Denne artikel er udgivet i det elektroniske tidsskrift
Artikler fra Trafikdage på Aalborg Universitet
(Proceedings from the Annual Transport Conference at Aalborg University)
ISSN 1603-9696
https://journals.aau.dk/index.php/td

Flexible Parking Standards and Sustainable Mobility Choices – Swedish perspectives

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Abstract
Parking is considered a key policy for achieving sustainable mobility. Swedish public agencies have promoted lowering parking requirements to decrease automobile travel, oil consumption and carbon emissions. However, the implementation of restrictive parking policies lacks discussions about the role of the built environment and accessibility. If low parking standards are introduced in developments where it is impossible to walk, cycle or use public transportation, they do not work. This paper proposes a conceptual framework that links parking with the research on the effect of built environment on travel. It describes a model to calculate flexible parking standards based on built environment and accessibility factors commonly used in urban design and planning practices. Transportation systems need environmental preconditions. Parking requirements and expressways support driving around. Research shows that integrating walking, cycling and public transportation need complex sets of factors. The rationale is that parking standards can be lowered if the built environment supports walking, cycling and public transportation. The model aims to inform municipality officials, developers, architects, urban designers and planners about sustainable mobility choices and integration of the built environment with walking, cycling and public transportation and possibilities to reduce parking requirements to meet sustainable mobility goals.

Introduction
Urban transportation is a major cause for environmental damage and accelerating climate change (Marshall, 2001; Banister, 2008). Curbing carbon emissions and reducing oil dependence are most important issues in environmental debates concerning sustainable mobility in Sweden. Many Swedish municipalities have ambitious environmental goals to tackle transportation problems, lower carbon emissions and achieve sustainable mobility, but the built environment is a major obstacle (Ringeson, 2018; Stojanovski, 2019a). Many Swedish cities since the middle of the 20th century were designed for the private automobiles and today they are highly dependent on the automobile and imports of oil. Parking standards played important role to create the Swedish car society (Lundin, 2003; 2008). Parking is considered as a key policy for new sustainable development and transformation of car-dependent cities. Swedish public agencies in recent years have promoted restricting parking standards to decrease automobile travel

(Trafikverket, 2014; Boverket, 2018; Johansson et al., 2017; 2019; Johansson, 2019). However, in the current debates on parking in Sweden there are no discussions on the role of the built environment and accessibility in making parking policy.

In practice, parking problems are conventionally solved by predicting future parking demand and prescribing minimum number of parking spaces. The parking standards in Sweden are calculated as ratios. Stockholm City (2015) recommends green parking ratios of 0.3-0.7 parking spaces per dwelling to decrease future motorization rates. In the literature and planning manuals, parking standards today are intertwined with zoning and land uses. Trip generation and parking ratios are calculated for land uses (ITE, 2017; 2019). To address the problem of parking in a broader perceptive of sustainable mobility and urbanist practices, this paper proposes a model to calculate flexible parking standards based on built environment and accessibility factors. Many architects and urban designers argue to replace conventional land uses and two dimensional zoning with more complex Form-Based Codes (FBCs) and design guidelines in three dimensions (Duany & Talen, 2002; Talen, 2002; 2009; 2012; 2013; Ben-Joseph, 2005; Walters, 2007; Marshall, 2011). The design elements in the FBCs and design guidelines such as street and sidewalks design, commercial frontages, building setbacks and feeling of enclosure and so on, are furthermore important factors for walkability, Transit-Oriented Developments (TODs) and creating livable cites (Southworth, 2003; 2016; Talen, 2003; Ewing et al., 2005; Ewing & Handy, 2009; Stojanovski, 2019b).

The flexible parking standards should be understood within a paradigm of sustainable mobility and multimodal accessibility that emphasizes mobility management and transformation of cities (Cervero, 1996; Marshall, 2001; Rye, 2002; Banister, 2008; Lyons, 2011; Rode et al, 2017; Ringeson, 2018). The flexible parking standards and parking management should be part of urban planning and design policy for sustainable development and change. Investments in sustainable mobility infrastructures such as walking, cycling and public transportation should allow for lowering of parking standards and redesigning cities. In a virtuous cycle for sustainable mobility, less parking and sustainable urban development would produce more walking, cycling and transit use, contribute to modal shift towards environmentally friendly mobilities and decrease in carbon emissions and oil consumption.

Theoretical framework

Sustainable mobility

Sustainable mobility paradigm approaches the complex link between transportation and cities by focusing on mobility management and transformation of cities (Cervero, 1996; Marshall, 2001; Rye, 2002; Banister, 2008; Lyons, 2011; Rode et al, 2017; Ringeson, 2018; Johansson, 2019; Stojanovski, 2019b). Crucial aspect is accessibility and promoting access with a choices of various sustainable travel alternative by optimizing the co-dependence of the land uses and transportation systems (Marshall, 2001; Banister, 2008; Rode et al., 2017). Accessibility is conventionally defined as a potential for interaction between places (Hansen, 1959) or "the extent to which land use and transportation systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transportation mode(s)" (Geurs & Van Wee; 2004, p.128). There are much research on accessibility definitions and metrics (Hansen, 1959; Brotchie, 1984; Handy & Niemeier, 1997; Talen & Anselin, 1998; Talen, 2003; Geurs & Van Wee, 2004; Curl et al., 2011; Páez et al., 2012; Papa & Bertolini, 2015; Rode et al, 2017). The built environment and accessibility are interlinked. The built environment affords mobility choices that define the potential of movement. There is an extensive body of research on the effect of built environment on travel (Cervero, 1989; 1997; 2002; Southworth & Owens, 1993; Cervero & Kockelman. 1997; Southworth, 1997; 2005; Ewing & Cervero, 2001; 2010; Crane & Boarnett, 2001; Naess, 2006; 2011; 2012; Cervero et al., 2009; Boarnet, 2011; Boarnet et al., 2011; Papa & Bertolini, 2014; Rode et al, 2017; Stojanovski, 2018). In the end, accessibility has a broader meaning in the sustainable mobility paradigm including experiences while traveling (e.g. use of time, Lyons & Urry, 2005), subjective perception on accessibility (Curl et al., 2015; Lättman et al., 2016; 2018; Curl, 2018) and perspective on social life and mobility cultures (Sheller & Urry, 2006; Urry, 2007).

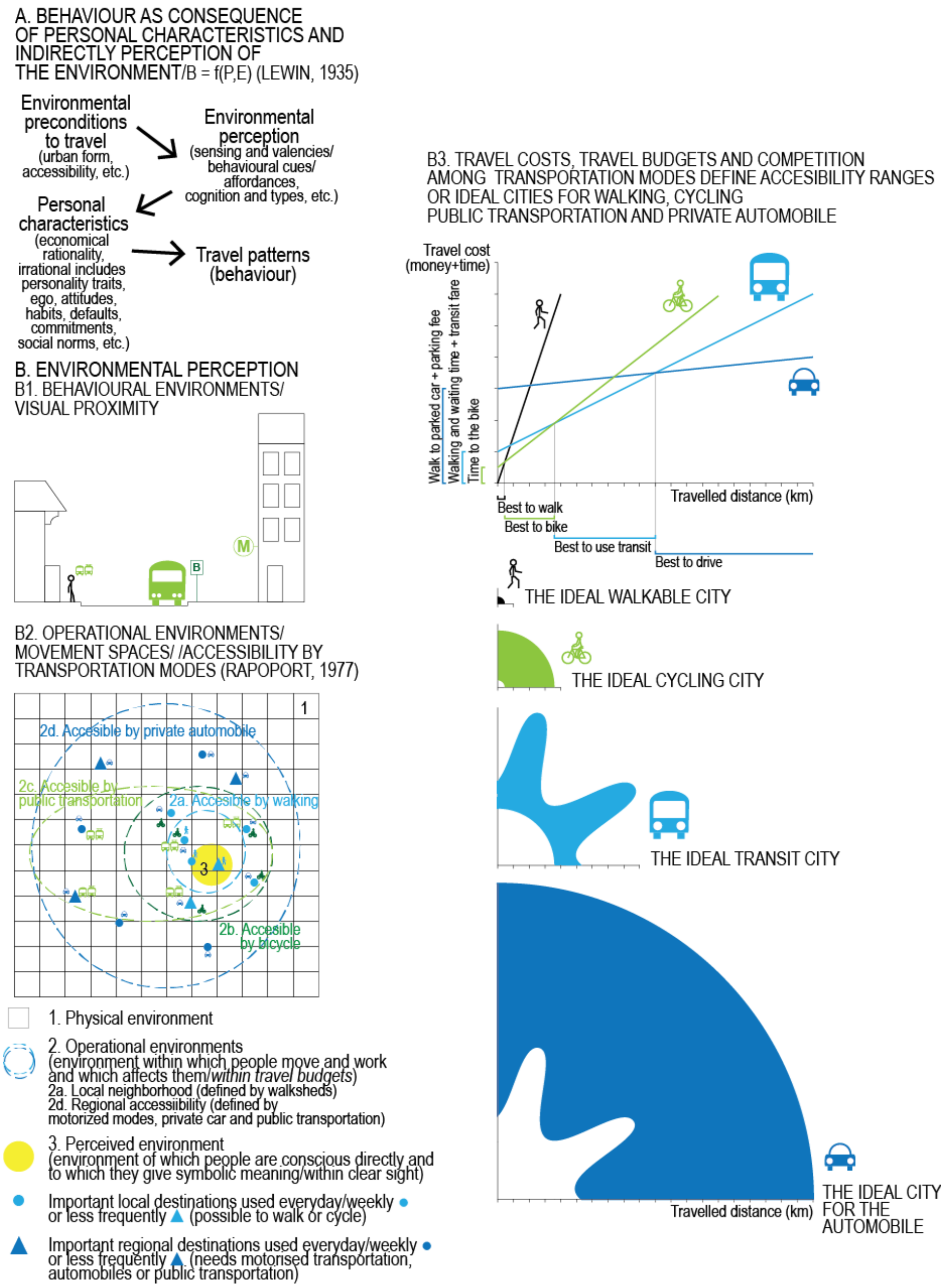

Figure 1: Theoretical framework to assess mobility choices based on built environment and accessibility factors

The theoretical framework combines research on accessibility and the effect of built environment on travel with urban morphology, urbanist advocacy for FBCs and environmental perception. Urban morphologists understand cities and the built environment at different scales, from a room, building on a lot and lot as part of the city block, neighborhoods with city blocks on a street layout and an urban region with neighborhoods (Moudon, 1986; 1997; 2019; Kropf, 2011; 2014). The built environment factors on all of these scales influence accessibility as potential of movement. These scales work together. Parking is typically regulated on a scale of a lot or a city block, but it influences automobility on a regional scale. Accessibility and travel are influenced by environmental perception at different morphological scales. Environmental perception involves the interpretation of sensory information from physical and social surroundings, as well as the emotional responses they provoke. Environmental perception influences travel behavior indirectly (Figure 2A) and structures environmental preconditiosn to travel as a set of built environment and accessibility factors. The built environment elements (such as parking lots, transit stops, bike racks, expressways, regional transit, etc.) can prioritize some transportation modes and hinder others.

Two scales are particularly important. Preconditions to travel as embedded affordances in built environment exist within perceptual environments (Figure 2B1) and the cognitive understanding of urban regions as operational environments (Figure 2B2) or accessibility ranges (Figure 2B3). The operational environment is the space where people move and work. People are directly conscious and give symbolic meaning to their perceptual environment. In the perceptual/behavioral environment, people are not only aware but also produce behavioral responses (Rapoport, 1977).

Accessibility at a regional scale is equally important as factors of the built environment in perceptual/behavioural environment such as visual proximity or neighbourhood scale. These ideal accessibility ranges are calculated based on competition between transportation modes and the theory of travel budgets. The competition between different transportation modes includes making tradeoffs between costs in money and time (Crane, 1996b; Crane & Boarnet, 2001; Boarnet, 2011). For shorter distances, it is more economically rational to walk or bike. For longer distances, public transportation as an aggregate of travel time, convenience and transit fare competes with the private automobile as parking fees and costs to drive a car (Figure 2B3). Transportation as an economic activity cannot exceed expenditures over a certain budget or the price of a good. Yacov Zahavi (1974) argues that there are fixed travel budgets defined by the time and money that an individual is willing to spend on travel per day. Travel surveys in the last century show that an average person travels roughly one hour (1.1 h in Zahavi's studies) and makes around 1000 journeys per year (Zahavi & Talvitie, 1980; Zahavi & Ryan, 1980; Banister, 2011). Recent research on acceptable travel times concludes that a journey of 15 minutes poses no problems, whereas most individuals find a commuting journey of 45 minutes or more as inconvenient and tiresome (Milakis et al., 2015a; 2015b; Milakis & Van Wee, 2018). The radius of the ideal city for the walking, cycling, public transportation and private car does not exceed the convenient journey of 30 to maximum 45min. The only difference is that the public transportation consists of lines and the shape of the ideal city is amoebic or looks as band of pearls (Calthorpe, 1993).

Parking standards

When calculating parking standards, municipal officials and planners do not consider environmental perception, embedded affordances in built environments or accessibility ranges. In practice, parking standards are conventionally calculated as ratios. For each car, typically one parking space is provided at home and three to four elsewhere (Gruen, 1977; Shoup, 2011). Parking ratios are minimum or maximum parking requirements that provide number of parking spaces to match travel patterns and motorization trends (Figure 1A). These numbers were copied between the USA and Sweden in the 1960s (Lundin, 2004).

The parking ratio rationale in relationship to car ownership has not changed. The concerns for managing future motorization remains in the parking ratios calculus. The parking ratios in Sweden are negotiated between developers and the municipalities that own the land for development. The parking ratios are conceived as flexible standards (that can be adjusted), maxistandards or ministandards (maximum and minimum parking requirements) (Boverket, 2018). Stockholm Municipality (2015) recommends green parking ratios of 0.3-0.7 parking spaces per dwelling to facilitate lower motorization rates in the future. Lower parking ratios of 0.6 parking spaces per dwelling are typically introduced to curb automobile use in new sustainable neighborhoods like Hammarby Sjöstad in Stockholm, Sweden. There are new Swedish sustainable neighborhood experiments with zero parking standard (e.g. Valastaden in Linköping, Brf Viva housing project in Göteborg, Mo-Bo concept in Stockholm, etc.). Setting low parking ratios has caused parking shortages and additional investment in parking garages, particularly in developments where there were uncompetitive travel alternatives to the private car.

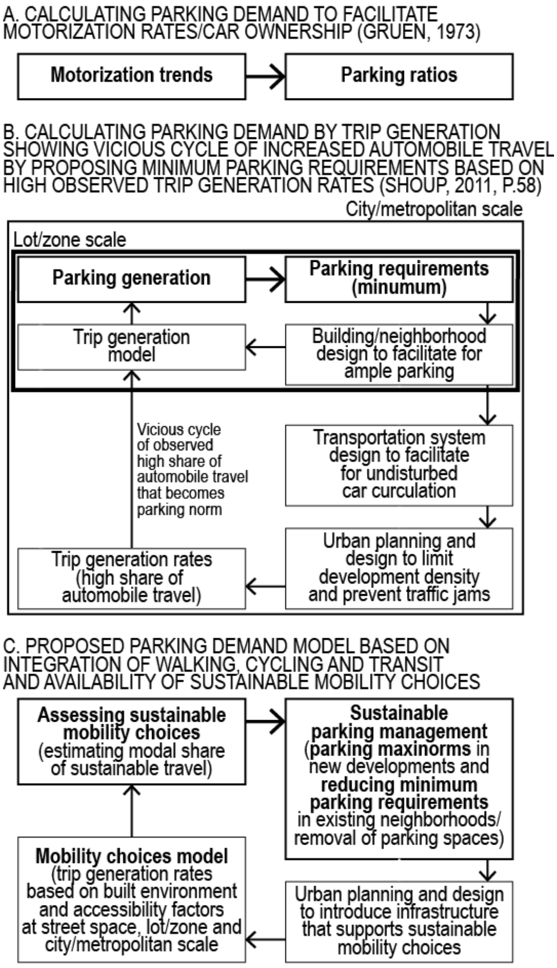

Figure 2: Methodologies to access parking demand and theoretical framework to gradually reduce parking or propose restrictive parking maximums in new developments by availability of sustainable mobility choice

In the USA, the land uses define minimum parking requirements. The Institute of Transportation Engineers (ITE) publishes and continuously updates the Trip Generation Manual (first published in 1976) and Parking Generation Manual (first published in 1985). The minimum parking requirements calculated by observing and predicting trip and parking generation rates (Figure 1B). The handbooks compile empirical studies on trip and parking generation in different land uses. There is an extensive literature on parking and land use (Shoup & Pickrell, 1978; Willson & Shoup, 1990; Shoup, 1995, 1999; 2011; Willson, 1995; 2013; Littman, 2006) including new research on mobility management and parking (Rye, 2002; Rye et al., 2006; Ison & Mulley, 2014; Mingardo et al., 2015; Simicevic and Milosavljević, 2019). There are several problems with using the influential ITE handbooks. Donald Shoup points out to the low significance of the empirical evidence in the observation studies. The trip and parking generation rates for commercial land uses are not linear. The observations are often conducted in places where automobile travel dominates the modal split. As such they prescribe exaggerated minimum parking requirements based on high trip generation rates for the automobile. This creates a vicious cycle where high modal shares for automobile and parking generation rates are prescribed as minimums (Shoup & Pickrell, 1978; Willson & Shoup, 1990; Shoup, 1995, 1999; 2011). New research aims to correct and enrich the standardative assumptions of ITE's handbooks by conducting observation studies in dense urban environments and transit-oriented neighborhoods (Cervero et al., 2010; Clifton, et al., 2012; 2015; Shafizadeh et al., 2012; Schneider et al., 2015; Weinberger et al., 2015, Ewing et al., 2017; Currans & Clifton, 2019; Tian et al., 2019). Another problematic aspect is that the trip and parking generation is observed on a scale of a lot or zone. Assessing trip and parking generation on a lot obscures the accessibility range at the scale of the city/metropolitan area. The accessibility is as important as the land use. The methodology of trip and parking generation does not consider experiential qualities of the urban space such as street and sidewalks design, commercial frontages, building setbacks and feeling of enclosure and so on. (Southworth, 2003; 2016; Talen, 2003; Ewing et al., 2005; Ewing & Handy, 2009; Stojanovski, 2019b). These factors are crucial in urban design practices that deliver urban plans.

Figure 1C proposes a theoretical framework to calculate and recommend flexible parking maxistandards based on availability of built environment and accessibility factors that support sustainable mobility alternatives such as walking, cycling and public transportation. The proposed theoretical framework implies continuous parking management to transform the cities to boost the share of sustainable transportation modes by gradually reducing parking minimums and parking removal in existing neighborhoods and proposing restrictive parking maximums in new developments. The sustainable mobility paradigm emphasizes mobility management and transforming cities into built environments that support sustainable mobilities. The process perspective of continuously ongoing sustainable parking management (Simicevic and Milosavljević, 2019) needs to be supported by urban design interventions such as introduction of new transit systems, creation of walkable and bikable environments and removal of parking.

Methodology

The methodology builds upon theory of environmental perception, urban morphology or the study of built environment and sustainable indicators. Figure 3 shows the steps in the model that assesses environmental preconditions to walk, cycle, use public transportation and drive. Based on this assessment it estimates modal shares and calculate flexible parking norms.

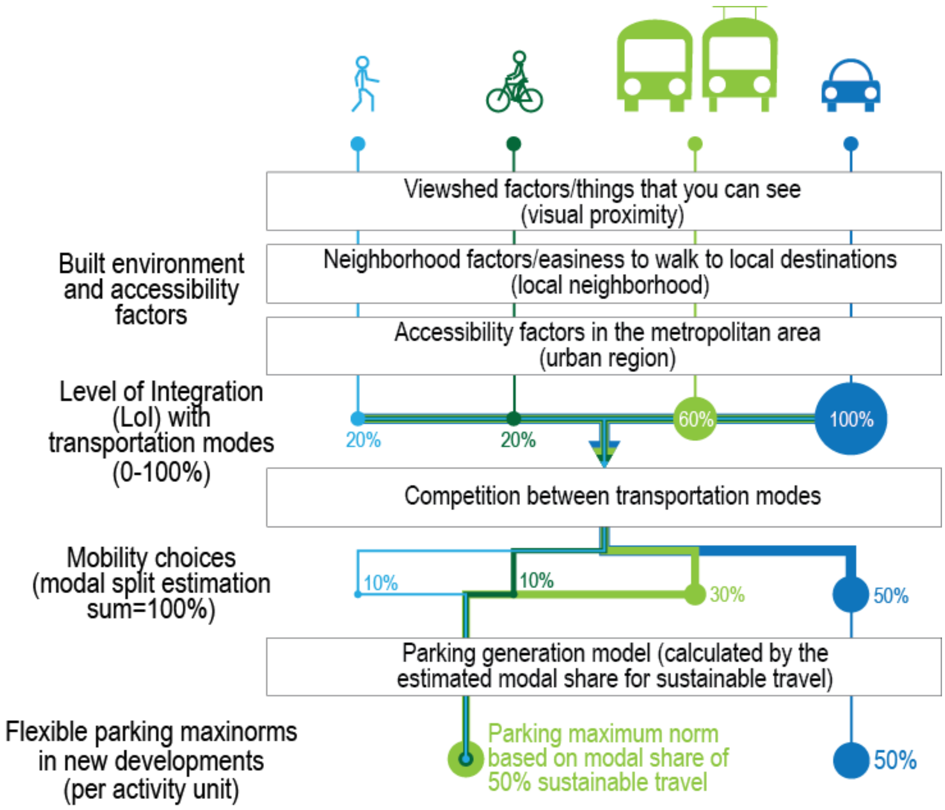

Figure 3: Methodology of structuring and weighing built environmental and accessibility factors to estimate the modal share of sustainable travel (dependence on the private automobile).

The model comprises of a set of weighed built environment factors that measure Level of Integrations (LoIs) with walking, cycling, public transportation and private car. The LoIs illustrate preconditions to travel embedded in the built environment and they vary in complexity. A private automobile needs parking space at the destination and a quick access to an expressway. These two crucial factors give 100% integration. Walking, cycling and public transportation require a very complex combination of built environment and accessibility factors. The integration with public transportation include more than ten weighed factors (including the factors for walking). If the private automobile has 100% integration, while public transportation is 60 % and walking and cycling are 20%, the modal shares will be 50%, 30 % and 10% accordingly. The estimated 50% of sustainable transportation would lower the parking norm. Based on the LoIs for the transportation modes (0–100%) as precondition to travel, the model calculates modal shares proportionally and then proposes flexible parking norms. Better preconditions to travel with particular transportation modes means better integration with the buildings and that would arguably result in higher modal shares for that transportation mode. Table 1 shows the built environment and accessibility factors as sustainable mobility indicators with weights for different factors and the scales (viewshed/visual proximity, walkshed/neighborhood and regional access).

Table 1: Integration with transportation modes (as a set of sustainable mobility indicators/built environment and accessibility factors).

Built environment and accessibility factors	**Walking**	**Cycling**	**Public transportation**	**Private car**	**Scale**	**Source**
Sidewalk design and continuity	(3) 5[1]				Viewshed	LEED[4]
Street segment length/city block width/intersection density	(7) 15				Viewshed	(Southworth, 1997), D-variables[3], Walk Score[4]
Speed limit	(3) 5[1]				Viewshed	LEED[4]
Bike infrastructures (racks, parking and cycling lanes)		(3) 20			Viewshed	
Bus line/busway/tramway on street			(3) 5		Viewshed	
Transit stop/station exit on street			(3) 5		Viewshed	
Parking				(9) 60	Viewshed	LEED[4]
No visible congestion				(3) 10	Viewshed	
Building setbacks	(3) 5[1]				Viewshed	LEED[4]
Building height/street width ratio	(3) 5[1]				Viewshed	LEED[4]
Building façade activity/openness	(9) 20[1]				Viewshed	LEED[4]
Lot/block density (residents and jobs)	(9) 40[2]		(3) 5		Walkshed	D-variables[3]
Neighborhood topography (slope)		(9) 40			Walkshed	Walk Score[4]
Access to everyday activities	(9) 20				Walkshed	Walk Score[4]
Access to event-type activities	(3) 5				Walkshed	Walk Score[4]
Access to a mix of activities	(9) 20				Walkshed	D-variables[3], Walk Score[4]
Access to a local transit stop			(9) 30		Walkshed	Walk Score[4]
Access to a regional transit stop			(9) 30		Regional	Walk Score[4]
Access to an expressway				(5) 30	Regional	
Bikable location		(9) 40			Regional	
			Walking (5) 20			
Sum	(51) 100	(24) 100	(27) 100	(17) 100		

[1] value assigned to street space
[2] value assigned to the built parameter of the city blocks/perimeter within building façades (the values for street spaces and built parameters city blocks are averaged with block statistics in 100m radius)
[3] D-variables is a term coined by Robert Cervero to describe built environment factors such as Density, Diversity, Design and so on (Cervero, 1989; Cervero & Kockelman. 1997; Ewing & Cervero, 2001; 2010; Cervero et al., 2009)
[4] LEED, or Leadership in Energy and Environmental Design, is assessment system that has integrated urbanist advocacy for FBCs and livable streets at LEED-ND, assessment at a neighborhood scale.
[5] Walk Score (https://www.walkscore.com/) shows integration with walking, cycling and transit online based on accessibility factors

Table 2: Methods used to assess the built environment and accessibility factors.

Built environment and accessibility factors	Method
Sidewalk design and continuity	I_1 is surveyed (I_1 = 100 is assigned for continuous sidewalks)
Street segment length/city block width/intersection density	$I_2 = 200 - cbw_x$ where $cbw_x = \sqrt{cba_x}$ cbw_x City block width (values lower than 100 m get 100% integration and 0 points for over 200 m, see Soutworth, 1997 on intersection density).
Speed limit	I_3 is surveyed (I_3 = 100 if speed limit = 30km/h)
Bike infrastructures (racks, parking and cycling lanes)	I_4 is surveyed (bicycle parking and cycling lanes on a street give I_4 = 100, I_4 = 50 if there are only bike racks or cycling lanes on the street)
Bus line/busway/tramway on street	I_5 is surveyed (street segments with bus lines receive I_5 = 50, whereas I_5 = 100 with busways/tramways on street)
Transit stop/station exit on street	I_6 is surveyed (city blocks with a transit stop/station exit on the streets receives I_6 = 100)
Parking	I_7 is surveyed (I_7 = 100 is assigned if there is visible parking)
No visible congestion	I_8 is surveyed (if there is no visible congestion I_9 = 100)
Building setbacks	I_9 is surveyed (building façade within 0.5m get I_9 = 100, between 0.5 and 5m I_9 = 50 and I_9 = 0 for over 5m)
Building height/street width ratio	I_{10} is surveyed (if the ratio is 1:3 or lower I_{10} = 100)
Building façade activity/openness	I_{11} is surveyed (if any part of the building façade is publicly accessible I_{11} = 100)
Lot/city block density (residents and jobs)	$I_{12} = \frac{q_{rj}}{100}$ q_{rj} residents and jobs per ha (if number of residents and jobs per ha > 100 then I_{12} =100)
Neighborhood topography (slope)	I_{13} is calculated in GIS with raster map algebra method. Two raster maps with cost distance from the central points of the neighborhoods are created to calculate the travel ratio (TTR): 1) without slope; and 2) with slope degree penalty: no penalty was given for 0-0.5 degrees, 50% for 0.5-1, 100% for 1-2, 300% for 2-5, 400 % for 5-10 and beyond 10%-degree slope got 100 times penalty (1000%). By dividing the raster without and with slope penalty it is possible to see how difficult is to reach a destination. A TTR of 1 would mean two points on the map connect without slope obstacles, whereas 2 would mean 0-1% slope. I_{15} is normalized (0-100) with map algebra formula: $I_{13} = -10 * ttr_x + 110$ (negative values are corrected to 0) ttr_x Travel time ratio in a cell of the raster map
Access to everyday activities	I_{14} is calculated in GIS. O-D matrix network analysis in ArcGIS is used to calculate distances from each supermarket, shop, restaurant, bar and so forth to every building in the neighborhood. Interpolation method (IDW) is used to calculate ranges. I_{14} = 100 if building is within 100 m (buffer tool is used), 60 if between 200-400 m network distance, 30 if within 400-800 m network distance.
Access to event-type activities	I_{15} is calculated in GIS with the same method as I_{14}, just destinations included in this case churches, libraries and so forth
Access to a mix of activities	I_{16} is calculated in GIS. Service area network analysis in ArcGIS is used. Service area polygons within 400 m to entries with different land uses (shopping, culture, recreation, bars and restaurants, services, education and public spaces) are created. An overlay in GIS is used to sum up the total number of land uses: The polygons are converted in a raster map with following values: I_{16} = 0 (0-1 uses); I_{16} = 25 (2-3 uses); I_{16} = 50 (4-5 uses): and I_{16} = 100 (6-7 uses).
Access to a local transit stop	I_{17} is calculated in GIS. O-D matrix network analysis in ArcGIS is used to calculate distances from local transit stops to every building in the neighborhood. Each local transit stop received a Transit Stop Performance Benchmark (TSPB) in respect to the frequency and type of service. The formula is: $TSPB = \frac{\ln(f_{ts})}{\ln(6000)}$ (values over 6000 are corrected to 6000) f_{ts} Frequency at transit stop (weekly departures multiplied by 2 for commuter rail/subway/regional bus lines, 1.5 for local trunk buses and 1 for standard buses). The reference for the calculus (TSPB = 100) is a bus stop with six lines operating with 10 minutes headway (roughly 1000 departures/week).
Access to a regional transit stop	I_{18} is calculated in GIS is used with the same method as for access to a local transit stop, just for transit stops with regional service.
Access to an expressway	I_{19} = 100 if the neighborhood center is within 5 km to an exit to an expressway
Bikable location (regionally)	I_{20} is calculated by the formula: $I_{20} = -20 * w_{cc} + 200$ w_{cc} Distance to the metropolitan core (in km) (if w_{cc} > 10 km then I_{20} = 0)

The built environment factors in Table 1 derive from research on the effect on travel (namely D-variables) cited in the theoretical framework, but also variables used in urbanist practices such as street and sidewalks design, commercial frontages, building setbacks and feeling of enclosure and so on. The accessibility factors derive from travel budget theory (e.g. bikable location is within 20km that corresponds to 1h journey). The importance of the factor (9-point scale) is shown in the brackets (x) with the weights. The sums in Table 1 shows the sum of the 9-scale values for all the factors and the 100% integration for the LoIs. The weights of the factors are rounded proportionally according to the 9-scale values in the brackets to sum up to 100% (e.g. Parking is extremely important gets value 9 that rounds to 9/17=~60% of the integration with the private car). The weighting is conducted by applying 9-point scale commonly used in Multi-Criteria Evaluation (MCE) in Geographic Information Systems (GIS) where only the top 4 values are used: 9 for extremely, 7 for very much, 5 for moderately and 3 for slightly effects the LoI. Table 2 describes in detail the methods used to calculate the built environment and accessibility factors.

In the first step, the built environment and accessibility factors indicators are surveyed in the field or measured, analyzed and geocoded in GIS according to the methods presented in Table 2. The LoIs for the transportation modes are calculated by the formula (1):

$$LoI_m = \sum_{i=1}^{n}(wBEA_i * BEA_i), \qquad (1)$$

LoI_m	Level of integration (0–100) for transportation mode m
$wBEA_i$	Weights for built environment or accessibility factor *I* (see the list in Table 1)
BEA_i	Built environment or accessibility factor *i*

In the second step, the modal shares are calculated as proportion of the *LoI* for a specific mode in respect to the sum of the *LoIs* for all modes:

$$MS_m = \frac{LoI_m}{\sum_{i=1}^{n}(LoI_N)}, \qquad (2)$$

MS_m	Modal share for transportation mode *m* (in percentage)
LoI_m	Level of integration (0–100) for transportation mode *m*
LoI_N	Level of integration (sum for all transportation modes *N*)

The private car is in a vicious circle in the modal split with the other sustainable transportation modes. Table 3 shows the normative framework for the modifier to estimate maximum parking norms as tradeoff of sustainable mobility choices. Car free development is possible if the estimated modal share of sustainable transportation modes (the sum of walking, cycling and transit) is over 70% (that means that the modal share of private car is 30%).

Table 3: Normative framework for parking maxinorm based on integration with sustainable transportation modes (walking, cycling and transit)

Integration with sustainable transportation modes (as estimated modal share of walking, cycling and transit)	Modal share of private car	Maximum parking norm
70%	below 30%	0 (car free possible)
40%	60%	1
10%	above 90%	2 (car oriented development)

Parking depends on the activity U_i and the accessibility (defined as modal share). Activity denotes number of units such as dwellings, residents, floor space, etc. in the building/lot/zone. Accessibility includes mobility choices. Higher modal shares of sustainable mobility, lower parking norms. The flexible parking norm (parking generation by one dwelling) are calculated by the following formula where the activity modifier is set to U_i = 1 unit (1 dwelling):

$$P_i = U_i * (MS_{car} - 30\%) * p_i \quad (3)$$

P_i Number of parking spaces per unit U_i (maximum parking norm if U_i = 1)
MS_{car} Estimated modal share of private automobile in a newly proposed development.
p_i Parking modifier to estimate maximum parking norm for one unit U_i
U_i Activity modifier (number of units e.g. if U_i = 1 dwelling and if $p_i = 4$ and m_{car} is 90% then the $P_i = 0.6 * 4 = 2.4$ for 1 dwelling, see Table 3)

Case study

Luleå is a small coastal city in northern Sweden. It is the seat of Luleå Municipality and the capital of Norrbotten County. The city has 75000 inhabitants in a county of 250000. Two neighborhoods are selected to test the model, the downtown of Luleå and Kronan (Figure 3). The downtown of Luleå is a typical urban core of a small Swedish city. It has a grid street plan with rectangular city blocks. Kronan (The Crown) is a proposed neighborhood development roughly 2 km (1.5 mile) eastward from the downtown. The development plan for Kronan includes residential buildings (city blocks with courtyards as in the downtown) and a new square surrounded by commercial storefronts and public buildings. The street plan is irregular and follows the foot on the hill. The new neighborhood will house 7000 inhabitants. Today, roughly 1500 people live in the area. Six residential towers were recently built on the hill westward from the newly planned development.

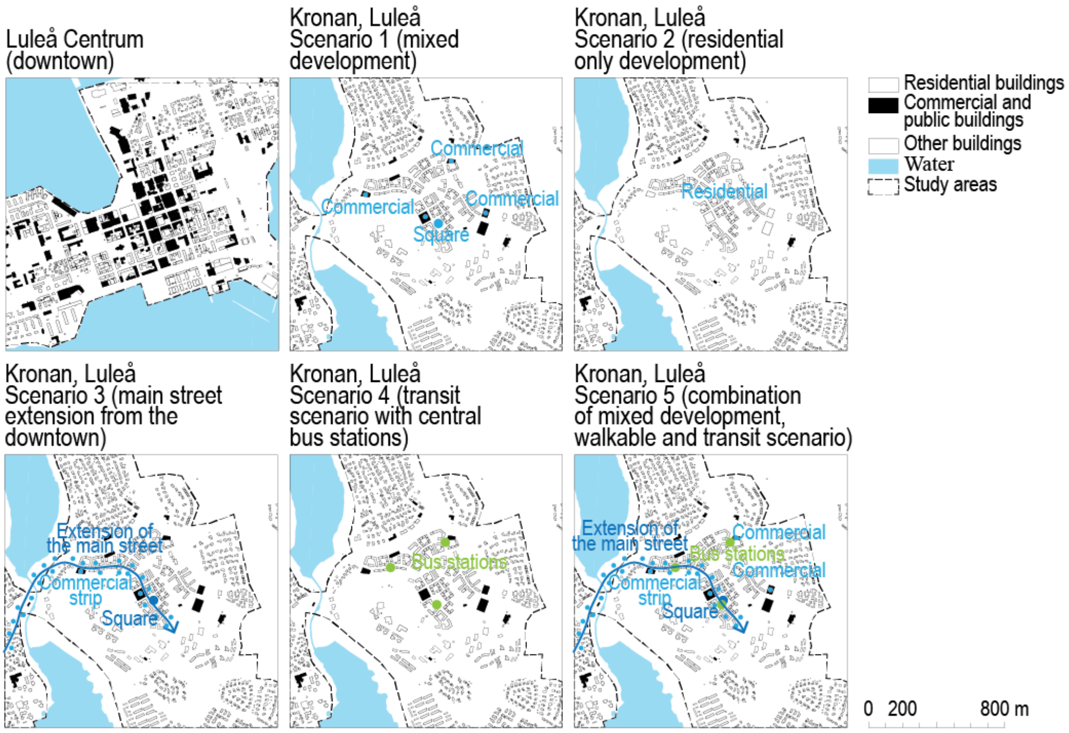

Figure 4: The study areas Luleå Centrum (the downtown) and five neighborhood development scenarios for Kronan

Five scenarios of Kronan are analyzed in this study. Scenario 1 illustrates the proposed mixed development with residential buildings, new square and commercial buildings. Scenario 2 shows a typical residential only development. In the smaller Swedish cities, the demand for commercial in the suburbs is often low and the typical outcome is dense neighborhood with residential apartment blocks. Scenario 3 shows a walkable city scenario where the main street in the downtown extends 2 km (1.5 mile) eastward and connects the new square. It creates a commercial strip induced by the existing main street. Scenario 4 is Transit-Oriented Development (TOD) scenario. Three bus station are introduced with six bus lines operating with 10 minutes headway (with frequency of 1000 weekly journeys). Scenario 5 overlays the walkable city Scenario 3 and TOD scenario 4.

Results

Figure 5 and Figure 6 show heat maps of the analyzed sustainable mobility indicators from Table 1 and Table 2, Levels of Integration (LoIs) and modal shares for walking, cycling, public transportation and private car for two scenarios, Luleå Centrum (downtown) and the most probable Kronan Scenario 2 (residential only scenario).

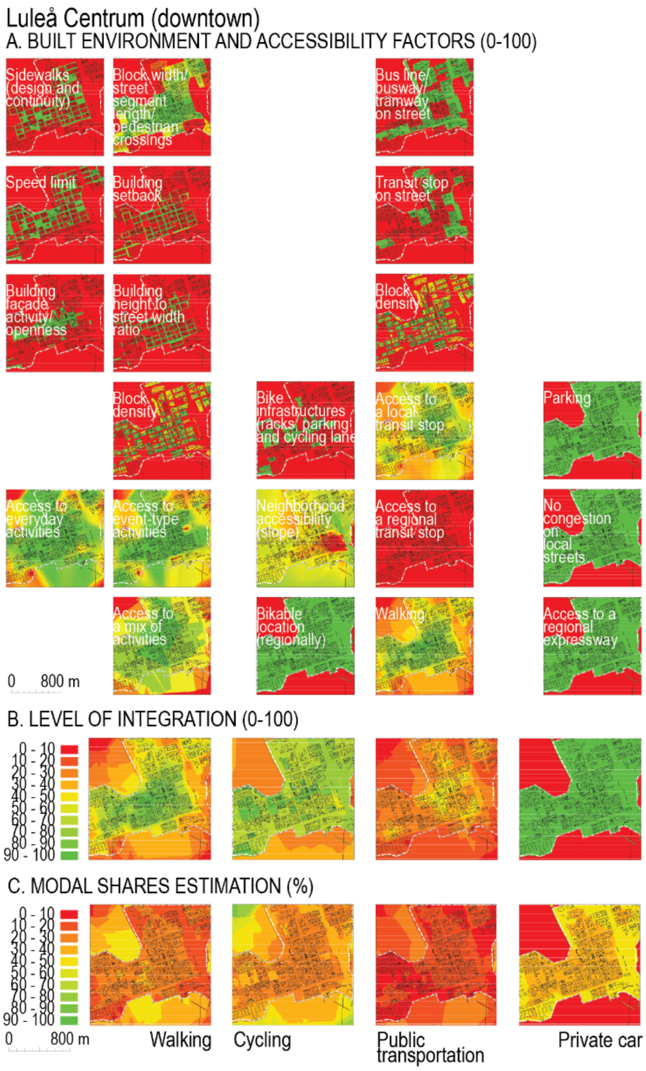

Figure 5: Heat maps of Luleå Centrum (downtown) showing the built environment and accessibility factors, Levels of Integration (LoIs) and modal shares estimation

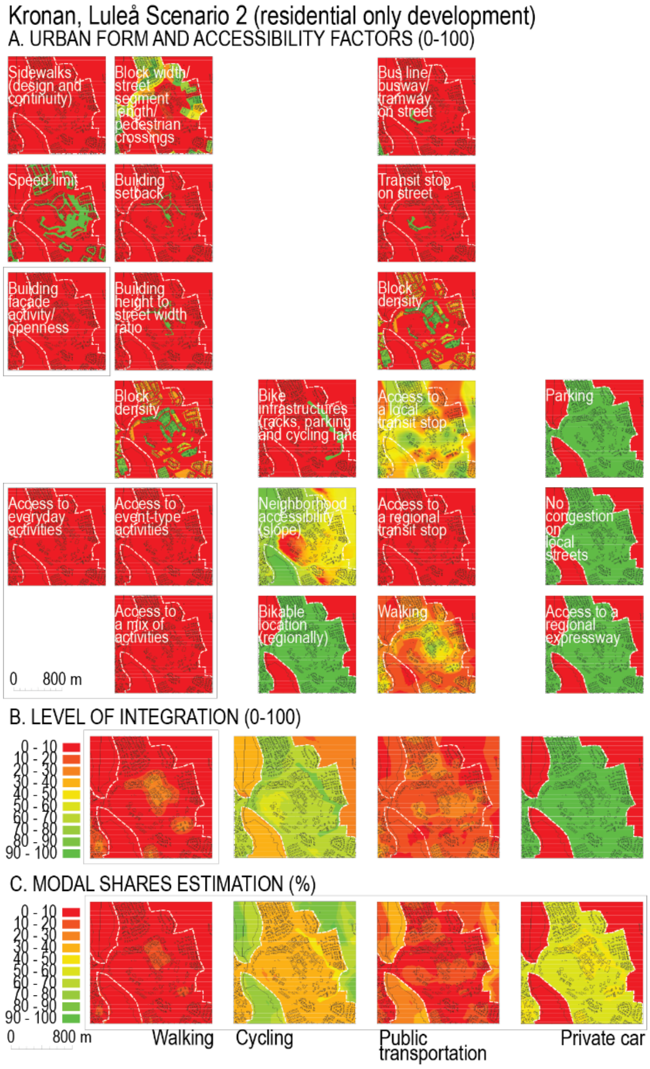

Figure 6: Heat maps of Kronan Scenario 2 (the most probable development scenario) showing the built environment and accessibility factors, Levels of Integration (LoIs) and modal shares estimation

Figure 7A shows a typical parking ratio approach that is fixed. One ratio is (of 0.6 parking spaces per dwelling) applied for the entire development. Figure 7B visualizes parking norms based on mobility choices or built environment and accessibility factors. Figure 7B1 presents the sum of walking, cycling and public transportation as modal share of sustainable transportation modes. Based on this modal split estimates, Figure 7B2 calculates and suggests parking maxinorms for new residences. In the proposed mixed development Scenario 1 in Kronan there is a sustainable mobility hotspot around the new square, but it quickly dissipates along the residential buildings. The hill on the east of the new development poses particular difficulties for pedestrians and especially bikers. The integration of sustainable transportation modes (mainly the biking possibilities to the downtown) produces estimates of modal shares between 40-60%. In the typical residential only Scenario 2 (the most probable scenario for small cities like Luleå) the walkability hotspot disappears and the estimates of sustainable modal shares drops by 10% (Figure 4A). The high density residential only development does not help. There is no reason to walk without commercial development, but it is still possible to bike to the downtown. Scenario 3 shows an increase of walkability along the extension of the main street. The commercial strip replicates a downtown and that reflects on the estimates of modal shares. Scenario 4 shows a sustainable mobility hotspot around the new square and bus stations. This area extends even further in Scenario 5 which overlays walkable main street with highly frequent bus stations. The integration of sustainable transportation modes in these sustainable mobility hotspot produces estimates of modal shares between 40-60% (like in Luleå Centrum, the downtown). The recommendations for maximum parking norms vary from 0-0.2 parking spaces/dwelling for the sustainable mobility hotspots to 1 parking space/dwelling for the towers on the hills and the residential only Scenario 2. These results are very different than the fixed parking ratios of 0.6 (Figure 7A).

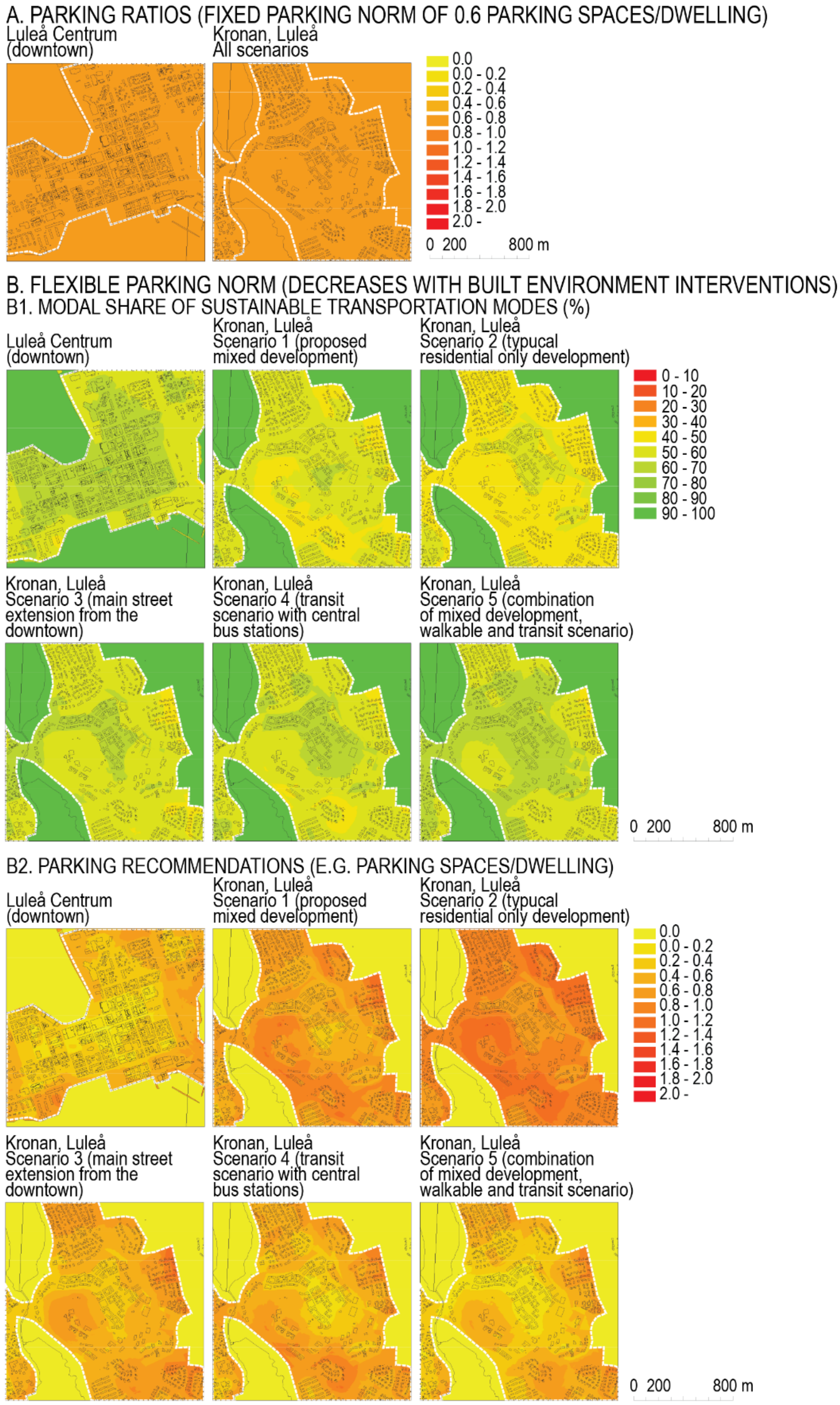

Figure 7: Modal shares forecasts and suggested flexible parking norm that can be lowered with built environment interventions.

The model calculate flexible parking norms based on availability of sustainable mobility choices. It analyzes a set of built environment and accessibility factors to visually inform about modal shares and integration with walking, cycling, public transportation (as sustainable mobility choices) and the private automobile.

Figure 7 compares the existing method of fixed parking ratios with visualizations of flexible parking norms. The parking maxinorms maps (Figure 7B2) show hot spots in the neighborhoods where zero parking can be introduced and under which conditions (very walkable streets, frequent transit stops, etc., see Table 1 and Figure 6A for built environment and accessibility factors). Higher integration with walking, cycling and public transportation would allow for lower parking norms and would give more space for sustainable travel alternatives in cities. This can reflect in removal of parking spaces, creating more walkable streets, orientation of buildings towards transit stops and constructing new cycling infrastructures. In a virtuous cycle for sustainable mobility, less parking and new sustainable mobility infrastructures would produce more walking, cycling and transit use, contribute to modal shift towards environmentally friendly mobilities and decrease in carbon emissions and oil consumption.

There are several limitations with the model. It works as a modified trip generation model (emphasizing built environment and accessibility factors), but the modal share estimates are reasonable considering the limitations of travel forecasting based on built environment factors (Cervero, 2002). The modal shares correspond to the aggregate statistic in the travel surveys in Luleå with a variation of 10%. The travel survey for Luleå Municipality from 2010 shows that the shares for walking, cycling, transit and automobile are roughly 50%, 15%, 5% and 30% in the downtown and 25%, 10%, 10% and 55% in the neighborhoods surrounding the downtown like Kronan (Luleå Municipality, 2010). It also proposes parking modifiers arbitrary in respect of the percentage of high integration with sustainable transportation modes. These arbitrary numbers derive from the proportional nature of the mobility choices model. Above 70% estimated modal shares of sustainable transportation modes means that walking, cycling and public transportation are almost 100% integrated. This means that all the sustainable mobility indicators for walking, cycling and public transportation are fulfilled. This involves a very frequent local and regional transit service, main street level of walkability and cycling infrastructure.

Conclusions

Achieving sustainable mobility is a major challenge in many cities that were designed for the automobile. This paper presents an analytical tool that visualizes integration with different transportation modes, estimation of modal shares and parking maxinorms. The visual information as heat maps aims to inform urban planning and design practitioners, municipal officials and developers about sustainable mobility choices. There are discussions about flexible parking norms in Sweden, but there are no practical models that can be used in the debate. Many attractive developments are located on hills or waterfronts that are not always walkable, bikeable and easily supplied with frequent transit services. Developing these neighborhoods with lack of sustainable mobility choices contributes to additional automobile travel and oil dependence.

The model aims to contribute in shaping appropriate parking management strategies by informing municipality officials and developers, urban planners and designers about integration with walking, cycling and public transportation and possibilities to reduce parking requirements. The model captures orientation of buildings to sidewalks, cycling paths and transit facilities (as part of the FCB advocacy), but also regional accessibility factors that derive from transportation and land use research. The parking ratios, conventional zoning, trip generation models based on land uses and minimum parking requirements are often simplistic and focus on a lot or zone, neglecting both three-dimensional aspects. In the end, the model is not conceived as a framework that links research on the effect of built environment and accessibility on modal shares. The sustainable mobility indicators are not fixed. It should be constantly updated and revised to best inform planning debates and inspire discussions among municipal officials, developers, architects, urban designers, etc. on the integration of sustainable transportation modes with cities and the effect of the built environment on the travel.

In the end, he model informs directly about sustainable mobility in a concise form (modal shares and parking recommendation) and shows a complex set of built environment and accessibility factors as background for the modal shares forecast. Both the concise and complex information are need to reflect upon the complex link between built environment and sustainable mobility both in the planning, development and parking management phases. Sustainable mobility as paradigm implies continuous managerial processes of monitoring and revising the parking norms and the set of sustainable mobility indicators.

Acknowledgments

This research is supported by grants from Energimyndigheten, the Swedish Energy Agency (P44455-1 and P44455-2). It is based mainly on the doctoral thesis focusing on built environment and sustainable mobility choices (Stojanovski, 2019a)

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