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Active transportation policy and practice in the city of Oulu from 1998 to 2016—A mixed methods study

Mikko Kärmeniemi
(corresponding author)
Research Unit of Population Health, University of Oulu
mikko.karmeniemi@oulu.fi

Kari Nykänen
City of Oulu, Department of Urban and Environmental Services

Raija Korpelainen
Department of Sport and Exercise Medicine, Oulu Deaconess Institute, and Research Unit of Population Health, University of Oulu

Tiina Lankila
Geography Research Unit, University of Oulu
Department of Sport and Exercise Medicine, Oulu Deaconess Institute

Heli Koivumaa-Honkanen
Department of Psychiatry, University of Eastern Finland; Department of Psychiatry, Kuopio University Hospital; and Department of Psychiatry, Lapland Hospital District

Emilia Rönkkö
Oulu School of Architecture, University of Oulu

Abstract: Land use and transportation policies have been recognized globally as major sources of physical inactivity, but there has been a gap between research and policy implementation. Our objective for this research was to produce an integrated view of community planning policies and the association between urban form characteristics and transportation mode choices in the city of Oulu from 1998 to 2016.

Our findings showed that increasing density and diversity of the urban form, emphasizing active transportation, and developing the city center were highlighted in the community and transportation planning policies. In practice, urban form development focused on the inner city, but in the outer urban area and urban fringe, sprawl and car dependency increased. Overall, the active transportation mode share decreased by 2 percentage points during the follow-up, but increases in density, mix and access networks were associated with increased walking and cycling compared to car use.

In conclusion, no consensus was established in Oulu to limit the dominance of private motor vehicles. Decreased active transportation mode share might have been due to inadequately assessed functional mix outside the inner city, increased urban sprawl and building more capacity for cars. In the future, stronger political leadership, increased density, better access to nearby services combined with investments in public transportation will be required to meet the policy goals.

Keywords: Physical activity, walking, cycling, built environment, walkability, urban planning

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1 Introduction

Globally, anthropogenic drivers such as the built environment, which is modified through urban planning, land use and transportation policies, have been suggested to be major contributors to non-communicable diseases (Sallis et al., 2016). Today, physical inactivity and exposure to traffic emissions are among the leading risk-factors of non-communicable diseases such as cancers, diabetes, cardiovascular disease and chronic respiratory diseases that account for 71% of all deaths annually (World Health Organization, 2019). A global mode shift from private motor vehicles to sustainable modes of transportation is required to manage increasing levels of urbanization (United Nations, 2015b), and to meet the environmental and health related demands of future cities. The strive for more active cities is highly interconnected to many of the political priorities of the sustainable development agenda (United Nations, 2015a).

Evidence-based policy making is an important strategic goal, but the information flow between policy makers and researchers is rarely reciprocal (Brownell & Roberto, 2015). A gap between research and policy and practice exists in active living research targeting to increase population physical activity by changing the ways community structures are developed (Giles-Corti et al., 2015). As land use and transportation policies are recognized globally as major sources of physical inactivity, enhanced use of science to guide city planning is needed (Sallis et al., 2016).

The creation of healthier communities is dependent on cooperation with fields beyond physical activity and health, such as urban and transportation planning, finance, parks and recreation, and environmental protection (Giles-Corti et al., 2015). Successful research translation requires context-specific, local, policy-relevant evidence of the implementation of local policies (Hooper et al., 2019). Growing scientific evidence suggests that dense, compact and diverse neighborhoods are positively associated with active transportation (Giles-Corti et al., 2016; Kärmeniemi et al., 2019; Sallis et al., 2016), which implies that density, land-use mix and street network characteristics contribute to walkability and bikeability of the environment (Frank et al., 2010; Muhs & Clifton, 2016; Winters et al., 2013).

In recent years, an increasing number of longitudinal studies and natural experiments have supported the hypothesis of the built environment as a determinant of physical activity (Ding et al., 2018; Kärmeniemi et al., 2018; Smith et al., 2017). Nevertheless, a gap between research and practice remains and there is a lack of studies that have evaluated the health impacts of local community planning policies (Hooper et al., 2019).

A variety of predictors such as geographic, economic, psychological, and sociodemographic factors, travel time and costs, car availability have been utilized in different studies to understand how to promote alternative travel mode choices besides car use (Hoffmann et al., 2017). However, there are a limited number of studies that have specifically focused both on policies and the built environment which are emphasized by the ecological models of behavior change to achieve population level effects (Hovell et al., 2002; Sallis et al., 2008). This study will seek to generate local policy relevant information in order to increase the applicability of the findings in urban and transportation planning.

This study draws on both qualitative and quantitative data on urban form and transportation in the city of Oulu from 1998 to 2016. Our first objective was to qualitatively examine the development of land use and transportation policies based on strategy-level documents that the city has produced to understand the focus areas of urban planning. The second objective was to quantitatively analyze the urban form development and its association with transportation mode choices. Finally, we aimed to produce an integrated view of these two approaches. We hypothesized that an increase in the urban form density, mix and access networks (DMA) would be associated with increases in active transportation mode choices.

2 Theoretical background

The built environment "comprises urban design, land use, and the transportation system, and encompasses patterns of human activity within the physical environment" (Handy et al., 2002), and has been suggested to be one of the primary contributors to global disease burden caused by physical inactivity (Pinter-Wollman et al., 2018; Sallis et al., 2016). Due to undesired externalities of car-centric planning, policies that promote compact urban form, mixed land use, and high-quality infrastructure for walking, cycling and public transportation have gained popularity, but their implementation is difficult (Grant, 2009; Trudeau, 2013).

Hence, the mechanisms by which population behavior patterns could be most effectively changed remain one of the greatest challenges for public health research and policy (Ogilvie et al., 2020). Evidently, individual- and group–focused behavior change interventions have not been sufficient because of their moderate and temporary effects and reach for small numbers of people (Sallis et al., 2006). As a consequence, ecological models have been suggested as comprehensive frameworks for effective multilevel interventions for population level behavior changes, as they take account of the built environment and policies besides individual-level psychosocial factors (Hovell et al., 2002; Sallis et al., 2008).

Transportation planning literature has also recognized a variety of factors that are associated with transportation behavior and citizens' mode choices. These factors can be categorized as individual characteristics, household characteristics, season and weather characteristics, trip characteristics, built environment, and work conditions but active transportation modes seem most sensitive to trip characteristics and the built environment (Ton et al., 2019).

Moreover, accessibility is an important concept of travel behavior given that land-use policies that decrease the distance between residents and daily destinations and provide alternative transportation options might be causally linked with reduced driving and increased walking behavior (Cao et al., 2007). Accessibility concepts have been increasingly utilized to understand connections between land use and transportation infrastructure in cities and urban regions (te Brömmelstroet et al., 2016) but user-friendliness problems, organizational barriers, and lack of institutionalization of accessibility instruments hinder their wider acceptance in planning practice and increase the implementation gap (Silva et al., 2017). As a measure of access, proximity of residential location to the main city center has been shown to contribute to shorter travel distances and lower shares of car travel not only in relation to commuting but also for overall car-driving distances (Næss et al., 2021).

In regard to designing and building neighborhoods, community structures, and cities that make people walk, cycle, and use public transportation more, neighborhood walkability has become a well-recognized set of morphological ingredients among both practitioners and academics for creating sustainable and livable urban environments. Neighborhood walkability has been defined as "the extent to which characteristics of the built environment and land use may or may not be conducive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work" (Leslie et al., 2007).

Proximity to different types of destinations and street connectivity are the two underlying factors of walkability and have been associated especially with walking for transport (Saelens et al., 2003). Proximity refers to the distance between destinations and is determined by density (compactness of land use) and land-use mix (blending of different types of land uses such as residential and commercial) (Saelens et al., 2003). On the other hand, street network connectivity involves the directness of travel and the ease of moving between origins and destinations within the street and sidewalk network (Saelens et al., 2003).

Dovey and Pafka (2020) also argue that the interconnections and synergies between density, mix and access (the urban DMA) are fundamental for understanding how cities work and creating more walkable cities with high urban street-life intensity (Dovey, 2016). These morphological conditions are capacities of any given neighborhood regarding the densities (concentrations) of buildings and people, the mix of different functions, and the access networks that are used to navigate between them (Dovey & Pafka, 2020). Walkability as an aspect of the urban DMA can be regarded as a set of interrelated and interdependent characteristics of any given neighborhood included in urban morphologies (Dovey & Pafka, 2020).

Integrated density measures related to buildings, populations and open space define how much population and built form is concentrated in a given area, making distances shorter between people and accessible destinations (Dovey & Pafka, 2014). Functional mix has been described as the co-functioning of different functions, bringing activities, attractions and people into accessible proximity and reducing the need to travel while contributing to street-life intensity (Dovey & Pafka, 2017). Due to instability of multicategory classification systems of functional mix, three main categories (live, work and visit) has been suggested (Dovey & Pafka, 2017). Access networks can be defined by street network connectivity enabling or constraining urban activity (Pafka & Dovey, 2017). In regard to access networks, permeability refers to the ease of movement through a particular area and the variety of route choices between origins and destinations (Pafka & Dovey, 2017).

3 Materials and methods

3.1 Study design

This mixed methods study combined both quantitative and qualitative data to enhance the utility and credibility of findings (Schoonenboom & Johnson, 2017). As the complexity of a policy process involving several parties also gives rise to unplanned outcomes, this combination of data allowed us to examine the underlying focus areas of land use and transportation planning policy and quantitatively assess their practical implementations. Quantitative and qualitative datasets were collected concurrently and analyzed independently before the results were integrated. We used Dovey's (2016) concept of the urban DMA as a theoretical framework.

3.2 Setting

This study was conducted in the city of Oulu in Northern Finland. Oulu is the fifth largest city of Finland, with over 200 000 inhabitants. The land area of Oulu is 2 972 km^2. The overall residential density is 0,69 inhabitants per hectare, and the city center is the most densely populated postal code area (49 residents per ha) in Oulu (Statistics Finland, 2020). The years between 1998 and 2016 have been characterized by population growth (City of Oulu, 2016b), but generally, the community structure is loose and has expanded into new greenfield developments in the urban fringe in recent decades (City of Oulu, 2011). Rapid urbanization started in 1960s, and the subsequent urban sprawl has increased car dependency (Figure 1). However, the mode share of cycling has remained relatively high compared to that of other Finnish cities (ELY Centre of North Ostrobothnia, 2010; Finnish Transport Agency, 2012, 2018b). In 2013, the adjacent municipalities Haukipudas, Kiiminki, Oulunsalo and Yli-Ii were merged with the city of Oulu.

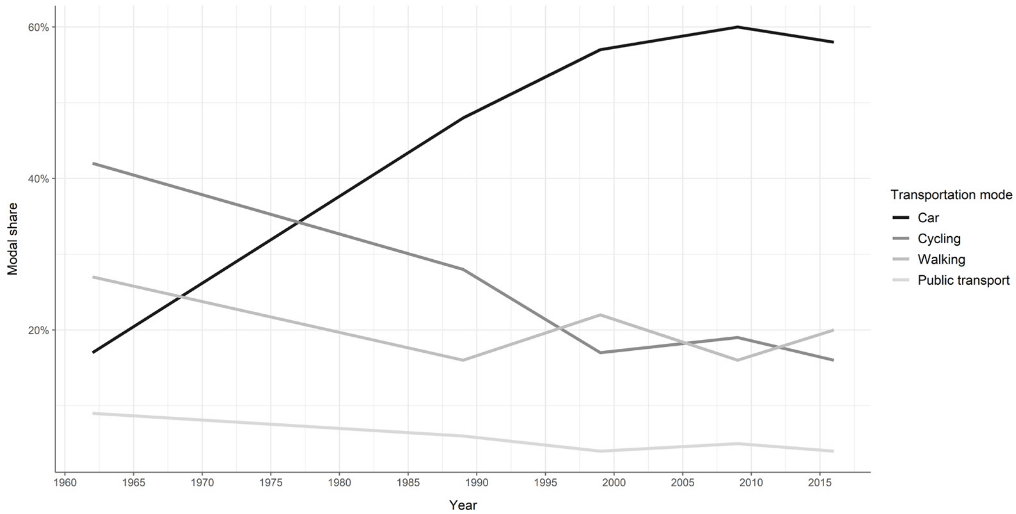

Figure 1. Transportation mode share development in the city of Oulu during the period 1962–2016, according to the Finnish National Travel Surveys (1998, 2010 and 2016) and the Oulu regional travel surveys (1962 and 1989)

3.3 Travel surveys

The Finnish National Travel Survey is a repeated cross-sectional study that has been conducted every six years since 1974 and provides an overview of Finns' mobility and demographic, regional and temporal variations of trips. We derived data from the four most recent surveys conducted in 1998, 2004, 2010 and 2016 (Finnish Transport Agency, 2012, 2018b; Ministry of Transport and Communications, 1999, 2006).

All surveys used a travel diary to record detailed travel information (all trips, time, primary travel mode, destination and purpose of the trip) within 24 hours and background information of the participants. The 2016 survey (N = 70 215, response rate 44%) was conducted as a multimode survey so that the participants were able to respond by phone, online or by mail. The previous surveys in 2010 (N = 20 023, response rate 56%), 2004 (N = 19 402, response rate 67%) and 1998 (N = 18 250, response rate 64%) were conducted by telephone interviews. Location information of the participants' places of residence were available according to postal code areas in all surveys.

All Finns above six years old were eligible for the National Travel Surveys except for people living in Åland Islands and under institutional care. The Finnish Population Register Center defined the samples for each survey using systematic sampling, and each survey was conducted over the course of a full year. We included participants who were sampled from the city of Oulu (year 1998: n = 271, year 2004: n = 342, year 2010: n = 417 and year 2016: n = 1568). The characteristics of the study participants at each data collection point are presented in Table 1.

Table 1. Characteristics of the participants sampled from the city of Oulu in the 1998, 2004, 2010 and 2016 National Travel Surveys.

Variable	1998 (N = 271)	2004 (N = 342)	2010 (N = 417)	2016 (N = 1568)
Age (years)	**n (%)**	**n (%)**	**n (%)**	**n (%)**
6–17	58 (21.4)	68 (19.9)	60 (14.4)	326 (20.8)
18–64	194 (71.6)	251 (73.4)	286 (68.6)	1020 (65.1)
65 and over	19 (7)	23 (6.7)	71 (17)	222 (14.2)
Sex				
Male	130 (48)	169 (49.4)	254 (60.9)	744 (47.4)
Female	141 (52)	173 (50.6)	163 (39.1)	824 (52.6)
Employment status				
Employed	130 (54.4)	168 (49.1)	216 (58.9)	780 (59.5)
Unemployed or outside workforce	109 (45.6)	174 (50.9)	151 (41.1)	532 (40.5)
Profession				
Farmer/entrepreneur/ white-collar worker/ blue-collar worker	139 (58.2)	175 (51.2)	214 (51.3)	699 (44.6)
Parental leave/ pensioner/conscript	43 (18.0)	56 (16.4)	111 (26.6)	341 (21.7)
Student	36 (15.1)	53 (15.5)	28 (6.7)	181 (11.5)
Schoolchild	16 (6.7)	58 (17)	55 (13.2)	280 (17.9)
Other	5 (2.1)	0	9 (2.2)	67 (4.3)
Car ownership				
Yes	223 (82.6)	283 (82.7)	366 (87.8)	1393 (88.8)
No	47 (17.4)	59 (17.3)	51 (12.2)	175 (11.2)
Driver's license				
Yes	178 (82.4)	243 (71.1)	331 (79.4)	1138 (91.6)
No	38 (17.6)	99 (28.9)	86 (20.6)	104 (8.4)
DMA category				
Urban fringe	143 (52.8)	173 (50.6)	239 (57.3)	1121 (71.5)
Outer urban area	76 (28)	110 (32.2)	110 (26.4)	297 (18.9)
Inner urban area	52 (19.2)	59 (17.3)	68 (16.3)	150 (9.6)

DMA = density, mix and access networks

3.4 Policy documents

Publicly available official strategy documents related to community planning policies were derived from the web pages and archives of the city of Oulu according to the domains of city strategy, transportation, land use and environment for the years 1998–2016. To increase the relevance for practical implementation, we used only policy documents that were approved by the city council or the city government.

The strategic control system in the city of Oulu is based on the city strategy, which is a declaration of the political intent of the city council (City of Oulu, 2013a). The environmental program is prepared by the city officials and directs the implementation of sustainable urban form goals presented in the city strategy. It defines the objectives, targets, measures and indicators for an integrated urban structure, a sustainable service network and sustainable mobility (City of Oulu, 2014). A land use masterplan is also prepared by city officials. It is a long-term legal strategy document that guides the city's development over the next 10 years, providing general guidance on land use, urban structure and the integration of functions (City of Oulu, 2016a). A land use program guides the implementation of the goals presented in the land-use master plan (City of Oulu, 2016b). Transportation strategies present the goals and course of actions for developing the transportation system in the region (City of Oulu, 2013b).

In the present study, the analysis included 4 city strategy documents (years 1999, 2001, 2005 and 2013), 2 transportation strategies (years 2003 and 2013), 12 land-use strategy documents (years 2001, 2003, 2004, 2005, 2007, 2009, 2011, 2012, 2013 and 2016) and 3 environmental strategies (years 2001, 2005, and 2014). In terms of land-use strategies, the documents were related to 1) the city's agreements on land use, housing and transportation with the state; 2) land-use master plans; 3) land-use programs; and 4) a development plan for the city center. Transportation strategies were regional plans including adjacent municipalities.

3.5 Urban form and street network data

Urban form data were derived from the Finnish Community Structure Grid Database from the years 2000, 2002, 2003, 2005 and 2007−2016 (Statistics Finland, 2018). It is based on 250m * 250m grids and includes variables related to population structure, land use, buildings, dwellings, workplaces, stores, employment and income. Street network data from the years 2005, 2010, 2012 and 2015 were derived from the Finnish National Road and Street Database (Finnish Transport Agency, 2018a).

3.6 Variables used in quantitative analysis

3.6.1 Outcome variables

The outcome was the transportation mode choice of each trip which was stratified into four categories: 1 = walking, 2 = cycling, 3 = public transportation, 4 = car, and calculated based on the participants' residential locations according to the postal code areas. A trip was defined as moving from one place to any given location outside home yard, whereas mode choice implies to the travel mode utilized in any given trip. The trip to the destination and the trip back from the destination were considered as two separate trips.

3.6.2 Exposure variables: Density, mix and access networks

The exposure variables related to urban form and street network were measured according to postal code areas for each year from 1998 to 2016. The municipalities that were merged with the city of Oulu in 2013 were included in the analysis for the whole follow-up time.

Gross densities were calculated in terms of floor area ratio (total floor area/site area), dwellings per hectare, residents per hectare and jobs per hectare. Functional mix was calculated according to the categories live, work and visit (amenities). For each function, we calculated floor area per site area. The category live included dwellings. The category work included office, education and industry. Lastly, the category visit included stores and restaurants, care (including hospital) and social work, and recreation and community institutions. Based on these three categories, we also calculated an entropy score to measure land-use mix (Song et al., 2013) using the following equation:

$$Entropy = -\sum_{i=1}^{k} \frac{P_i \times \ln(P_i)}{\ln(k)}$$

where k is the number of land-use categories and Pi is the proportion of floor area for land use i. The entropy score values vary from 0 to 1, a higher value indicating a greater land-use mix. We calculated access networks according to the number of intersections per hectare. Only intersections with three or more legs were included and roads where walking and cycling were prohibited were excluded.

Then we standardized the variables related to the density of buildings (floor area ratio) and people (residents and jobs per hectare), entropy and access networks using z-scores by subtracting the variable mean and dividing the centered value by the variable standard deviation. Finally, we combined the standardized variables for a DMA score that was used in the statistical analyses. The DMA score was also classified into three classes representing roughly the urban fringe (DMA class 1), the outer urban area (DMA class 2) and the inner urban area (DMA class 3) to improve interpretation (Table 2).

Table 2. Descriptive statistics of the DMA classes

DMA class	DMA score			
	min	max	mean	SD
1: Urban fringe	-4.14	1.33	-2.21	1.30
2: Outer urban area	0.12	3.67	1.67	0.88
3: Inner urban area	4.28	19.87	8.15	4.14

SD = standard deviation, DMA = density, mix and access networks

3.6.3 Confounding variables

We selected sociodemographic and socioeconomic variables – including age (continuous), sex (male, female), employment (employed, outside workforce), and profession (blue/white collar worker, parental leave/pensioner/military service, high school/university student, school child or younger) as potential confounding factors because these have been associated with physical activity and residential location. Moreover, the models were adjusted for the year of sample collection, car ownership (yes, no) and the distance between the center of the postal code area and the city center (continuous).

3.7 Analysis methods

Land use and transportation policies were analyzed with document analysis and the aim was to reveal their possible changing emphasis over time (Bowen, 2009). The analysis involved elements of qualitative content analysis and thematic analysis (Bowen, 2009; Fereday & Muir-Cochrane, 2006) and the identification of the main community planning themes was an inductive process derived empirically from the documents. The analysis involved reading and re-reading the documents, coding text into categories to reveal patterns and pertinent themes of the data and analyzing the urban form policy development according to these themes. First, all coded information was combined into a timeline from baseline to endpoint of the follow-up according to the policy document areas (city strategy, land use, transportation, and environment). Finally, all information was thematically combined into categories and analyzed accordingly to triangulate findings from quantitative urban form analysis by seeking convergence, corroboration and correspondence (Bowen, 2009).

We used R version 3.6.2 (R Core Team, 2018) for statistical analysis and QGIS version 3.10.0 (QGIS Development Team, 2019) for geospatial data analysis. In terms of statistical methods, we used multinomial logit models with the nnet package (Venables & Ripley, 2002) to study the statistical significance of the association between urban form and transportation mode choice. The exposure (DMA score) was used both as a continuous variable and as an ordinal variable categorized into three classes (Table 2) in separate models. Outcome variable related to the transportation modes was coded as a categorical variable (1 = walking, 2 = cycling, 3 = public transportation, 4 = car), and car use was considered as the reference level. We ran the models both unadjusted and adjusted for possible confounders. The effect sizes are presented with odds ratios and 95% confidence intervals.

Given that the sample sizes were relatively small and might not be considered as population representative, post-stratification weights were used in the analyses. The weights were calculated based on population, age and sex distributions in Oulu according to each study year using the rake function in the survey package (Lumley, 2004), which uses iterative post-stratification to match marginal distributions of a survey sample to known population margins.

4 Results

4.1 Urban form development

The characteristics of the postal code areas are presented in supplementary material (Table S1) and the categorization into DMA classes in Figure 2. The most dense and diverse postal code areas were found in the inner city. Teknologiakylä and Rusko-Heikinharju in the urban fringe and Kontinkangas (the main hospital district) in the inner urban area were particularly characterized as places for work. Still, the majority of the postal code areas were characterized predominantly as single-use areas for housing. On average, 55% of the population in Oulu lived in the urban fringe, 28% lived in the outer urban area and 17% lived in the inner urban area during the period 1998−2016. In the inner urban area, the population decreased by 0.4 percentage points and in the urban fringe by 1.2 percentage points. On the contrary, in the outer urban area the population has increased by 1.6 percentage points during the follow-up.

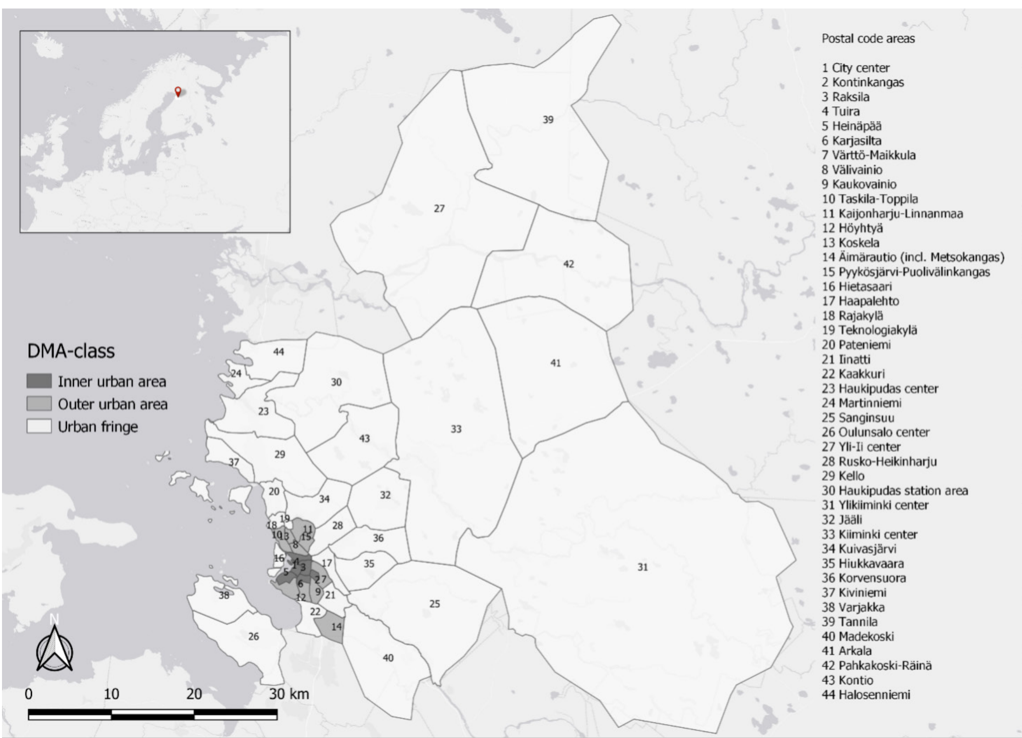

Figure 2. Postal code areas in the city of Oulu stratified by DMA class

Four main interconnected themes emerged from the land use and transportation planning policy analysis: 1) infill development and densification of the community structure, 2) mixing functions in local and regional centers to improve accessibility of services, 3) development of the city center and 4) increasing active transportation mode share.

The development of the DMA score, according to postal code areas, is presented in Figure 3. Development of each individual component related to the postal code area density, functional mix and access networks are presented in supplementary material (Figures S1−S10). Overall, during the period 1998−2016, the development focused on the city center and the adjacent postal code areas in the inner city. In the outer urban area, moderate progress was evident from 2007 onwards. On the contrary, in the urban fringe, according to the DMA score, there has not been much progress except for in few postal code areas.

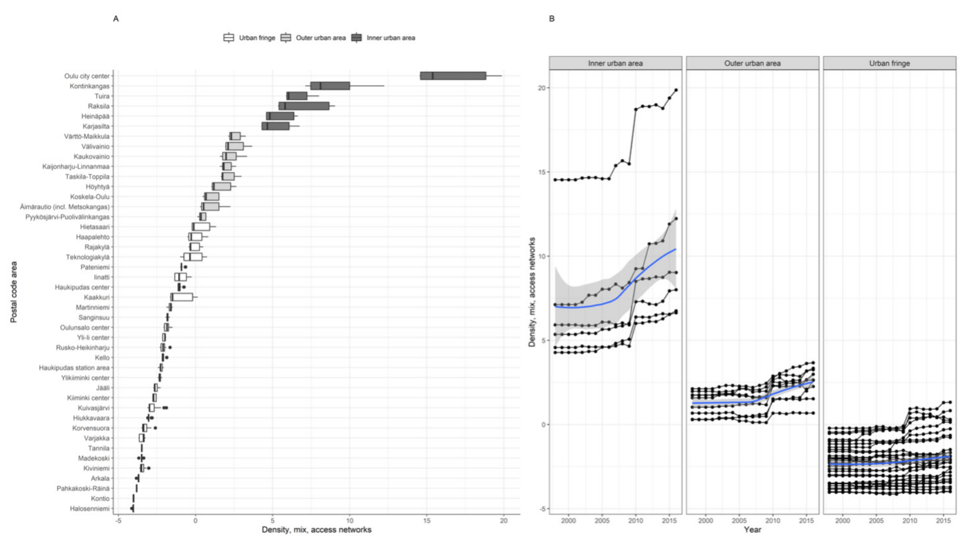

Figure 3. Urban form development in the city of Oulu from 1998 to 2016: Panel A: Boxplot of DMA scores in postal code areas; Panel B: Development of the DMA-score according to postal code areas stratified by DMA class

4.1.1 Density

All strategies related to community structure, housing and transportation development repeatedly emphasized the need for urban form densification between 1998 and 2016. Already, the 1993 land-use master plan set the goal of increasing population density and creating more dwellings in the city center (City of Oulu, 1993). The most significant part of the 2004 land-use master plan was the development corridor from north to south that was planned to offer possibilities for a high-quality urban structure in terms of mixing functions and supporting public transportation (City of Oulu, 2004). New dwellings were mainly directed to existing housing areas, but two new regional centers were also established in the eastern and southern parts of the urban fringe (City of Oulu, 2004).

The density of buildings, residents and workplaces increased according to the plan, especially in the inner urban area. However, it is questionable whether the goals were reached in the outer urban area and the urban fringe. The floor area ratio increased steadily in the inner urban area and especially in the city center and in Kontinkangas. Dwellings and residents per hectare increased mostly in the inner urban area, in addition to Välivainio in the outer urban area. Workplaces per hectare were highest in the city center and in the adjacent postal code area Kontinkangas. The growth of jobs per hectare during the period 1998−2016 focused mostly on Kontinkangas and remained stable or slightly decreased in other areas. Generally, infill development focused on dwellings as compared to the diversity of amenities.

4.1.2 Functional mix

The policy documents emphasized the need for a good service structure not only in the city center but also in local centers in suburban areas. However, it is apparent that different functions were mainly separated, and there were clearly defined zones for commerce, housing and workplaces according to modernist planning principles. Overall, functional mix decreased in most of the postal code areas in the city of Oulu during the period 1998–2016. The growth in floor area, according to the functional mix categories, mostly focused on the inner urban area, which was especially evident in terms of the growth of amenities.

The category *live* in the functional mix increased mainly in the city center and in the inner urban area. In the outer urban area, the growth focused only in Välivainio and Äimärautio (including Metsokangas), and in the urban fringe only in Haapalehto. Regarding the function of *work*, the highest ratios of workplace floor area per hectare were found in the inner urban area. However, growth in the category of *work* mostly focused on Teknologiakylä in the urban fringe, in addition to Kontinkangas in the inner city. The floor area per hectare of amenities in the category *visit* was highest in the inner urban area, and the growth focused mainly on the city center and Kontinkangas.

The category live was the dominant part of the functional mix in most of the postal code areas in Oulu, and during the period 1998–2016, this tendency increased (Figure 4). There were more postal code areas that mixed *living with workplaces* than with places to visit, especially in the inner and outer urban areas. The city center was the only area with balanced land use in terms of the live, work and visit categories, and the others were predominantly characterized as housing or working areas. Teknologiakylä and Rusko-Heikinharju were profiled primarily as *work* areas. Correspondingly, Kontinkangas was the only postal code area that mixed mainly the functional categories work and visit.

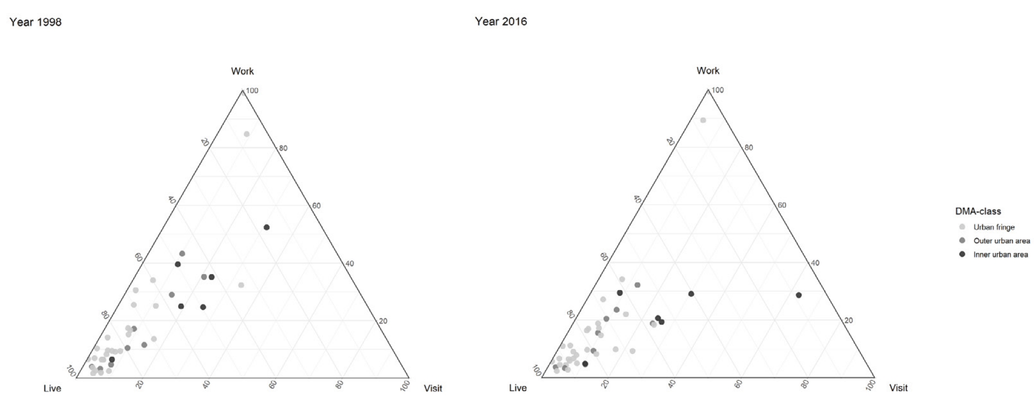

Figure 4. Ternary plots of postal code areas in 1998 and 2016, according to floor area of functions for live, work and visit

The entropy score representing land-use mix was generally higher closer to the city center. However, some postal code areas in the outer urban area and in the urban fringe also received high entropy scores. The greatest increase in entropy during the period 1998–2016 was focused on Kaakkuri in the urban fringe and remained stable or decreased in other postal code areas. Regarding access networks, intersection density increased especially in the inner urban area.

4.1.3 Development of the city center

Developing the city center was one of the main community planning goals, given that all land use and transportations strategies repeatedly emphasized it by the means that were congruent to a great extent:

increasing service level, increasing the number of dwellings and workplaces, mixing functions and emphasizing walking, cycling and public transportation. There were improvements in the number of dwellings and workplaces, and functional mix and mode choices of walking and cycling increased in the inner urban area.

4.2 The association between urban form development and transportation mode choice

Emphasis on walking, cycling and public transportation was a part of the city strategy already in 1998 (City of Oulu, 1996). It was also presented as part of the city's land-use master plan in 2004 (City of Oulu, 2004) and in both fairly recent agreements on land use, housing and transportation with the state (Ministry of the Environment, 2013, 2016). Also, both transportation strategies set the goal of increasing the mode shares of walking, cycling and public transportation and limiting the growth of car traffic, especially on short trips (City of Oulu, 2003, 2013b).

Despite the goal to emphasize walking cycling and public transport in all policies, the active transportation mode share decreased in the city of Oulu from 47% in 1998 to 45% in 2016. The mode share of walking decreased by 2 percentage points and cycling increased by 1 percentage point, whereas trips made by car increased from 51% to 53%. Public transport mode share has remained steadily around 4%.

Mostly, the frequency of traveling by car has increased in the urban fringe, whereas in the inner urban area, the active transportation mode share increased from 59% to 65% due to an increase in walking trips (Figure 5). In the outer urban area, the active transportation mode share started to increase in 2010 (46%) – ending up to 54% in 2016, which was especially due to an increase in cycling trips.

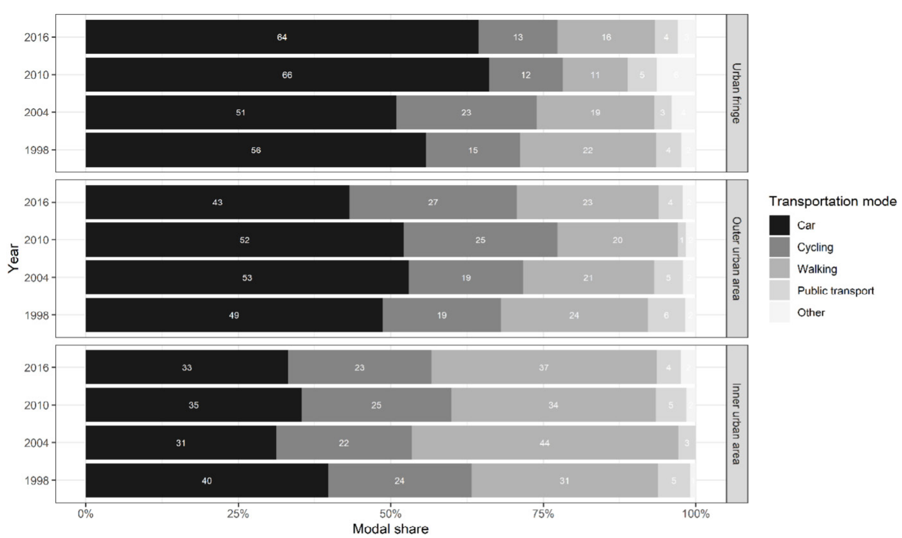

Figure 5. Transportation mode share development during the period 1998−2016 in the city of Oulu stratified by DMA class

An increase in the urban DMA was associated with increased walking and cycling mode choice as compared to car use. As shown in Table 3, a one-unit increase in the DMA score was associated with a 12% increase in walking (OR 1.12; 95% CI: 1.11, 1.14; $p < 0.001$), and 9% increase in cycling (OR 1.09; 95% CI: 1.08, 1.11; $p < 0.001$) as compared to car use in the unadjusted multinomial logit models. The results in the adjusted models were similar for walking (OR 1.08; 95% CI: 1.07, 1.10; $p < 0.001$) and cycling (OR 1.04; 95% CI: 1.02, 1.06; $p < 0.001$) compared to car use. On the contrary, the urban DMA was associated with the use of public transportation only in the unadjusted model (OR 1.06; 95% CI: 1.04, 1.09; $p < 0.001$) but not in the adjusted model when sociodemographic factors were accounted for.

Table 3. The association between DMA-score as a continuous variable and transportation mode choice according to multinomial logit models

Variable	Walking		Cycling		Public transport	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
DMA-score (unadjusted model)	1.12 (1.11, 1.14)	<0.001	1.09 (1.08, 1.11)	<0.001	1.06 (1.04, 1.09)	<0.001
DMA-score (adjusted model*)	1.08 (1.07, 1.10)	<0.001	1.04 (1.02, 1.06)	<0.001	1.00 (0.97, 1.03)	0.947

Note: car use was considered as the reference level
*Adjusted for age, sex, employment, profession, distance to the city center, car ownership, and year of the sample collection

The associations between DMA classes and transportation mode choices are presented in Figure 6. There was a dose-response association between DMA categories and walking and cycling as compared to traveling by car. In the adjusted models, using DMA class 1 (the urban fringe) as the reference category, walking increased according to an increase in DMA class (OR 1.47; 95% CI: 1.23, 1.76; $p < 0.001$ for the outer urban area and OR 2.64; 95% CI: 2.14, 3.25; $p < 0.001$ for the inner urban area) as compared to traveling by car.

Similar pattern was observed for cycling vs. car use (OR 1.49; 95% CI: 1.21, 1.83; $p < 0.001$ for the outer urban area and OR 1.84; 95% CI: 1.44, 2.36; $p < 0.001$ for the inner urban area) but the difference between the effect estimates for outer urban area and the inner urban area was not as large. The use of public transport vs. car increased according to increase in DMA class in the unadjusted models but decreased when sociodemographic factors were included in the model (OR 0.52; 95% CI: 0.36, 0.74; $p < 0.001$ for the outer urban area and OR 0.64; 95% CI: 0.42, 0.99; $p = 0.048$ for the inner urban area).

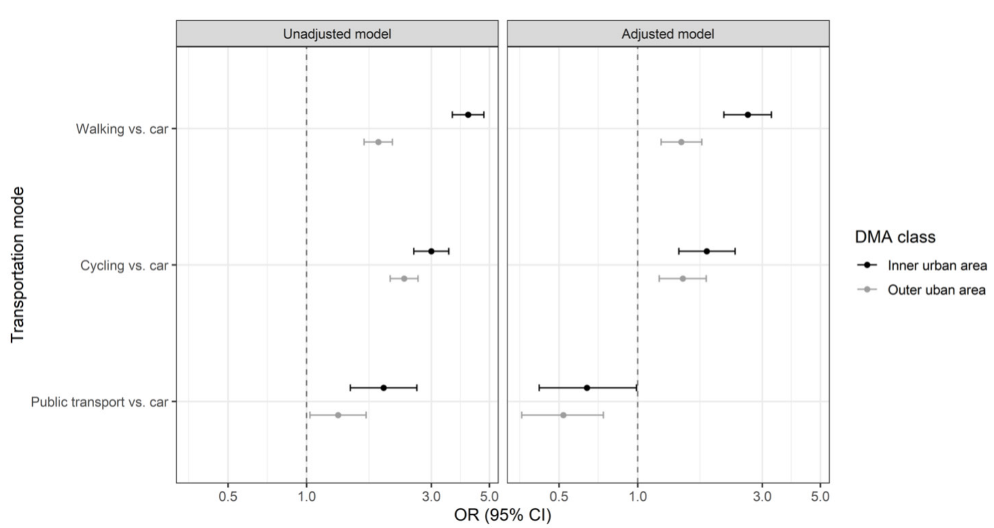

Figure 6. The association between DMA class and transportation modes, according to the multinomial logit models (adjusted model included the following factors: age, sex, employment, profession, distance to the city center, car ownership, and year of the sample collection). Odds ratios and confidence intervals are presented on a logarithmic scale. DMA class 1 (urban fringe) was used as a reference category.

5 Discussion

This mixed methods study is the first to combine qualitative and quantitative data to provide an integrated local analysis of land use and transportation policies and the association between urban form development and transportation mode choices. We found that developing the characteristics of the urban DMA to increase the active transportation mode share were highlighted in all community and transportation planning policies in the city of Oulu over the last 20 years, but there was no willingness to make decisions on structural changes that would hinder the flow of private motor vehicles. Our results showed that urban DMA increased especially in the inner urban area and higher DMA score was associated with higher odds of walking and cycling compared to the use of private motor vehicles.

A one-unit increase in the DMA-score were associated with 8% higher odds of walking, and 4% higher odds of cycling as compared to the use of private motor vehicles. Moreover, walking and cycling increased compared to car use in a dose-response manner when comparing the inner and outer urban areas to the urban fringe. However, altogether, the urban form development in the city of Oulu during the follow-up was not sufficient to support the growth of the active transportation mode share that decreased by 2 percentage points, which might be due to several factors.

Specific zones for housing, workplaces and amenities and dependency on large hypermarkets in the outer urban area and the urban fringe are most likely to increase car travel. For example, in Denmark and the Netherlands, planning regulations for big-box stores in relation to maximum sizes for a single store or a maximum number of stores under one roof have proven to be a successful strategy to foster smaller-scale shops (Schipperijn, 2017).

Even though accessibility of local municipal and commercial services was highlighted in the service network plans of the city of Oulu (City of Oulu, 2012; Finnish Consulting Group, 2010), it is questionable whether the level of mixing functions has been sufficiently assessed in the suburbs of the outer urban area and in the urban fringe to support active transportation. Land-use mix has been recognized as one of the primary factors of neighborhood walkability (Frank et al., 2010). It was also highlighted as one of the key factors for human-scaled urban design – according to the charter of the Congress for the New Urbanism, which is a movement that emerged as a counterforce for the car-oriented, low-density, separated-use sprawl development in the US (Trudeau, 2013).

In Oulu, new land use and zoning mainly involves locations where the city owns the land that sets the boundaries for growth areas and locations for services and workplaces. Due to political and economic reasons, the service network has been diminished and centralized into bigger units which is in line with the development of other Finnish cities. Even though the density of the central areas of bigger Finnish cities increased during the previous two decades, car dependency has increased overall, as different functions are located further away from each other (Rehunen et al., 2018). Nevertheless, in the future, a more proactive and comprehensive approach is needed for combining infill development with a better service structure. Major decisions related to land use and transportation networks are political, which highlights the importance of strong political leadership to successfully implement the policy goals.

Moreover, many large development plans and projects have been related to car infrastructure in both transportation strategies in the city of Oulu. The growth of car traffic was taken for granted as the city is growing. The arguments for new car infrastructure arose mainly from the trade and industry point of view and the willingness to support commerce and increase economic activity by investing in smooth traffic flow in major arterials and in parking conditions in the city center. As an example, an underground car park was built beneath the city center for 900 cars, and recently, the city, in cooperation with the state, has expanded the main highway that runs under 2 km away from the city center, which casts doubts on future increases in the active transportation mode share. These massive investments undermine the focus areas of all active transportation strategies in the city of Oulu during the last

20 years. There is also consistent evidence that highway capacity expansion is not a feasible long-term solution to tackle traffic congestion because the expansion generates an exactly proportional increase in vehicle travel, which is expected to revert traffic speeds to pre-expansion levels in approximately five years (Hymel, 2019).

The Finnish municipalities have high community planning autonomy in relation to the central government, and economic growth has traditionally been emphasized in the Finnish spatial planning regime (Hytönen & Ahlqvist, 2019). Since the municipal autonomy and market-driven private interests are strengthened by the new Land Use and Building Act, the municipal planning abilities to address long-term complex issues are becoming even more difficult (Hytönen & Ahlqvist, 2019).

Our findings are in agreement with those of natural experimental studies from Australia (Hooper et al., 2020) and the UK (Goodman et al., 2013) that have demonstrated that urban design policies, and especially their successful implementation, are essential when changing the built environment to promote active transportation and reduce car dependency. In Australia, the RESIDential Environments Project, inspired by the New Urbanist planning principles, focused on community design, movement network, lot layout and public parkland to reduce dependency on private motor vehicles and emphasize walking, cycling and public transport use (Hooper et al., 2020). The results of the project showed that the "Livable Neighborhoods" planning policy, which aimed to generate more walkable suburbs, provided support for healthy behaviors such as transportation-related walking and recreational walking, in addition to a stronger sense of community and safety. In the UK, town-level cycling initiatives were associated with increased cycling and walking to work and decreased driving to work (Goodman et al., 2013).

Increasing the mode shares of walking, cycling and public transportation inevitably requires taking up space from private motor vehicles, which was not supported by the policies of the city of Oulu. On the contrary, during the period 1998−2016, more capacity for cars was planned and built, which conflicts with the overall goals of increasing the active transportation mode share. It could be argued that there has been inconsistency between the goals and the actual projects and investments. For example, in cities such as Groningen and Copenhagen, which are famous for their high active transportation mode shares, it took several decades and a long-term vision with strong political leadership to create the built environment that generated and continues to support a walking and cycling culture (Schipperijn, 2017).

Hence, the growth of car traffic does not occur coincidentally but is dependent on conscious and unconscious decisions made by planners and policy makers. Evidently, increasing the density and diversity of the urban form provided better circumstances for the mode choices of walking and cycling to increase in the inner urban area of Oulu, and more recently, in the outer urban area. To continue this positive development, besides developing the city center further, combining infill development with a mixed service network in suburban local centers is needed to reduce car dependency. Moreover, given that the mode share of public transportation has been minimal in Oulu during the last 20 years, enormous investments into better infrastructure and service level are required to increase the use of public transportation.

This study has limitations that need to be acknowledged. In relation to the large more or less rural areas that were merged with the city of Oulu in 2013, policies and development plans might not have been fully implemented by 2016. The *live, work* and *visit* categories that were used to assess functional mix are partly overlapping. For example, the floor area of health care was assigned to the category visit, even though many people work in the health-care sector. The policy documents included in the document analysis have different meanings, time spans, political scopes and legal consequences that might affect their content and comprehensiveness. In addition, the statistical models were not adjusted for several important potential confounding factors such as income, education, marital status, and presence of children which might introduce bias. Lastly, the study was conducted in a single Northern European city, and hence, the results are not generalizable to other cities as such. However, the methodology used is applicable anywhere, and similar studies could act as a starting point in tying up the gap between research and practice, which is required to meet the environmental and health-related demands of future cities.

In conclusion, we found that in Oulu, during the period 1998–2016, the urban form became denser and more diverse in the inner urban area, but at the same time, urban sprawl and car dependency increased in the urban fringe. A higher urban form density, increased mixed land use and a higher intersection density were associated with higher mode choices of walking and cycling compared to the use of private motor vehicles. The starting point for all urban development strategies since 1998 were good communication between land use and transportation, both of which aimed to increase the mode share of walking, cycling and public transportation. Still, it seems that no consensus was reached in relation to limiting the flow of private motor vehicles – the dominant mode of transportation. It could be argued that no common language has been found, and the actions of transportation development in relation to urban form development have not been fully in line with the goals. In the future, increasing density by proactively combining infill and mixed-use development, high-quality walking environments and cycling infrastructure, greater investments in public transportation and stronger political leadership are required to meet the policy goals.

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