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Urban density, accessibility, and proximities

Mapping and understanding the relationship between urban densities and cycling accessibility to grocery shops in the 10-minute city in the context of Stavanger metropolitan area

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Abstract

Denser urban environments can enable more effective use of resources such as space, energy, and raw materials. Denser cities require less space, preserving valuable peri-urban lands that can provide environmental services and agricultural goods. When organised thoughtfully, compact urban settlements also tend to enhance the accessibility to everyday urban services. Thanks to proximity, cycling and walking, combined with public transport, can replace car-based transportation, reducing the use of fossil fuels and space for road infrastructure. The dimension of time is increasingly used to measure the built environment performance regarding accessibility and proximity. Concepts such as the 5, 10, 15, 20 or 30-minute city are increasingly used in different contexts to study how people access urban spaces in more environmentally friendly and efficient ways.

In this paper, we use the concept of the 10-minute city to map the potential of cycling to access groceries in Stavanger metropolitan area. Increasing cycling has become one crucial element of local strategies towards carbon neutrality on national, regional, and metropolitan levels. Local authorities have been improving cycling infrastructure in recent years. However, the low rate of cycling in local mobility suggests that these efforts have not been sufficient. The paper elaborates on a scientific approach based on GIS network analysis. Moreover, the analysis uses correlations with urban densities to explore the empirical relationships and sketch actual potentials regarding the service of interest. As a result, the study quantifies the prospect of cycling to cater sufficiently to the needs of Stavanger MA's population based on the existing morphology and networks. On the other hand, this assumption also provokes some practical considerations regarding the present challenges for cycling to be an effectively employed mobility mode for grocery shopping, such as improving the existing bicycle network and the parking provision for bikes by stores.

Keywords: *urban density, 10-minute city, morphology, accessibility, GIS*

Introduction

The relationship between spatial form and transport modes within cities has always been central to urban planning. In essence, this relationship is expressed in the need to attend to urban populations' needs to access the various social, economic, and cultural amenities that cities provide. Thus, the improvement of urban transport revolves around seeking technical and economic possibilities to offer longer, faster and cheaper connections. Car-based transportation allowed the masses to access a vast periurban surface at affordable prices, leading to an unprecedented urban sprawl. However, a growing environmental concern in recent decades has lead to a re-frame of this trend. This new approach seeks to reducing the ecological footprint of transport, focusing on accessibility rather than mobility (Banister, 2008).

This primary switch of ideological focus has transformed the relationship between urban form and transport by considering them as interrelated elements. In addition to the fundamental ambition of carbon-neutral societies, cycling and walking are promoted as healthier mobility modes, that combined with public transport, can also enhance urban quality of life. As a result, we have seen the rise of concepts such as 30, 20, 15, or 10-minute city, depending on the size and compactness of different metropolitan areas (Da Silva et al., 2020; Levinson, 2020; Moreno et al., 2021). This trend has gained force with the restrictive measures to contain the COVID19 pandemic spread. In Norway, where cities and towns are small, the time isochrons to operationalise the concept tend to be 15, 10, and even 5 minutes (Øksenholt et al., 2016).

This study, in particular, employs the framework of the 10-minute city for the metropolitan area of Stavanger in Norway. It focuses on cycling as a mobility mode and accessibility of grocery shops as urban services of interest. Despite usually not representing a substantial part of the personal time budgets of citizens, going to the supermarket is required in every household. Furthermore, we correlate the degrees of accessibility with spatial density indicators with the ambition to measure how the latter can influence the distribution of urban services, contributing to people's time efficiency.

Background

Cycling has been promoted as an alternative urban transport mode since 1977 when the Norwegian Road Plan II was approved. This plan aimed to develop an integrated bicycling network in every urban area with a population larger than 5000 inhabitants before 1985 (Strand et al., 2015). Later, in the National Transport Plan 2014-2023, this goal remained by outlining the requirement that all cities (> 5000 inhabitants) should have an approved plan to develop a core cycling network. Still, the National Transport Plan (2018-2029) emphasises the potential of cycling and walking to cover a significant part of urban transport needs. The plan also allocates a substantial amount of financial back-up to develop physical infrastructure and innovative solutions to facilitate the integration of cycling with public transport. This strategy translates into ambitious plans at the local level, implemented by regional and municipal authorities. For example, in the Stavanger Region, numerous new dedicated pathways and lanes for cyclists have been implemented within the existing urban fabric. A remarkable example of this endeavour is the 13-kilometers long bicycle highway, which aims to connect the two largest cities in the region, Stavanger and Sandnes, where cyclists will not conflict with other traffic[1].

Despite these plans, cycling has not increased as expected. On the contrary, National Travel Surveys (RVU[2]) illustrate a decline in cycling, i.e. 7% in 1991, 5% in 2013-14, and 4% in 2019. The figures, however, are more

[1] Ellingsen, Ø. et al. (August 27, 2020, NRK): https://www.nrk.no/rogaland/apner-snart-sykkelvei-til-1_4-milliarder_-_-bortkastede-penger-1.15137842 [accessed on June 10].
[2] Archive of the National Travel Surveys (RVU), data source: Norwegian Public Roads Administration (Statens vegvesen) - https://www.vegvesen.no/fag/trafikk/transport/reisevaner [accessed on June 10, 2021].

positive in larger urban areas, where people travel shorter distances than in sparsely populated rural regions. For example, in Stavanger metropolitan area (Stavanger MA), the number for 2019 had increased to 9% compared to 2013/14 when the modal share of cycling was 8% in the region. However, it is worth outlining that Stavanger MA had developed as a region with a high automobile dependency in the late 20th and early 21st centuries due to its spatial expansion and car-friendly infrastructure (Tarigan, Bayer & Berg, 2010).

Figure 1. *Newly established cycling infrastructures in Stavanger MA, i.e. a separated cycling path (on the left) and a cycling lane on the roadway (on the right).*

Nevertheless, the figures above illustrate the challenges of promoting cycling in Norwegian cities despite governmental ambitions. This study aims to elucidate whether the relationship between urban form and cycling accessibilities in the region can shed more light on the reason for this meagre advance. To generate more understanding of the observed discrepancy between institutional intentions to promote cycling and actual utilisation of the mobility mode, we explore the relationship between urban form and the accessibility to the grocery stores within the framework of the 10-minute city. The thematic focus seems relevant since the official travel survey for 2018 reports that the highest share of trips in Norway serves the purpose of trade and service, i.e. 28%[3]. Extrapolated from transport surveys, we estimate that approximately 23% of all trips are made for the purchase of goods and services (Hjorthol, Engebretsen & Uteng, 2014). Based on the same sources, only 3% of all trips for the purpose are made by bike. To compare, the official travel survey for 2018 in Denmark illustrates that 17.6% of all trips serve trade purposes, and 10% of those are made by cycling.[4]

[3] National Travel Survey (RVU, 2018), data source: Norwegian Public Roads Administration (Statens vegvesen) - https://www.vegvesen.no/fag/trafikk/transport/reisevaner/reisevaner-2019/ [accessed on June 4, 2021].
[4] Archive of the annual reports of the Center for Transport Analytics (DTU), data source: *Transportvaneundersøgelsen* (DTU) - https://www.cta.man.dtu.dk/Transportvaneundersoegelsen/Udgivelser [accessed on August 11, 2021].

Methodology

The method applied in this research combines a multivariable quantitative approach to explore relationships between characteristics of the built environment and the cycling accessibility to grocery shops. First, we use GIS software to gather, classify and visualise the data of the analysed variables. Then, through linear regression models, we explore the geospatial relationships. This process consists of three main steps: (1) data preparation, (2) processing GIS analysis, and (3) processing statistical correlations.

Data preparation

The data preparation includes collecting and integrating the various datasets to set the basis for calculating density indicators and running network analyses regarding cycling accessibility. These datasets include:

- Census data on *grunnkrets* level, the smallest administrative, statistical unit in Norway.
- Cadastre data (*FKB-Bygning*) combined with building details data from the Norwegian Mapping Authority (*Kartverket*).
- Road network dataset, incl. pedestrian and cycle paths, from the National Road Data Bank (NVDB) of Statens *Vegvesen*.
- Data collected from OSM (Open street map) concerning the service points of interest (POIs).

Processing GIS analysis

The second step of the research process consists of executing subsequent operations: running *Network Analyst*, estimating the degree of serviceability and correlating the serviceability, census data, and building characteristics.

Run Network Analyst

First of all, we create a cycling network dataset based on the adapted transport infrastructure data. As part of this operation, the model's primary analytical parameter is also set up: travel time for passing through each network's segment. Based on the works of Schaap et al. (2016), Pritchard et al. (2019) and Lin et al. (2008), we employ a cycling speed of 15 km/h for the context of Norway. This refers to a distance isochron of 2500 meters for 10 minutes on the network. Next, the accessibility calculations to/from the grocery objects (POIs) are estimated through service area polygons away from each facility of interest. This operation generates an initial polygon shapefile, including 275 shapes that equal the number of POIs, representing the 10-minute service reach away from each object.

Estimate the level of serviceability

After the service areas for each object (POIs) is calculated upon the transport network, we execute an overlay analysis to specify the level of serviceability within 10-minute isochrons. Traditionally, the overlay analysis within the ArcGIS environment represents a methodology to combine different inputs and generate an integrated value concerning optimal site selection or suitability modelling. For this study, we develop the

overlay analysis in a simplified manner since the input is technically coherent and integration of different information is not required. The purpose of the executed operation is to specify the number of POIs reached from each geographic location within the Stavanger metropolitan area. This way, we can develop analytical correlations between serviceability levels and other urban characteristics, such as density.

Correlate the level of serviceability, census data and building characteristics

The next step of the data analysis includes the spatial correlation between the processed service area polygons with the processed building data (*FKB-Bygning*) and the census data on *grunnkrets* level. First, we aggregate the sum of the different characteristics (e.g. gross floor area, gross building footprint, the total number of dwellings, etc.) of all buildings whose centroids are positioned within a specific service area polygon and transferred these sums to the latter. Second, we estimate the number of occupants per building based on the administrative area (*grunnkrets*) where it is located. Once this estimation is processed, the specific number of inhabitants per dwelling can be correlated to each building and calculate the total number of residents for each residential house. Finally, based on this approach, the population is aggregated to the individual service area polygon level.

Processing statistical correlations

The last analytic step consists of processing statistical correlations through linear regressions between the estimated level of accessibility to the services of interest and urban density indicators. This activity is realised through correlation analyses with Pearson's correlation coefficient (r) and coefficient of determination (r^2). On this principle, we execute multiple correlations by relating the level of serviceability for the areas of Stavanger MA to individual urban density indicators of the respective zones. The considered indicators in the correlations are Floor Area Ratio (FAR), Gross Space Index (GSI), Open Space Ratio (OSR), Network Density (ND), Dwelling Density (DWd), Population Density (POPd), Floor Area Ratio for Residential Use (FARre) and Floor Area Ratio for Other Uses (FARoth), such as commercial or indoor parking spaces.

Results and Discussions

Serviceability of grocery objects within the Stavanger MA - coverage and intensity of services

The first perspective focuses on the results achieved through the network analyst tool and the executed overlay analysis. Figure 2 illustrates the visual outcome from the computations as particular highlights for the core of the Stavanger MA (the municipality of Stavanger and its surroundings) are included. To produce the different maps, we apply further classifications of the processed data. Figure 2 refers to the thresholds of serviceability levels or the intensity (number of POIs). Based on the generated service area polygons around the groceries objects; we define the areas as such with access to 1 object within 10 minutes of cycling (2500 meters), and respectively 2-3, 4-5, 6-10, 11-25 and more of 25 objects within the same time isochron. The representation also depicts the areas where there are no objects reached within 10 minutes.

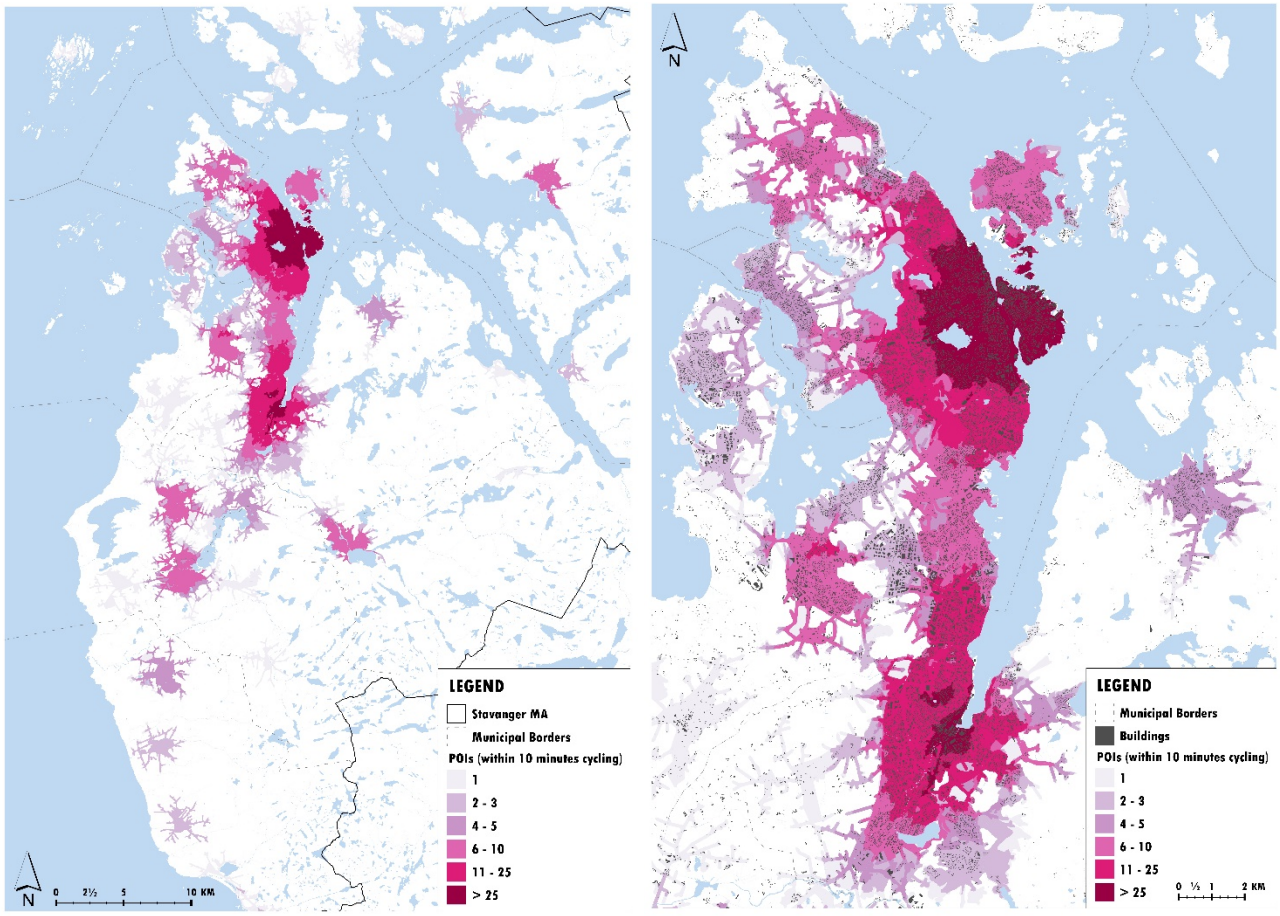

Figure 2. *A representation of serviceability of groceries objects within the whole Stavanger MA (left) and the core of Stavanger MA (right).*

Apart from visual representation, we can interpret the results further based on the spatial coverage of the classified service areas, the correlated census information, and the extracted statistics from the processed data (see Table 1). The statistics show that only (5.27%) of all citizens live further than 10 minutes of cycling away from their closest grocery object. On the other hand, the most significant number of citizens within Stavanger MA (68.07%) have access to at least six grocery objects within the distance of interest, while 6.16% of the total population (21 194) rely on a single POI. These results show that most people have a wide variety of grocery services (more than five objects) at hand within 10 minutes of cycling.

Table 1. *Spatial coverage and serviced population within 10 minutes cycling away from grocery objects, organised in the defined classes.*

POIs REACHED	covered area (ha)	% of the total Stavanger MA	people serviced	% of the total population
Class I: 1 Object	12 681	3.69%	21 194	6.16%
Class II: 2-3 Objects	7 285	2.12%	37 877	11.01%
Class III: 4-5 Objects	4 181	1.22%	32 628	9.49%
Class IV: 6-10 Objects	7 239	2.10%	97 186	28.26%
Class V: 11-25 Objects	3 289	0.96%	78 575	22.85%
Class VI: > 25 Objects	1 434	0.42%	58 326	16.96%
TOTAL	**36 109**	**13.84%**	**325 786**	**94.73%**

Correlation with density indicators

A series of statistical correlations were also executed as part of the analysis. This activity explores the empirical relationships between groceries' serviceability levels and urban densities indicators, including Floor Area Ratio (FAR), incl. variations for floor area ratio residential and other uses, Gross Space Index (GSI), Open Space Ration (OSR), Network Density (ND), Dwelling Density (DWd) and Population Density (POPd). The details of the correlation analysis are presented in Table 2.

Table 2. *Correlation between the level of grocery serviceability and urban density indicators via Pearson's correlation coefficient and coefficient of determination (r-square).*

DENSITY INDICATORS	Pearson's correlation coefficient (r)	Coefficient of determination (r^2)
Floor Area Ratio (FAR)	.79	.62
Gross Space Index (GSI)	.67	.44
Open Space Ratio (OSR)	-.67	.44
Network Density (ND)	.83	.69
Dwelling Density (DWd)	.77	.59
Population Density (POPd)	.76	.58
Floor Area Ratio for Residential Use (FARre)	.82	.67
Floor Area Ratio for Other Uses (FARoth)	.57	.32

Based on the presented results, we can identify few main assumptions. First, we can see that the level of serviceability within the time isochron of 10 minutes cycling has the strongest correlation with ND (r = 0.83). This is somewhat logical and refers to the notion of permeability of urban form that can enhance highly flexible mobility modes, such as cycling. Apart from this, it can be observed that there is a strong correlation between the intensities of grocery objects' provisions in respect to the concentration of residences expressed in the indicators of DWd (r = 0.78), POPd (r = 0.75) and FARre (0.82). These values assume a logical, robust connection between the locations of grocery shops and residential areas. This claim is defined further by the weaker correlation between the level of serviceability and FARoth (0.57).

Further reflection on the results

Elaborating further on the outcomes of the undertaken analysis, looking at the existing urban form, the positioning of the POIs within it and their interconnectivity in respect to the street network, we can support the following statement:
Cycling has sufficient potential to serve as an effective mobility mode for performing trips to grocery stores within Stavanger metropolitan area.

However, this somewhat contradicts the general trend reported by official data from the travel surveys in Norway presented in section 2. They note that only 3% of all reported trips for trade (incl. groceries) are performed by a bicycle. This contradiction seems even more peculiar considering the persistent institutional intentions to encourage cycling in cities by extending the physical infrastructure. Thus, one can assume that

other aspects negatively influence the use of bicycling to grocery stores. In this regard, at least few factors can be underlined based on our observations:

- The development of non-segregated bicycle lanes along automobile roads, which negatively reflect on the users' perceptions of safety.
- An abundance of free parking for cars in supermarkets and shopping malls.
- Poor parking infrastructure for cyclists, especially next to supermarkets.
- A dominant driving culture - people are used to driving, even for short trips.

As Lunke et al. (2018) outline, the type of cycling infrastructure regarding safety and user satisfaction utilised to realise individual trips is influential. Therefore, one can assume that a potential shortcoming of some of the newly developed infrastructures for cycling is that they do not isolate fully the users, who should deal with traffic conflicts more often (see Figure 3). This claim is justified by the high percentage of cyclists who feel predominantly unsafe in Stavanger (68%) by the survey of Lunke et al. (2018:66).

Figure 3. *Examples of newly established cycling infrastructures in Stavanger MA, both representing cycling lanes on the roadway. High levels of motorised traffic characterise the concrete two examples along them.*

Another challenge related to the provisions of cycling infrastructure is the available parking facilities (if any) in front of grocery shops. Figure 4 illustrates a comparison between the provided facilities for cyclists and drivers immediately located to a supermarket in the city centre of Stavanger. Only visually, the prioritisation of the facilities for automobiles above those for bikes is explicit. Indeed, supermarkets and shopping malls predominantly provide free parking to cars, incentivising their use for purchasing purposes, even if these trips are short. This further reinforces the assumption for the presence of dominant driving culture in

Stavanger MA, underlined by the facts that only 13% of the households do not possess a private car, 56% of all trips and 71% of the trips for trade purposes are executed by an automobile.[5]

Figure 4. *Visual comparison of the available parking facilities for cyclists and automobiles in front of a major supermarket in the city centre of Stavanger.*

Conclusions

This study elaborates on a method to explore the level of serviceability regarding a particular urban amenity in correlation with the established spatial form and networks. Furthermore, the approach includes a flexible variation of time/distance, expressed by focusing on cycling. Concerning the method's characteristics, few details can be outlined:

- It represents an exploratory approach to delve into the contextual specifics without requiring strong pre-determined empirical assumptions.
- A context-sensitive method that responds well to concrete cases and has the potential to reveal various empirical outcomes.
- The approach can effectively incorporate many urban parameters related to spatial form, transport networks and demographics.
- Depending on the research framework, the developed method seems to have the capacity to both generate and verify assumptions regarding particular research relationships of interest.

[5] National Travel Survey (RVU, 2018), data source: Norwegian Public Roads Administration (Statens vegvesen) - https://www.vegvesen.no/fag/trafikk/transport/reisevaner/reisevaner-2019/ [accessed on June 4, 2021].

- The elaborated approach demonstrates the potential for high replicability by involving different parameters, POIs and mobility modes. This characteristic is strongly dependent on the availability of concrete datasets within each context of interest.

However, to evaluate the potentials and method's limitations with better precision, it seems necessary to test it further by correlating the mobility mode of interest with other means of transport, i.e. walking and public transport. This will allow us to develop a more holistic perspective towards the exploration interests of a particular analysis. One might assume this can be challenging, especially when travel time/distances need to be combined with waiting times for interchanges, travel mode transitions, etc.

Another research avenue of interest to explore the method's potential is to include further depth regarding the considered POIs. In the particular exemplary study, they are regarded as entities with equal values. Still, one can apply different weights to each object based on their total floor area, the number of offered products, monthly revenues, energy consumption etc. In a somewhat similar fashion, one can include additional density indicators to correlate with, if considered relevant, e.g. job densities, commercial densities, etc. Experimenting with these notions will eventually reveal further details regarding the method's potential and limitations.

References

1. Banister, D. (2008) 'The sustainable mobility paradigm', *Transport Policy* 15, 73-80.
2. Da Silva, D.C., King, D.A. and Lamar, S. (2020) 'Accessibility in Practice: 20-Minute City as a Sustainability Planning Goal', *Sustainability* 12(1), 129. https://doi.org/10.3390/su12010129
3. Hjorthol, R., Engebretsen, Ø. and Uteng, T.P. (2014) 'Den nasjonale reisevaneundersøkelsen 2013/14 – nøkkelrapport' (Norwegian Centre for Transport Research: TØI report 1338/2014), ISBN: ISBN 978-82-480-1598-7 [retrieved on August 10, 2021].
4. Levinson, D.M. (2020) 'The 30-minute city: designing for access', *Network Design Lab: Overleaf*.
5. Lin, S., He, M., Tan, Y., & He, M. (2008) 'Comparison Study on Operating Speeds of Electric Bicycles and Bicycles: Experience from Field Investigation in Kunming, China' *Transportation research record*, 2048(1), 52-59. doi:10.3141/2048-07
6. Lunke, E.B., Aarhaug, J., de Jong, T. and Fyhri, A. (2018) 'Cycling in Oslo, Bergen, Stavanger and Trondheim: A study of cycling and travel behaviour' (Norwegian Centre for Transport Research: TØI report 1667/2018), ISBN: 978-82-480-2189-6 [retrieved on May 25, 2021].
7. Moreno, C., Allam, Z., Chabaud, D., Gall, C. and Florent Pratlong (2021) 'Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities', *Smart Cities* 4(1), 93-111.
8. Norwegian Ministry of Transport and Communications (2018) 'National Transport Plan 2018-2029: A targeted and historic commitment to the Norwegian transport sector.' English summary [retrieved on June 10, 2021].
9. Pritchard, R., Frøyen, Y. and Snizek, B. (2019) 'Bicycle Level of Service for Route Choice—A GIS Evaluation of Four Existing Indicators with Empirical Data', *International Journal of Geo-Information* 8(5), 214. https://doi.org/10.3390/ijgi8050214
10. Schaap, N., Harms, L., Kansen, M. and Wüst, H. (2016) 'Cycling and walking: the grease in our mobility chain' (Dutch Ministry of Infrastructure and the Environment: KiM-16-A03), ISBN: 978-90-8902-145-8. [retrieved on June 10, 2021].
11. Strand, A., Nenseth, V. and Christiansen, P. (2015) 'Norsk sykkelpolitikk - på vei' (Norwegian Centre for Transport Research: TØI report 1453/2015), ISBN: 978-82-480-1680-9. English summary [retrieved on June 1, 2021].
12. Tarigan, A., Bayer, S. and Berg, C. (2010) 'Suburbanisation of employment means less sustainable travel? - The effects of policy location on commuters' travel patterns in the Stavanger region, Norway', *50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy"*, 19-23 August 2010, Jönköping, Sweden, European Regional Science Association (ERSA), Louvain-la-Neuve.
13. Øksenholt, V. K., Tønnesen, A. and Tennøy, A. (2016). Hvordan utforme selvforsynte boligsatellitter med lav bilavhengighet? (Norwegian Centre for Transport Research: TØI report 1530/2016), ISBN: ISBN 978-82-480-1779-0 [retrieved on June 1, 2021].