data analytics, Morgan Kaufmann*, 271-304.

Gerritsen, M. (2022, April 12, 2022) *M.e.r., mobiliteit en 15-minutenstad/Interviewer: A. Freije*. Utrecht.

De Graaf, L. (2022, April 6, 2022) *Interview (10-/)15-minutenstad/Interviewer: A. Freije*. Delft.

Guit, M., & Leurs, K. (2022, May 30, 2022) *Interview 15-minutenstad/Interviewer: A. Freije*. Municipality of Rotterdam, Rotterdam.

Guzman, L. A., Arellana, J., Oviedo, D., & Aristizábal, C. A. M. (2021). COVID-19, activity and mobility patterns in Bogotá. Are we ready for a '15-minute city'? *Travel Behaviour and Society, 24*, 245-256.

Li, T. (2022). Modeling the Efficacy of the 15-Minute City Using Large-Scale Mobility Data from the Perspective of Accessibility and User Choice: A Case Study on the Urban Food Environment. In: Massachusetts Institute of Technology.

López, M. d. M. P., Annema, J. A., & van Wee, B. (2022). The added value of having multiple options to travel to. An explorative study. *Journal of Transport geography, 98*, 103258.

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4*(1), 93-111.

MRDH. (2022). Gemeenten. Retrieved from https://mrdh.nl/wie-zijn/gemeenten

Zuid-Holland, P. (2022). Zuid-Holland doet breed woonbod aan minister De Jonge. Retrieved from https://www.zuid-holland.nl/actueel/nieuws/juni-2022/zuid-holland-doet-breed-woonbod-minister-jonge/

Appendix 2: Literature review table

Source	Purpose	Method	Findings	Uniqueness	Limitations	Future research recommendations
Clerici Maestosi, Andreucci, and Civiero (2021)	Discussing innovative frameworks to boost more sustainable urban areas	Desk research	- The 15 minute city can contribute to the climate-neutral city goals	The FMC can be approached from neighbourhoods to regional scale, from mobility infrastructure to more flexible transport possibilities	Little in-depth comparison	Knowledge gaps in several topics prevent a successful implementation of new innovative approaches, such as the FMC
Moreno et al. (2021)	Introduction of the fifteen-minute city concept, its origin and future directions	Desk research	- The FMC may contribute to both environmental and equitable futures - Proximity of basic needs, amenities, is insufficient in current urban planning	The FMC can improve human interaction with proximity of basic facilities. With lower travel times, social community interactions increase	15 minutes may seem arbitrary, but only steer proximity-based planning	Showcase the concept in the global south. The respective importance of density, proximity, diversity and digitalisation should be researched. Research on how to complement classical modelisation approaches
Pinto and Akhavan (2022)	Scenarios for a Post-Pandemic City: urban planning strategies and challenges of making "Milan 15-minutes city	Desk research	- Milan ranks and weighs proximity of amenities to steer its FMC goals. Sustainable mobility networks connect the differentiated neighbourhoods	"The city of proximity is not a radical turning point but rather a model for a lifestyle that many already aspire to have"	More essayish estimations, little prove by surveys/models, in-depth research	Research how short networks of daily life connect with long ones, such as study or cultural.
Abdelfattah et al. (2022)	The fifteen-minute city: interpreting the model to bring out urban resiliencies	Desk research, mapping, measuring walkability	- Some densely-populated areas have a low pedestrian access	Soft mobility policies and long term infrastructure strategies benefit the FMC. Design for all perspective creates new opportunities to link demand and supply better	Not very in-depth analysis of what is needed	New inclusive concepts of accessibility are needed

Gaglione et al. (2022)	Urban accessibility in a fifteen-minute city: a measure in the city of Naples, Italy	GIS analysis	- Young, higher educated are better served - High population-density not always well-served by amenities	Directing public interventions to develop urban areas, supporting local life	Highly analytical, little focus on urban mobility potential	Modifiable areal unit problem, administrative districts, should be improved
Badii et al. (2021)	Computing 15MinCityIndexes on the Basis of Open Data and Services	GIS analysis	- With open data, FMC indicators are computable - 15MinCityIndex works well in urban, but not in rural areas	Method applicable for similar indexes in other areas. Compute normalization factors	Relations between Moreno's concept and indexes are not always clear	Index should be evaluated more precisely
Borghetti et al. (2021)	Relationship between railway stations and the territory: case study in Lombardy – Italy for 15-min station	GIS analysis	- Train stations services can be compared by this method	Focus on stations as 'doors' to neighbourhoods	Services are poorly defined	Research on relative weights of services is needed: MCA can be considered
Staricco and Brovarone (2022)	Livable neighborhoods for sustainable cities: Insights from Barcelona	Desk research, interviews	- Superblocks consider only green areas as amenities - Conflicts may exist between those 'inside' the blocks and those 'outside'	Relation between 'superblocks' and FMC approach. Reorganisation of mobility	The FMC Is not considered in the conclusion/discussion	Appropriate participation methods are crucial in implementing urban redesign
Balletto et al. (2021)	fifteen-minute city in Urban Regeneration Perspective: Two Methodological Approaches Compared to Support Decisions	Literature review, GIS analysis, compare analyses	- Authors conclude that FMC is poorly dealt with from the academic perspective - Community-based approach is needed for effective design	Identification of effective and significant characteristics for the FMC	Focus on buildings to improve proximity of amenities, less on a higher level	Geographical output and indices, the two analysed methods, combined need to be evaluated
Graells-Garrido et al. (2021)	A city of cities: Measuring how 15-minutes urban accessibility shapes human mobility in Barcelona	Mobile phone data analysis, Open Street Map and Spanish statistics data analysis.	- Administrative boundaries cannot explain mobility patterns - Mobility related to amenities is significantly different in importance for different neighbourhoods within the same city.	Model relations between amenities and origin-destination flows. Very clear, practical approach	Mobile phone data has a bias, limited knowledge about mobility patterns	Multi-city analysis is needed. The effect of tourists/visitors on mobility demand. Detailed statistical data on neighbourhoods can reveal more user group patterns on 15-minute cities.

		Geographically Weighted Regression analysis				
Pozoukidou and Chatziyiannaki (2021)	fifteen-minute city: Decomposing the New Urban Planning Eutopia	Case study analysis, desk research, qualitative ranking	- Proximity of resources instead of accessibility is key in the FMC - Assessed cities focused more on accessibility instead of proximity of services	15-minute cities' policies are not fully in line with the FMC concept. Quantification and proximity (instead of accessibility) is rather difficult	The subjectivity of ranking. Policy-aimed, less practical	No recommendations. Citywide resource allocation challenges are not referred to in the neighbourhood focused policies
Gaxiola-Beltrán et al. (2021)	Assessing Urban Accessibility in Monterrey, Mexico: A Transferable Approach to Evaluate Access to Main Destinations at the Metropolitan and Local Levels	GIS analysis, rating, Urban Mobility Accessibility Computer (UrMoAC) tool (MR and district scale)	- Urban planning based on accessibility can benefit sustainable planning - For some amenities, the assessed Monterrey district is an FMC - Cycling gives significantly different results than only walking FMC analysis	Focus on both the local as on the metropolitan region Decentralise a city results in better FMC potential	Limited selection of mapped amenities	Add more socio-economic and demographic factors Assess active modes in combination with PT, although it is not officially part of the FMC concept Analyse from different perspectives with multiple variables Start at the local level for planning the city
Fabris et al. (2020)	New Healthy Settlements Responding to Pandemic Outbreaks: Approaches from (and for) the Global City	Case studies analysis, desk research, fieldwork and interviews	- The COVID-19 pandemic accelerated the FMC policy in Milan	FMC in perspective of the global city and in relation to other urban approaches	Very essayish, no quantitative substantiation	How universal are the healthy settlement approaches, as the FMC, in creating more resilient systems in other systems.
Salih and Hussein (2021)	Cities after pandemic: enabling social distancing as a new design standard to achieve urban immunity	Desk research and case study analysis and design	Walking and cycling can improve urban immunity and increase liveability	Urban immunity perspective, spatial planning determines health and safety	Low quality English and difficult line of reasoning. Not very in—depth	No recommendations

Bertoni, Dubini, and Monti (2021)	Bringing Back in the Spatial Dimension in the Assessment of Cultural and Creative Industries and Its Relationship with a City's Sustainability: The Case of Milan	Mapping cultural amenities and related indicators on neighbourhood level	- Very heterogenous urban sprawl of cultural activities with specific hotspots. Cultural vibrancy has more potential in peripheral neighbourhoods	Extensive research on mapping several cultural amenities, including events, economic factors and connectivity (mobility)	No analysis within neighbourhoods for more specific 15 minutes indication. Indicators are quite rough Neighbourhoods' inhabitants composition was beyond the scope of the research	Apply the cultural approach in other cities, including more geographical factors Stakeholders' demands and interplay needs further research
Carpio-Pinedo, Benito-Moreno, and Lamíquiz-Daudén (2021)	Beyond land use mix, walkable trips. An approach based on parcel-level land use data and network analysis	Case study analysis, data analysis, network analysis, origin-destination generation	- Regarding walkability, Madrid has a high centre-oriented trip variation - Significant imbalances exit between the generation of walkable trips for the FMC and the destination	Walkability analysis between origins and destinations in the Madrid metropolitan area	On the metropolitan scale (of Madrid) further application of the method is difficult related to the data quality	Research on the difference between the number of walkable trips and the actual walked trips The exploration of destination areas specified more in-depth Research on difference in walkability for different land use types
Kissfazekas (2022)	Circle of paradigms? Or '15-minute' neighbourhoods from the 1950s	Analysis of real estate advertisements	- Although the analysed areas are very neighbourhood, high-accessibility-oriented, accessibility is rarely mentioned as benefit of the locations - Other neighbourhood unit concept characteristics are listed as benefits - Green areas are very important, closeness of basic facilities is not	Review of how the neighbourhood approach years after creation is described by unaware real estate sellers	Limited number of cases, indirect research	No recommendations, but an important lesson: what will remain of the intentions of an urban concept decades after construction? Some qualities are still valued, while others are never mentioned
Moro (2022)	Co-design of public spaces for pedestrian use and soft-mobility in	Case study, descriptive analysis of a	- Social initiatives can be a useful starting to point to stimulate active modes locally	Focus on safety and community-building by the FMC concept	Only descriptive analysis of but one case	To improve neighbourhood-oriented community-building certain recommendations are given that improve public design

	the perspective of communities reappropriation and activation	neighbourhood	- Good public design enhances local community-building			
Caselli et al. (2022)	Exploring the 15-minute neighbourhoods. An evaluation based on the walkability performance to public facilities	GIS analysis, case study analysis	- Pedestrian accessibility can be mapped well on the district scale by the authors' GIS method - The proximity of kindergartens and of other inhabitants is almost similar in the case study area	Aims to assess FMC performance on very small scale	Borders of district limit indication of amenities	Slow mobility and transport infrastructure planning should intertwine with urban plans and policies, considering the distribution of services
Majstorović et al. (2022)	The City of Zagreb Lower Town Urban mobility development program	Desk research	- Zagreb's spatial plan proposes a wide range of possibilities, but most important are the intermodal connections	Opportunities for FMC urban reconstruction after an earthquake	Limited focus on FMC, mentioned as goal, but no in-depth analysis No focus on proximity	Continuous cooperation between experts is needed Technical traffic solutions should be further developed
Chen and Crooks (2021)	Delineating a 'fifteen-minute city': An Agent-based Modeling Approach to Estimate the Size of Local Communities	Agent-based modelling integrated with GIS	- Model uses diversity of amenities as energy for active trips - DFMC model contributes to quantification of the FMC	Defining benchmarks for the FMC city	Simplified situation, mainly based on physical structure and POIs of amenities	Recommend incorporating real world mobility data and demographic and socio-economic data
Guzman et al. (2021)	COVID-19, activity and mobility patterns in Bogota. Are we ready for a 'fifteen-minute city'?	Survey, desk research, GIS analysis, binary logit model	- Significant differences between working from home between high- and low-income groups. - Lower incomes needed to travel more, disbalance between housing and work locations - Other amenities, such as education, are spread unequally	The social possibilities for an FMC in the Global South	Several topics, less in-depth analysis. Individual spatial-temporal dimensions gained little attention (Geurs & Van Wee, 2004)	The FMC brings not only transport planning effects, but also urban planning to address social and spatial urban inequalities Developing the FMC and reducing inequality can be applied together

Appendix 3: The amenities, mapped and analysed by scholars

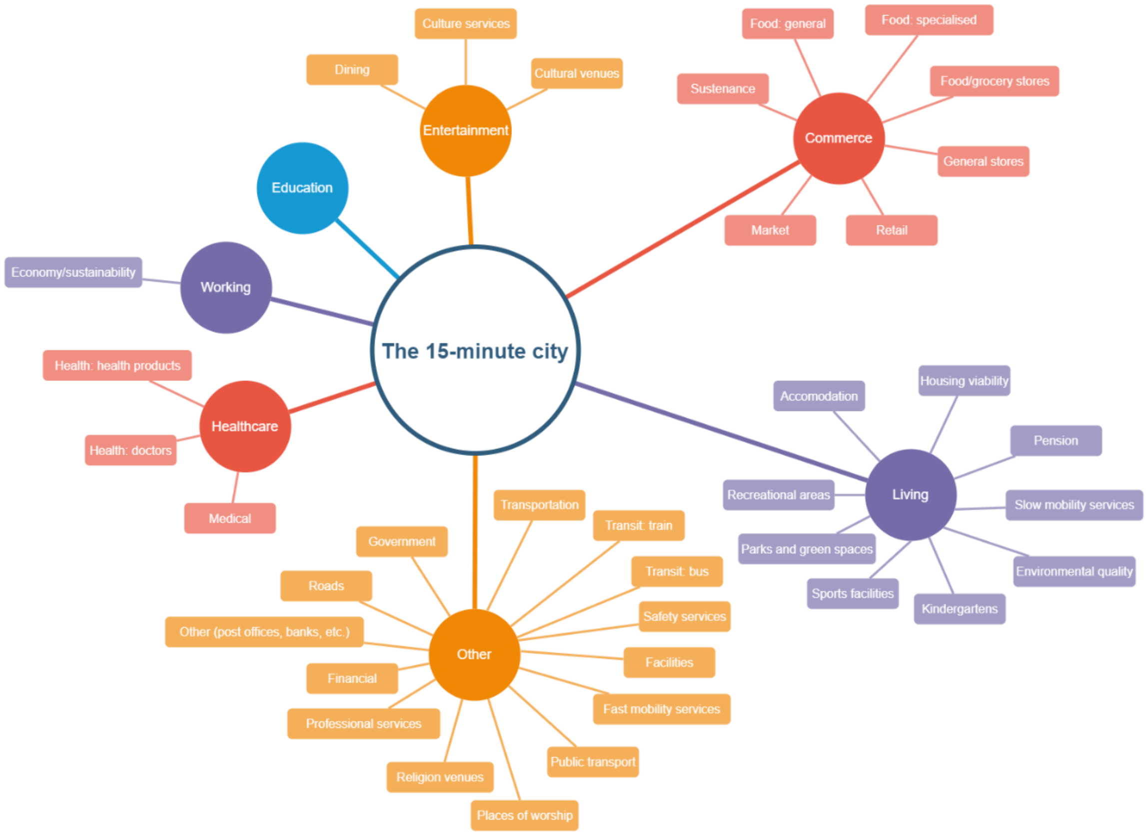

Table 13: The scholarly mapped amenities with the related frequencies (number of papers that mention this amenity), ordered by Moreno's functions. The last column are other amenities, which did not fit within one of the other functions.

Living	**2**	**Commerce**	**3**	**Entertainment**	**6**	**Education**	**9**	**Working**	**2**	**Healthcare**	**8**	**Government**	**4**
Accommodation	1	Market	1	Dining	2			Economy/sustainability	1	Medical	2	Roads	1
Housing viability	2	Retail	1	Culture services	4					Health: doctors	1	Other (post offices, banks, etc.)	2
Pension	1	General stores	2							Health: health products	2	Financial	4
Kindergartens	1	Food/grocery stores	4									Professional services	1
Parks and green spaces	3	Food: specialised	1									Religion venues	2
Recreational areas	2	Food: general	1									Public transport	1
Slow mobility services	1	Sustenance	1									Fast mobility services	1
Environmental quality	1											Transit: bus	1
Sports facilities	5											Transit: train	1
												Transportation	1
												Safety services	1
												Facilities	1

Appendix 4: Interview format

The set-up for the interview and form of consent were used for the first part of the research. The following persons have been interviewed:

- Pim Uijtdewilligen, project manager mobility, MRDH, March 31, 2022
- Yannick Angkotta, urban designer, TAUW, April 6, 2022
- Leon de Graaf, strategic advisor mobility, municipality of Utrecht, April 6, 2022
- Rients Dijkstra, professor in Urban Design, TU Delft, April 7, 2022
- Martijn Gerritsen, senior advisor space and environment, TAUW, April 12, 2022
- Anno Drenth, programme manager sustainability, TAUW, April 12, 2022
- Frank Druijff, environmental manager rural areas, TAUW, April 19, 2022
- Martin Guit and Kristiaan Leurs, mobility advisor and strategist, municipality of Rotterdam, May 30, 2022

Interview guideline (3 min.)

Section	Explanation	Context
Introduction	Short explanation of research goals	Thank you for participating. Contribute to master thesis to the FMC. Many different perspectives and unclarity about which characteristics it contains. You can contribute by your expert view on the topic. Related to background, I have read several papers and fully focus on the FMC and the value of proximity of amenities/services.
	Background gathering data	Different experts interviewed. Semi-structured, explorative of nature. No standard questions, but flexible direction interview
Clarification	Reciprocal consent Records possible?	Records can be checked afterwards. If you want, you can review how you are quoted before the final thesis

Questions (30 min.)

Theme	Question	Follow-up question	Context
The FMC concept	How would you define the FMC?	What do you think about Moreno's definition? Does it entail the core idea?	Perspective of interviewee on the FMC
Moreno's core ideas	How do you consider the relative relevance of Moreno's core ideas for the FMC; density, diversity, proximity and digitalisation?	Why? Which ideas could be added or removed?	Breaking down the FMC in separate ideas
Mobility in the FMC	How could active modes and shared mobility interplay?	Where should spatial developers focus on regarding the mobility system in the FMC?	Developing a mobility system for the FMC
Shift towards proximity	To what extent is bringing amenities proximate enough a realistic approach to reduce car use?	What is needed to do so?	Core idea of FMC Difference with accessibility, 'nearness' with less infrastructure

Link with spatial planning	How to bridge the gap of the inspirational idea of the FMC towards practical implication? How could this steer, i.e., housing development?	Improving existing neighbourhoods and/or developing new FMC neighbourhoods. What do you prefer? How effective?	Different types of spatial development
Challenges	How do you consider in relation to residential self-selection the potential of creating FMC neighbourhoods in already existing sub-urban places, such as Pijnacker, Bleiswijk or Barendrecht? (voorsteden)	To what extent are people willing to have their basic needs close to their homes?	Focus on difficulties of the FMC

Moreno's definition FMC: "A city where people can access all of their basic essentials at distances that would not take them more than 15 minutes by foot or by bicycle"

Moreno's functions:

- Living

- Working
- Commerce
- Healthcare
- Education
- Entertainment

Finishing (3 min.)

Section	Explanation	Context
Finishing up	Something important you'd like to share?	Own contribution/main message
Snowballing	Do you know another expert whom I should talk according to you? Could you give me his/her contact details?	Connecting people
Continuation	Could I contact you afterwards if something pops up?	Changing perspectives or new questions coming up afterwards
Finish	Thank you for your contribution and time. If you'd like the final thesis to be send, please tell me	

Specific questions:

- *(Some specific questions added for every stakeholder, depends per interviewee)*

Appendix 5: GIS analysis steps

The data for GIS analysis is retrieved from different sources thereby aiming to use similar sources. A total of four different datasets have been loaded in QGIS. The quality of green areas is retrieved from the Mulier indicator. This score reveals the proximity of green and blue and recreational areas and is directly added as a variable for statistical analysis. Table 14 displays the datasets of all analysed amenities.

Table 14: Mapped amenities with data sources and indicators

Function	*Amenity*	*Dataset*	*Year*	*Quantitative*	*Features*
Living	Sports facilities	Voorzieningen voor de samenlevingsatlas + OpenStreetMap	2021 + 2022	#sport locations	Sport fields (VVS) and swimming pools (OSM)
	Green area	Mulier	2021	Proximity of recreational green and blue. Score 0-100	Indicator of recreational green and blue by Mulier research
Commerce	Food supply	Voorzieningen voor de samenlevingsatlas	2021	#supermarkets	Locations of supermarkets
Entertainment	Restaurants	Voorzieningen voor de samenlevingsatlas	2021	#restaurants and #cafes	Places to eat, including takeaway
Education	Education	Voorzieningen voor de samenlevingsatlas	2021	#schools	Combination of primary and secondary schools
Working	Job supply	Nationaal Georegister	2019	#work location	Industrial area polygons and office locations
	Sustainable job accessibility	OpenStreetMap	2022	#train and metro stations	All metro and train stations
Healthcare	Health	Voorzieningen voor de samenlevingsatlas	2021	#general practitioners	Locations of general practitioner practices
Other		Voorzieningen voor de samenlevingsatlas + OpenStreetMap	2021 + 2022	#financial locations	Banks (OSM) and ATMs (VVS)
		OpenStreetMap	2022	#religious venues	All churches, mosques etc, all building with a religious purpose
		OpenStreetMap	2022	#town halls	Governmental buildings, including city district offices and service points
		Voorzieningen voor de samenlevingsatlas	2021	#libraries	Library buildings

The QGIS analysis steps are visible in Figure 9 and elaborated. The basic background map is from OSM, which has been used for verification if points of interest (POIs) are located correctly. For all layers the Amersfoort New coordinate reference system has been applied. The PC4 areas have been changed from polygons to points by the centroids tool to have one starting point to do distance calculations. From these centroids, travel time isochrones are calculated, see Figure 9 left above. PC4 polygons on itself are not suitable since the size of PC4 areas differs significantly. The average size of a PC4 area is 8.3 km^2, while the size of the 25% smallest, which the MRDH mainly consists of, is 1,1 km^2 (Kaal, Vanderveen, & McConnell, 2008). Moreover, the benefits of proximate amenities outside a PC4 polygon would not be considered. Therefore, the isochrones consider the OSM sub-layer and ignore the exact edges of each PC4 area. The geographical representation though is on the PC4 level. Thus, differences between more and less urbanized areas can be highlighted with more aggregation than on the individual or PC6 level. The data from VVS and OSM was not always directly suitable as only POI data could be used for analysis. All polyline and polygon amenities are transformed via centroids of these features into points. These are merged and multipoint layers for each amenity are the result.

The 'distance matrix' tool has been applied to calculate the minimum Euclidean distance from each centroid of each PC4 polygon area to the nearest amenity of that type, for example the most proximate transit hub. The left side analysis in Figure 9 shows the different steps for the data preparation in QGIS. For each PC4 are the coverage of the POIs of amenities within the buffers are calculated and expressed in amount within the travel time isochrone.

To determine the level coverage the number of amenities within polygons is calculated. The multiplication of the amenities distance and density maps is used to calculate the proximities. The construction of buffer zones, isochrones of travel time, is done for three active modes, namely cycling, electric cycling and walking. The isochrone travel time polygons have been created by the Open Route Service (ORS) tool. For different modalities, walking, bike and electric bike, the infrastructure characteristics have been taken into account, which results in realistic isochrone areas. Isochrone areas of the PC4 centroids, as visible in Figure 18, have been generated and represent the area that can be reached within 5, 10 and 15 minutes for the different active modes. For simplicity, only the isochrones and related level coverage data for conventional cycling is used.

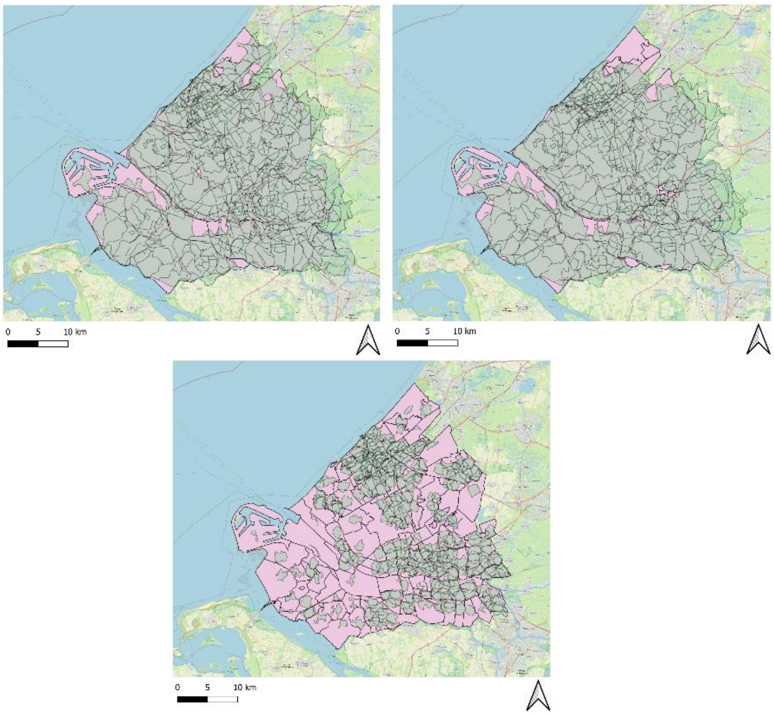

Figure 18: Representation of areas in the MRDH within 15 minutes by conventional bike (left), e-bike (middle) and by foot (right)

Specific steps to retrieve suitable data for individual amenities is described below:

Steps calculating sport fields

- The OSM data ‘soccer fields’ is loaded
- The four line shapes are removed. The polygon shapes are transformed into multipoints for distance analysis
- By ‘select features using an expression’ the sport fields with areas of at least 1000m^2 are filtered. This is a reasonable size to filter small fields with little value to do sports. Also, this is about the size of a Cruyff Court, a standard small soccer field, which is 1176m^2
- Points and centroids of fields are joined by ‘union’ tool and form the ‘sports’ layer

Steps stations/metro stations

- From OSM layer ‘public transport’, ‘stations’ loaded with Quick OSM tool. These include all metro and train stations within the MRDH
- Lines and polygons are removed because they are similar in location compared to the loaded points
- Irrelevant points for large-scale commuting purposes are removed, such as recreational ferries and a museum tram line

Quality of green area

- The Mulier institute of the university of Utrecht has conducted research on the quality of green based on the proximity of parks and the size of parks and the availability of recreational green. This map is loaded in QGIS
- The tool ‘add polygon attributes to points’ is used to add the data of the Mulier map of green quality to the PC4 points
- The data is joined to the PC4 points layer

Distance to work locations

- Combination of distance to office locations and business parks
- Office and business parks location data is loaded from Geodata Zuid-Holland, from the NGR
- The tool 'NNJoin' is used to calculate the minimum distance between points of PC4 and polygons of loaded data

Calculation of distance matrices of general amenities (such as town halls, restaurants, religious venues)

- Some point layers exist of different features, such as swimming pools and soccer fields or religious venues. These have first been unionized with the 'union' tool
- With tool 'convert multipoint to points' the OSM data has been converted
- This tool was not always working. In some cases, I have used the 'multipart to singleparts' tool
- These point layers are used for the tool 'distance matrix' together with the layer 'mean coordinates', the centroids of each PC4 polygon. A maximum of 1 features is indicated in the tool. The result is the minimum distance from each PC4 centroid to each most proximate amenity
- The distances are calculated in meters and are Euclidean
- The distances are added to Excel

To determine the level coverage, the number of points of amenities within travel time polygons are calculated.

- The basis are travel times of 5, 10 and 15 minutes by conventional bike. These are created based on infrastructure data from OSM and created by the Open Route Service plugin. Thus, the infrastructure properties for different modalities can also be considered in getting an indicator of the coverage level for different amenities per PC4 area
- The 'count points in polygon' tool is applied to count the number of amenities within the 5-, 10- and 15-minutes modalities polygons
- This data is added to Excel

Appendix 6: Full list of FMC indicators

FMC indicators developed before statistical analysis:

- Average distance to all 11 identified amenities in kilometres
- Average distance to a set of core amenities: supermarkets, schools, work locations and transit hubs, in kilometres
- Average distance to all identified amenities except for work locations, in kilometres
- Maximum distance to FMC amenities in kilometres
- Maximum distance to a set of core amenities: supermarkets, schools, work locations and transit hubs, in kilometres
- Percentage of FMC amenities within 15 minutes walking
- Percentage of FMC amenities within 15 minutes cycling
- Percentage of FMC amenities within 15 minutes electric cycling
- Binary: all FMC amenities are or are not within 15 minutes walking distance
- Binary: all FMC amenities are or are not within 15 minutes cycling distance
- Binary: all FMC amenities are or are not within 15 minutes electric cycling distance
- Binary: all core amenities are or are not within 15 minutes walking distance
- Binary: all core amenities are or are not within 15 minutes cycling distance
- Binary: all core amenities are or are not within 15 minutes electric cycling distance
- Level coverage of FMC amenities within 15 minutes cycling distance, in thousands
- Average number of amenities within 15 minutes cycling distance
- Further specified indicators, focusing on proximity and level coverage combinations:
    - Binary (core amenities, some very proximate): a supermarket < 1 km, a school < 1 km, a transit hub < 5 km and work locations within 5 km
    - Binary (core amenities and entertainment instead of work): at least 5 supermarkets, 5 schools, 5 transit hub and 500 cafes/restaurants within 15 minute cycling
    - Binary (recreational focus): at least 1 transit hub, 20 sport locations, 50 restaurants and cafes and 1 library within 15 minutes cycling
    - Binary (basis and more proximate): average distance < 1 km, at least 2 transit hub, 5 supermarkets, 5 schools and over 10 work locations within 15 minutes cycling

Appendix 7: Descriptive statistics

Basic statistical information of the applied data is displayed in this appendix. These are separated in socio-demographic and built environment, proximity and level coverage of amenities data and FMC indicators data.

Table 15: Descriptive statistics of socio-demographic and built environment data

	Mean	Std. Deviation	Minimum	Maximum
Urbanity level	1.475	0.792	1.000	4.000
Car ownership	1.242	0.965	0.000	10.000
Driver's license	0.693	0.461	0.000	1.000
Income	1.260	0.867	0.000	2.000
Children	0.537	0.499	0.000	1.000
Students	0.059	0.236	0.000	1.000
Female	0.508	0.500	0.000	1.000
Age (years)	40.597	20.983	0.000	98.000
Green quality	0.226	6.619	-99.990	1.000
Quality of cycle paths	0.471	0.108	0.240	0.810
Length of cycle paths	11.153	8.486	1.000	24.000
Address density	3.054	1.959	0.007	9.000

Table 16: Descriptive statistics of distances from centroids of PC4 areas to amenities

	Mean	Std. Deviation	Minimum	Maximum
Distance to sport locations	6.226	4.153	0.171	57.000
Distance to supermarkets	0.469	0.383	0.011	6.000
Distance to restaurants and cafes	0.426	0.349	0.028	2.000
Distance to schools	0.362	0.333	0.014	6.000
Distance to work locations	0.643	0.520	0.000	3.000
Distance to transit hubs	1.874	1.952	0.043	13.490
Distance to general practitioners	0.490	0.397	0.021	6.280
Distance to financial locations	0.667	0.540	0.019	6.000
Distance to religious venues	0.523	0.446	0.012	6.000
Distance town halls	1.552	1.022	0.061	8.000
Distance to libraries	1.125	0.855	0.024	6.000

Table 17: Descriptive statistics of level coverages of amenities within 15 minutes cycling around centroids of PC4 areas

	Mean	Std. Deviation	Minimum	Maximum
Level coverage sport areas	45.927	22.976	0.000	117.000
Level coverage supermarkets	39.432	29.978	0.000	117.000
Level coverage restaurants and cafes	320.668	350.059	1.000	1082.000
Level coverage schools	57.681	35.560	0.000	151.000
Level coverage work locations	17.349	10.234	0.000	54.000
Level coverage transit hubs	8.401	7.772	0.000	27.000
Level coverage general practitioners	55.448	39.055	0.000	155.000

	Mean	Std. Deviation	Minimum	Maximum
Level coverage financial locations	29.725	24.258	0.000	86.000
Level coverage religious venues	47.348	42.276	0.000	171.000
Level coverage transit hubs	3.427	2.995	0.000	12.000
Level coverage libraries	5.963	5.009	0.000	21.000

Table 18: Descriptive statistics of FMC indicators for PC4 areas

	Mean	Std. Deviation	Minimum	Maximum
FMC average distance amenities	1.270	0.694	0.367	10.000
FMC average distance core amenities	0.808	0.585	0.106	5.000
FMC max distance amenities	6.433	4.009	0.848	57.000
FMC max distance core amenities	1.952	1.902	0.234	13.490
FMC average distance all amenities except for work locations	1.334	0.767	0.370	11.000
FMC binary: level coverage, all amenities are or are not within 15 min cycling	0.808	0.394	0.000	1.000
FMC binary: level coverage, core amenities are or are not within 15 min cycling	0.853	0.355	0.000	1.000
FMC level coverage of all amenities within 15 min cycling	0.631	0.535	0.002	1.863
FMC average number of amenities within 15 min cycling	57.424	48.683	0.182	169.000
FMC percentage of amenities within 15 min by foot	0.800	0.142	0.000	1.000
FMC percentage of amenities within 15 min by bike	0.902	0.066	0.182	1.000
FMC percentage of amenities within 15 min by e-bike	0.927	0.057	0.182	1.000
FMC percentage core amenities within 15 min by foot	0.876	0.175	0.000	1.000
FMC percentage core amenities within 15 min by bike	0.958	0.094	0.250	1.000
FMC percentage core amenities within 15 min by e-bike	0.973	0.078	0.250	1.000
FMC specified: >9 supermarkets, >9 schools, >0 transit hubs, >9 work locations	0.733	0.443	0.000	1.000
FMC specified: supermarket <1 km, school <1 km, transit hub <5 km, work location <5 km	0.850	0.357	0.000	1.000
FMC specified, recreational focus: >0 transit hub, >20 sport locations, >50 restaurants and cafes and >0 libraries	0.637	0.481	0.000	1.000
FMC specified, smaller and sufficient basis: average distance< 1 km, >1 transit hubs, >4 supermarkets, >4 schools, >9 work locations	0.316	0.465	0.000	1.000
FMC specified, urban focus: >4 schools, >4 supermarkets, >4 transit hubs, >500 restaurants and cafes	0.247	0.431	0.000	1.000

Appendix 8: Simplification of ODiN modality groups

OViN (2017) had slightly different labels. In this case, the data is transformed to ODiN modalities and the group ‘cyclist as a passenger’ is labelled as ‘conventional bike’.

Original modality groups OViN 2017	**Simplified modality groups for research**
Train	Train
Touringcar/bus	Other motorized vehicles
Metro	Metro
Tram	Bus and tram
Bus	Bus and tram
Car driver	Car
Delivery car	Other motorized vehicles
Truck	Other motorized vehicles
Mobile home	Other motorized vehicles
Car, passenger	Car
Taxi	Other motorized vehicles
Motor	Other motorized vehicles
Moped (bromfiets)	Other motorized vehicles
Moped (snorfiets)	Other motorized vehicles
Bike (electric or conventional) Electric (in another column) Conventional (in another column)	Bike Electric bike Conventional bike
Bike, passenger	Conventional bike
Agricultural vehicle	Other motorized vehicles
Boat	Other motorized vehicles
Plane	Other motorized vehicles
Skates/skeelers/step	Walking
Disabled transport	Walking
Walking	Walking
Pram	Walking
Other	Other motorized vehicles

Original modality groups ODiN 2018-2019	**Simplified modality groups for research**
Personal car	Car
Train	Train
Bus	Bus and tram
Tram	Bus and tram
Metro	Metro
Speedpedelec	Electric bike
Electric bike	Electric bike
Non-electric bike	Conventional bike
Walking	Walking
Touring car	Other motorized vehicles
Delivery van	Other motorized vehicles
Truck	Other motorized vehicles
Motorhome	Other motorized vehicles
Taxi	Other motorized vehicles
Agricultural vehicle	Other motorized vehicles
Motor	Other motorized vehicles

Moped (bromfiets)	Other motorized vehicles
Moped (snorfiets)	Other motorized vehicles
Disabled transport with motor	Walking
Disabled transport without motor	Walking
Skates/skeelers/step	Walking
Boat	Other motorized vehicles
Other with motor	Other motorized vehicles
Other without motor	Other motorized vehicles

Appendix 9: Correlations of the variables

1.1 Correlations between the variables

This section describes and discusses the correlations between the geographical variables, the social-economic variables and the proximity and level coverage of FMC amenities. This analysis is relevant for the regression analysis as strong correlations influence the choice of indicators and too many highly correlated effects reduce the validity of the research. Moreover, unpredicted effects are explained by correlation analysis. Below, tables with correlations for four sub-groups of variables considered for analysis are displayed. The address density is in all tables and thus all variables can indirectly be compared. Significant correlations ($p < 0.001$) are indicated with black lines around the boxes. Red indicates a negative correlation, green a positive correlation. The correlations are retrieved all individual participants of ODiN living in PC4 areas with minimal 30 participants per PC4 area.

1.1.1 Correlations between socio-demographic and built environment variables

The tables are displayed on the next pages. The socio-demographic correlations are least significant, although these are almost all at the individual level, in contrast to the other three tables which are on PC4 level. Table 19 reveals notable correlations, for example that there is almost no correlation between car ownership and a driver's license. The address density is strongly negatively correlated with the quality of green area. Car ownership has a positive correlation with income, children, quality of green area and the percentage of cycle paths. The latter two may be related to the fact that these factors have a higher score in rural areas. This is in line with a negative correlation between address density and car ownership. Another indicator that the data seems appropriate is the strong negative correlation between the age of the ODiN participant and the binary variable for if the household has children or not.

1.1.2 Correlations between the distance to the analysed FMC amenities

Most correlations between distances to amenities are positive. Amenities are often clustered and therefore correlated. Interestingly, work locations have a weaker correlation with the other FMC amenities. Moreover, some correlations are over 0.5, which impacts the regression results as these have a high overlap. The correlations reveal a general negative relation with the address density. Interestingly the relation with work locations is weakest, which may indicate that work locations, which include both industrial areas as well office areas, are not located there were most people live. If you read this, I have this much respect for you that I would like to give something nice. You can send me an email with 'I read this, nice thesis until the end', you know my mail address. Actually, this is a test to see to what extent appendices are read. This special action accounts for 2022 only.

1.1.3 Correlations between the level coverage of the analysed FMC amenities

The level coverage of amenities is strongly correlated for most variables, except for work locations, sport locations and transit hubs. This is interesting as transit hubs are often within city centres and in line with earlier transit-oriented development proximate to other amenities. Still, the address density is strongly correlated with the level coverage of transit hubs, which indicates that there are more transit hubs within 15 minutes by (conventional) bike in areas with a higher address density. The strong correlations bring challenges for the validity of considering level coverage of separate amenities within the logistic regression analysis.

Table 19: Correlations between socio-demographic and built environment variables

Pearson's Correlations socio-demographic variables

Variable	**Car ownership**	**Driver's license**	**Income (standardised)**	**Kids (binary)**	**Students (binary)**	**Female**	**Age**	**Quality of green**	**Percentage of good cycle paths**	**Length of cycle paths per municipality**	**Address density**
1, Car ownership											
2, Driver's license											
3, Income (standardised)											
4, Kids (binary)											
5, Students (binary)											
6, Female											
7, Age											
8, Quality of green											
9, Percentage of good cycle paths											
10, Length of cycle paths per municipality											
11, Address density											

Correlation factor

1
0,75
0,5
0,25
0
-0,25
-0,5
-0,75
-1

Table 20: Correlations between FMC indicators and the address density

Pearson's Correlations FMC indicators

Variable	FMC av. dist. amenities	FMC max. dist. amenities	FMC amenities <15 walking	FMC amenities < 15 min cycling	FMC amenities < 15 e-bike	FMC binary (all amenities within or not within 15 min cycling)	FMC sum amenities < 15 min cycling	FMC av. number of amenities < 15 min cycling	Address density
1. FMC av. dist. amenities									
2. FMC max. dist. amenities	>0.5								
3. FMC amenities <15 walking	<-0.5	<-0.5							
4. FMC amenities < 15 min cycling	<-0.5	<-0.5							
5. FMC amenities < 15 e-bike	<-0.5	<-0.5		>0.5					
6. FMC binary (all amenities within or not within 15 min cycling)	<-0.5	<-0.5		>0.5	>0.5				
7. FMC sum amenities < 15 min cycling									
8. FMC av. number of amenities < 15 min cycling							>0.5		
9. Address density									

Correlation factor

- 1
- 0,75
- 0,5
- 0,25
- 0
- -0,25
- -0,5
- -0,75
- -1

Table 21: Correlations between distances to the possible FMC amenities

Pearson's Correlations distances to amenities

	Dist. sport accommodations	**Dist. to supermarkets**	**Dist. to restaurants and cafes**	**Dist. to schools**	**Dist. to work locations**	**Dist. to transit hubs**	**Dist. to general practitioners**	**Dist. to financial locations**	**Dist. to religious venues**	**Dist. to town halls**	**Dist. to libraries**	**Address density**
1. Dist. sport accommodations												
2. Dist. to supermarkets												
3. Dist. to restaurants and cafes		>0.5										
4. Dist. to schools		>0.5										
5. Dist. to work locations												
6. Dist. to transit hubs												
7. Dist. to general practitioners		>0.5	>0.5	>0.5								
8. Dist. to financial locations		>0.5	>0.5	>0.5			>0.5					
9. Dist. to religious venues		>0.5	>0.5	>0.5	not significant		>0.5	>0.5				
10. Dist. to town halls												
11. Dist. to libraries												
12. Address density			<-0.5									

Correlation factor

1
0,75
0,5
0,25
0
-0,25
-0,5
-0,75
-1

Table 22: Correlations between the level coverage of the possible FMC amenities

Pearson's Correlations level coverage of amenities

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Level coverage sport accommodations												
2. Level coverage supermarkets	>0.5											
3. Level coverage restaurants and cafes		>0.5										
4. Level coverage schools	>0.5	>0.5										
5. Level coverage work locations												
6. Level coverage transit hubs			>0.5									
7. Level coverage general practitioners	>0.5	>0.5	>0.5	>0.5								
8. Level coverage financial locations		>0.5	>0.5	>0.5		>0.5	>0.5					
9. Level coverage religious venues		>0.5	>0.5	>0.5			>0.5	>0.5				
10. Level coverage town halls			>0.5	>0.5			>0.5	>0.5	>0.5			
11. Level coverage libraries		>0.5	>0.5	>0.5			>0.5	>0.5	>0.5	>0.5		
12. Address density		>0.5	>0.5	>0.5		>0.5	>0.5	>0.5	>0.5	>0.5	>0.5	

Correlation factor

- 1
- 0,75
- 0,5
- 0,25
- 0
- -0,25
- -0,5
- -0,75
- -1

1.1.1 Correlations between the FMC indicators

The FMC indicators have strong correlations, logically in line with the definitions. For example, the third, fourth and fifth indicator represent the same features, only measured within larger isochrone areas, since by e-bike more amenities are within 15 minutes proximity. The difference between the average and the sum of amenities (indicators 1 and 2, and 7 and 8) is small as the correlations are strong. More interesting are the correlations with the address density. None of the FMC indicators have a strong (>0.5) correlation with the address density. The strongest correlation of the address density is with the first FMC indicator which is -0.264. Based on these results it is appropriate to use the FMC indicators next to the address density. The use of more than one indicator at the same time may be only suitable if the correlations are less than 0.5 and more than -0.5, which are indicated.

Appendix 10: Results of the logistic regression for the probability of making a trip by active modes in general

Table 23 gives slightly different results for the probability of making a trip by active modes. Based on both models B and E in Table 6 and Table 23, the increase in urbanity is slightly less, especially for level 1. The effect of income exists, but is small. An increase of income has a negative effect on the probability of making a trip by active modes. Other effects, such as the green quality or the length of cycle paths are small or not significant.

The R^2 of model F in Table 23 is higher than all other R^2s. This indicates that splitting up for different age groups gives more precise results to estimate the probability of making a trip by active modes. Especially children between 12 and 17 years have a far higher chance of making a trip by active modes, namely 3.58 times higher. Especially people with age 30-50 years have a far lower probability. This information is useful to focus on age groups where there is most to gain in stimulating the use of active modes.

Table 23: Trip by active modes as dependent variable with standard SD and BE independent variables

	Model D: trip by active modes		**Model E: trip by active modes and urbanity levels**		**Model F: trip by active modes and age groups**	
Variables	**Coefficients**	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**
Constant	0.329***	1.390	0.167	1.181	-0.111	0.895
Age	-0.007***	0.993	-0.007***	0.993		
Female	0.160***	1.174	0.162***	1.176	0.188***	1.206
Students	-0.293***	0.746	-0.292***	0.747	-0.083	0.920
Children	0.132***	1.141	0.100***	1.106	0.097***	1.102
Income	-0.062***	0.940	-0.070***	0.932	-0.027*	0.973
Car ownership	-0.359***	0.699	-0.381***	0.683	-0.396***	0.673
Green quality	0.003	1.003	0.002	1.002	0.003*	1.003
Quality of cycle paths	0.010*	1.010	-0.366**	1.442	0.041	1.042
Length of cycle paths	-0.006***	0.994	-0.003*	0.997	-0.003*	0.997
Address density	0.093***	1.098			0.103***	1.109
Reference: urbanity level 4						
Urbanity level 3			0.248**	1.282		
Urbanity level 2			0.068	1.070		
Urbanity level 1			0.408***	1.503		
Reference: age group ≥ 75 years						
65-74 years					0.189***	1.209
50-64 years					0.012	1.013
40-49 years					-0.180***	0.835
30-39 years					-0.201***	0.818
18-29 years					-0.080	0.923
12-17 years					1.277***	3.584
≤ 11 years					0.435***	1.545
McFadden R^2	0.033		0.030		0.052	

*** = P <0.001; ** = P<0.01; * = P <0.05

Appendix 11: Results of the logistic regression for the probability of making a trip by other modalities in general

Analysis of the effects of the variables on other mode choices within the MRDH reveals interesting relations. These are displayed in Table 24. Thereby, the probability of trips by other modes may be better predicted than trips by active modes alone, as some higher R^2s indicate. For example, a trip by e-bike is better predictable with the current variables than a trip by another active mode. Some variables which were highly insignificant were removed to achieve higher R^2s. Moreover, high probabilities of making not a trip by active modes does not necessarily mean that the trip is made by an unsustainable mode. Especially insights in the probability of making a trip by public transport are interesting.

A relevant insight is that address density has a positive effect on all modalities, except for car and e-bike. This indicates that car and e-bike are more competing with each other in rural areas, compared to the other modalities, although e-bikes are used in recent years.

Table 24: Logistic coefficients for trips by other modalities than active modes

	Model A: Walking		**Model B: Cycling**		**Model C: E-bike**		**Model D: Car**		**Model E: Public transport**	
Variables	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**
Constant	-1.231***	0.292	-0.479***	0.620	-4.976***	0.007	-1.127***	0.324	-2.232***	0.107
Age	0.000	1.000	-0.015***	0.985	0.036***	1.037	0.011***	1.011	-0.002	0.998
Female	0.134***	1.144	0.002	1.002	0.608***	1.837	-0.112***	0.894	0.154***	1.167
Students	-0.317***	0.728	-0.072	0.931	-1.177***	0.308	-0.665***	0.514	1.498***	4.471
Children	0.053	1.055	0.167***	1.182	-0.068	0.934	-0.119***	0.887	-0.059	0.943
Income	-0.207***	0.813	0.121***	1.129	0.091*	1.095	0.069***	1.071	0.074***	1.077
Car ownership	-0.228***	0.796	-0.287***	0.751	-0.126**	0.882	0.564***	1.759	-0.533***	0.587
Green quality	0.005*	1.005					-0.004**	0.996		
Quality of cycle paths			-0.172	0.842					-0.773***	0.462
Length of cycle paths	0.007***	1.007	-0.009***	0.991	-0.027***	0.974	-0.003**	0.997	0.026***	1.026
Address density	0.070***	1.072	0.059***	1.061	-0.073***	0.929	-0.113***	0.893	0.052***	1.053
McFadden R^2	0.033		0.030		0.087		0.078		0.084	

*** = P <0.001; ** = P<0.01; * = P <0.05

Appendix 12: Results of the logistic regression for the probability of making a trip by active modes with 10 different FMC indicator combinations

Table 25: Comparison of the values and the effects of different FMC indicators. The dependent variable is a trip by active modes

	Model A: FMC average distance to all 11 amenities	Model B: FMC binary level coverage: all amenities within 15 minutes	Model C: FMC average distance to supermarkets, schools, work locations and transit hubs	Model D: FMC average distance to and level coverage of all amenities within 15 minutes	Model E: FMC average distance to and average number of all amenities within 15 minutes	Model F: FMC average distance to and level coverage of supermarkets, schools, work locations and transit hubs
Variables	**Coefficient (O.R.)**	**Coefficient (O.R.)**	**Coefficient (O.R.)**	**Coefficient (O.R.)**	**Coefficient (O.R.)**	**Coefficient (O.R.)**
Constant	0.457*** (1.580)	0.597*** (1.817)	0.653*** (1.921)	0.455*** (1.576)	0.455*** 1.576)	0.799*** (2.223)
Age	-0.007*** (0.993)	-0.008*** (0.992)	-0.008*** (0.993)	-0.007*** (0.993)	-0.007*** (0.993)	-0.007*** (0.993)
Female	0.162*** (1.176)	0.162*** (1.176)	0.163*** (1.177)	0.161*** (1.175)	0.161*** (1.175)	0.162*** (1.176)
Students	-0.297*** (0.743)	-0.289*** (0.749)	-0.291*** (0.748)	-0.288*** (0.750)	-0.288*** (0.750)	-0.293*** (0.746)
Children	0.129*** (1.138)	0.097*** (1.102)	0.098*** (1.103)	0.138*** (1.148)	0.138*** (1.148)	0.100*** (1.105)
Income	-0.061*** (0.941)	-0.067*** (0.936)	-0.066*** (0.936)	-0.071*** (0.931)	-0.071*** (0.931)	-0.065*** (0.937)
Car ownership	-0.357*** (0.700)	-0.393*** (0.675)	-0.392*** (0.676)	-0.347*** (0.707)	-0.347*** (0.707)	-0.393*** (0.675)
Green quality	0.003*** (1.003)	0.003 (1.003)	0.003 (1.003)	0.002 (1.002)	0.002 (1.002)	0.003 (1.003)
Length of cycle paths	-0.005*** (0.995)	0.003* (1.003)	0.002 (1.002)	-0.009*** (0.991)	-0.009*** (0.991)	0.002 (1.002)
Address density	0.079 (1.082)					
FMC proximity indicator	-0.067*** (0.935)		-0.036* (0.964)	-0.043** (0.957)	-0.044** (0.957)	-0.092*** (0.912)
FMC level coverage indicator		0.033 (1.033)		0.383*** (1.467)	0.004*** (1.004)	-0.122** (0.885)
McFadden R^2	0.033	0.029	0.029	0.035	0.035	0.029

*** = P <0.001; ** = P<0.01; * = P <0.05

Table 26: Comparison of the values and the effects of specified amenities FMC indicators

	Model G: supermarket < 1 km, school < 1 km, transit hub < 5 km, work location < 5 km	**Model H: at least 5 supermarkets, schools, transit hubs and 500 cafes/restaurants within 15 minutes cycling**	**Model I: recreational focus: at least 1 transit hub, 20 sport locations, 50 restaurants and cafes and 1 library within 15 minutes cycling**	**Model J: average distance < 1 km, at least 2 transit hubs, 5 supermarkets, 5 schools and over 10 work locations within 15 minutes cycling**
Variables	**Coefficient (O.R.)**	**Coefficient (O.R.)**	**Coefficient (O.R.)**	**Coefficient (O.R.)**
Constant	0.513*** (1.671)	0.368*** (1,445)	0.311*** (1.364)	0.540*** (1.717)
Age	-0.008*** (0.992)	-0.007*** (0.993)	-0.007*** (0.993)	-0.007*** (0.993)
Female	0.163*** (1.177)	0.161*** (1.175)	0.162*** (1.176)	0.164*** (1.178)
Students	-0.292*** (0.747)	-0.294*** (0.745)	-0.299*** (0.742)	-0.293*** (0.746)
Children	0.098*** (1.103)	0.138*** (1.148)	0.128*** (1.137)	0.113*** (1.119)
Income	-0.065*** (0.937)	-0.063*** (0.939)	-0.065*** (0.937)	-0.066*** (0.937)
Car ownership	-0.390*** (0.677)	-0.358*** (0.699)	-0.356*** (0.700)	-0.382*** (0.683)
Green quality	0.003 (1.003)	0.003* (1.003)	0.003* (1.003)	0.002 (1.002)
Length of cycle paths		-0.007*** (0.993)	-0.006*** (0.994)	0.002 (1.002)
Address density		0.072*** (1.075)	0.080*** (1.083)	
FMC proximity indicator	0.158*** (1.171)	0.144*** (1.155)		0.177*** (1.194)
FMC level coverage indicator			0.111*** (1.117)	
McFadden R^2	0.029	0.033	0.033	0.030

*** = P <0.001; ** = P<0.01; * = P <0.05

Appendix 13: Geographical differences mode choices

Geographical differences between mode choice indicate how FMC each area currently is, based on the travel behaviour. Areas that have a high FMC indicator are in practice not always an FMC, if the share of active modes is low. Figure 19 displays areas with a low number of participants. Moreover, smaller towns as Brielle in the southwest, are also visible for having a higher share of active modes, but this PC4 area also has a low number of participants. Still, the geographical spread of areas where active modes are preferred is clear. These are mainly the areas very close to the city centres.

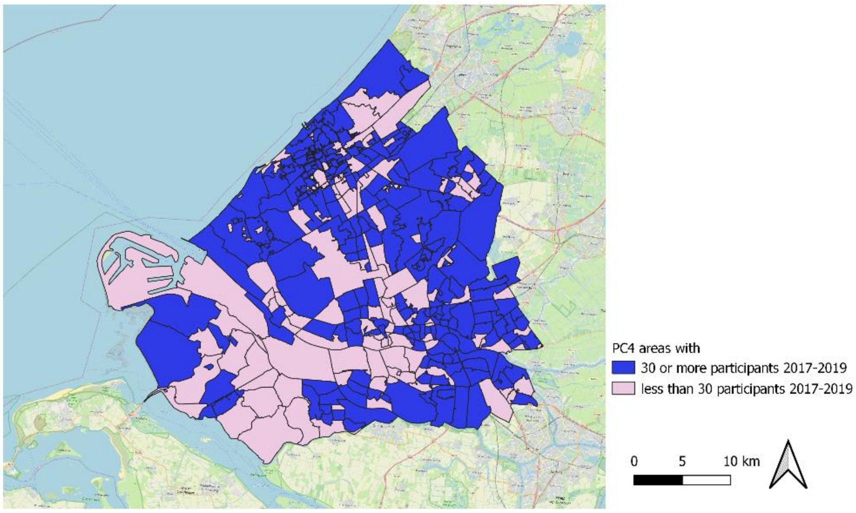

Figure 19: All MRDH PC4 areas, blue areas have ≥30 ODiN participants in the dataset 2017-2019

Figure 20 displays the share of active modes based on the number of trips for each PC4 area. In some urban regions the share of active modes is relatively low, but the share of another sustainable mode, public transport is often relatively high there, see Figure 22. Still, the urban regions are highlighted in Figure 20, especially with regards to the strongly urban PC4 areas are much smaller than rural ones. Some distortions are actually in the representations. For example, a large rural area in the centre (Schipluiden) stands out as dark green. This is an area with less than 30 participants for 2017-2019.

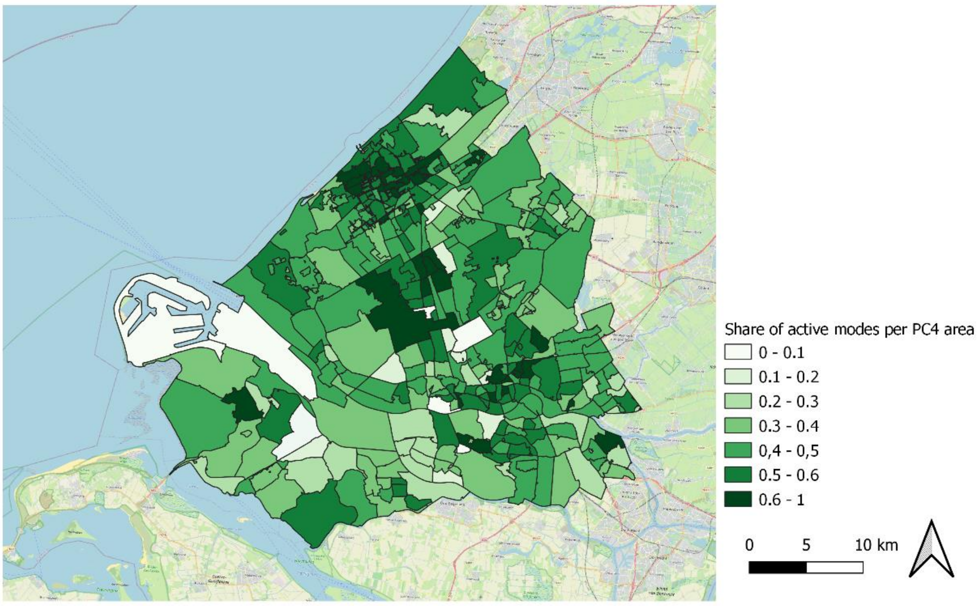

Figure 20: The higher the probability of inhabitants to choose for active modes, the greener

Figure 21 displays the areas where the car is often preferred over active modes. The rural areas have a far higher share of car trips. Interestingly, some suburbs, for example north of Rotterdam of the southern edge of Rotterdam, have also a high percentage of car use.

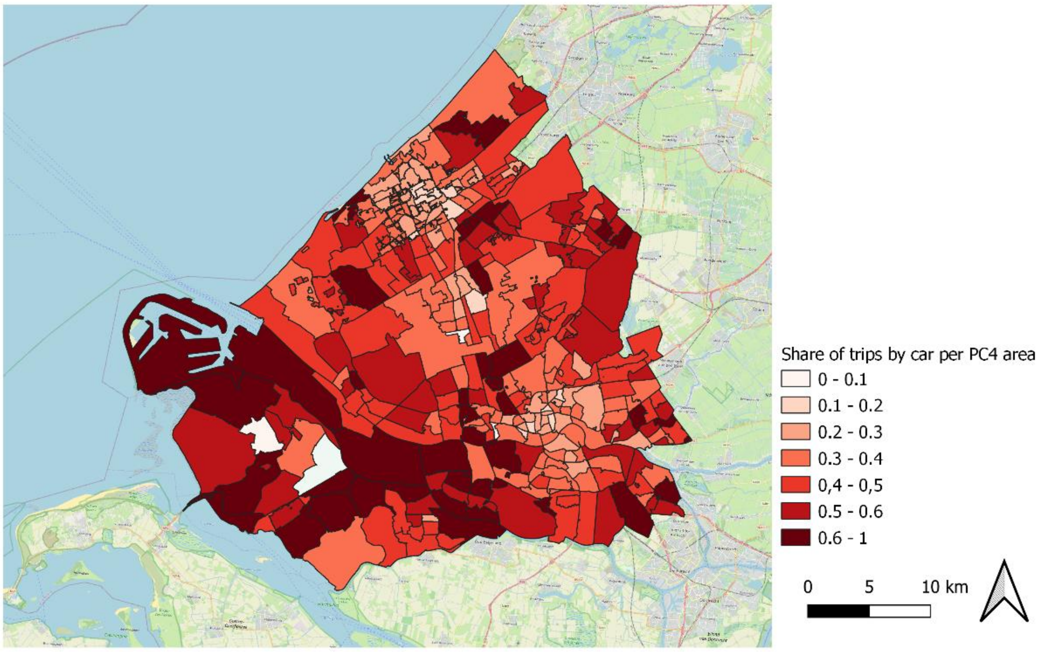

Figure 21: The higher the probability of choosing the car for making trips, the redder a PC4 area is

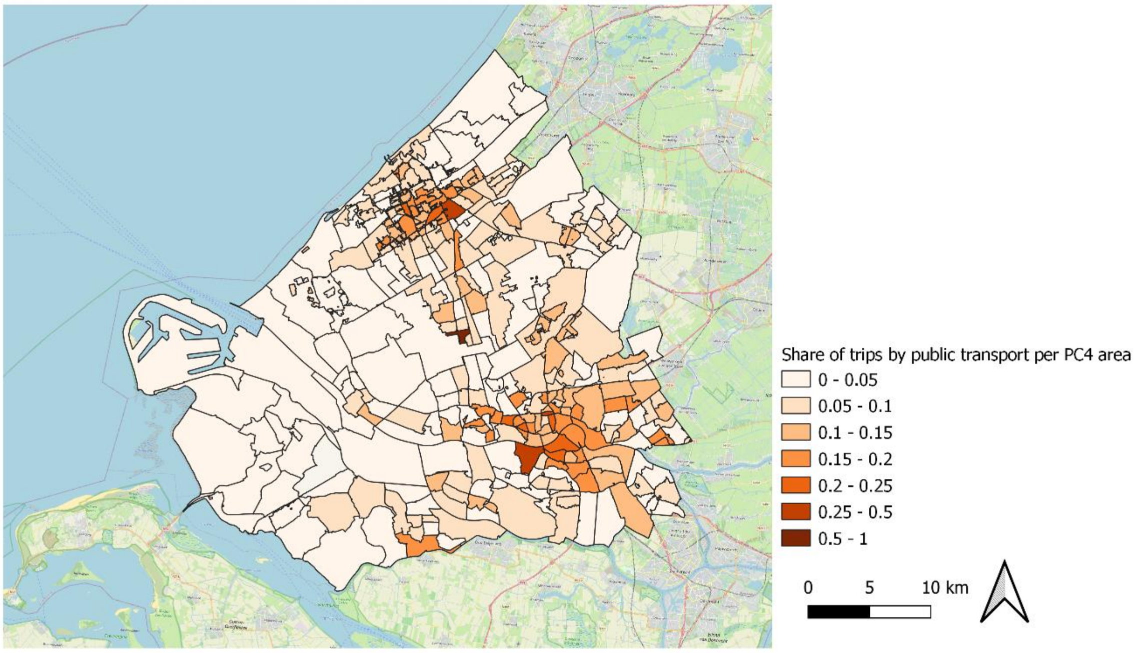

Figure 22: The modal share of trips by public transport for each PC4 area

The total combination of mode choices results in the modal split. The modal split for the whole MRDH is displayed in Table 27, based on number of trips, kilometres travelled and time travelled. The modal split expressed in travel time indicates that the percentage travelled by car is still largest, but has a lower share than only considering the travel distance. Especially the share of walking is larger, probably caused by the lower speed compared to other modalities. In comparison to the rest of the

Netherlands (Rijkswaterstaat, 2021), people within the MRDH make more trips by active modes, especially by foot.

Table 27: Modal splits MRDH

	Modal split based on:		
Modality	Number of trips	Kilometres travelled	Time travelled
Car	39,7%	73,3%	46,0%
Train	3,7%	2,8%	2,2%
Bus and tram	4,3%	1,7%	3,0%
Metro	2,5%	1,0%	1,3%
Electric bike	3,1%	2,0%	3,8%
Conventional bike	23,5%	9,4%	20,0%
Walking	19,5%	5,3%	19,7%
Other motorized vehicles	3,7%	4,4%	4,1%