Dynamic Land Use: An explorative study on the implications for transport and spatial planning

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Abstract The urban agenda is demanding new approaches for urban development. Urban flexibility has been recognized as crucial for coping with uncertainty and smart growth has been advocated as a sustainable urban practice. Flexibility applied to buildings leads to the concept of dynamic land use, defined in this study as modifications in building form, function, location and speed of change. Dynamic land use could be a way to achieve a smart and compact growth. However, the impact of a widespread application of dynamic land use on transport and accessibility remains unknown, as well as the required policies to respond to those impacts. This study applies scenario planning and transport modelling to explore the implications of dynamic land use for transport and spatial planning, using the city of Eindhoven, Netherlands, as case study. Results show that dynamic land use impacts are dominant on car and bike shares. Central areas are suitable for dynamic land use, as car congestion remains stable while bike share and accessibility increase. Policies could encourage dynamic land use and cycling in central areas, and upgrade road infrastructure in non-central areas.

Keywords Dynamic land use • Urban flexibility • Urban intensification • Transport planning • Spatial planning

1. Introduction

The urban agenda is demanding new approaches for urban development (United Nations, 2017; North, 2010; Brown, 2008; While et al., 2004). Cities maintain a fast pace of expansion in face of the sharp increase in urban population (Angel et al., 2011; Seto et al., 2012). Urban growth, increasing consumption patterns, urban expansion and pressure into the environment are central issues in current development practice (Dentinho, 2011; Bulkeley & Betsill, 2005; United Nations, 2005; Wittig et al., 2008; Klug and Hayashi, 2012; Gargiulo et al., 2012; Jenks & Burgess, 2000; United Nations, 2015).

The movement against urban sprawl in public and scientific debate has led to a general support for the smart growth concept, which aims to reduce the impacts of urban expansion without hampering economic development (Blair and Wellman, 2011; Handy, 2005; Song, 2005). Dierwechter (2017, p. 27) conceptualizes smart growth as a planning theory that advocates “shifting new development away from low-density residential and commercial sprawl into well-serviced cities and suburbs using tools like containment, mixed-use, transit and stronger regional coordination”.

The positive outcomes of a smart growth policy, however, are challenged by uncertainty. Continuous changes in economic standards, social preferences and technological developments have a strong impact on urban development and are difficult to plan and control (Lyons and Davidson, 2016; Marchau et al., 2013). In this context, urban flexibility has been recognized as
crucial to cope with uncertainty (Slaughter, 2001; Prato, 2007). Flexibility is becoming more achievable in the past decades with the advances in construction technology, e.g. modularity, prefabrication and modularization (World Economic Forum, 2016; Cowee & Schwehr, 2012; Brand, 1994).

The literature presents several studies regarding urban flexibility on an architectural and ecological perspective (Schut et al., 2015; Kronenburg, 2007; Slaughter, 2001; Tanner, 2014; Pickett et al., 2012; Pandit et al., 2017). The impacts of smart growth on transport are extensively covered (Escobar & Perez, 2017; Antoni et al., 2013; Ferreira and Batey, 2011; Naess et al., 2011). However, the combination of smart growth and urban flexibility has not been researched in a conceptual level or either on a transport perspective. Therefore, two research gaps can be identified: (1) how can urban flexibility and smart growth be integrated and (2) the impacts of such integration for transports.

This study aims to fill these gaps by exploring the concept of dynamic land use and its impacts on transports. The research question that then arises is:

“What are the implications of dynamic land use development for transport and spatial planning?”

2. Dynamic Land Use: definition

Urban flexibility applied as a means to achieve smart growth is what we call “Dynamic Land Use (DLU)”. Flexibility allows changes in form, use and location of buildings and urban areas which can be applied to intensify established urban areas. The DLU concept here applied is different from existing definitions in the literature, which describe the process of land use change over time (Gu et al., 2016; Aljoufie et al., 2013; Arsanjani, 2012).

DLU contains a space and a time dimension. Looking at the space dimension, dynamic land use modifies buildings and urban areas with respect to their form, function and location. Form modification refers to the change of building shape, e.g. the addition of floors on the top of existing buildings. Use modification refers to changes in building function, e.g. the transformation of a monofunctional to a mixed-use building. Location modification refers to the use of locations that are not conventionally used for development, e.g. free space on top of transport infrastructures. In a time dimension, DLU accelerates the speed of change from the existing state to a new state.

3. Method

The research aims to determine the implications of dynamic land use for transport and spatial planning. The concept of dynamic land use refers to changes in form, function and location, opening a broad range of combinations. The method of scenario planning is adopted to explore few indicative possibilities. A scenario describes a certain distribution of jobs and inhabitants reached as end state of a dynamic land use process. Four conceptual scenarios are based on two variables (randomness and magnitude) varying in two levels (large and small).

The distribution of jobs and inhabitants in each scenario is the input for the transport modeling stage. The transport model used is the Eindhoven Metropolitan Region transport model, which is an aggregate 4-step model containing car, cycling and public transport. The model outcomes are OD patterns, modal split, flows, travel costs and accessibility. After an analysis and
The indicator of spatial centrality is used to complement the spatial description of scenarios in addition to randomness and magnitude. Spatial centrality is calculated using the average distance of activities to the center (ADC) (Gordon and Bumsoo, 2015). In this study, the ADC measure is normalized using $S_0$ as a reference for the lowest centrality, since it develops only in urban edges. Therefore, the measure of Normalized Average Distance to Center (NADC) is applied, whose equation can be seen as follows.

$$NADC_n = 1 - \frac{\left[\sum_i e_i \frac{d_i}{E}\right] S_n}{\left[\sum_i e_i \frac{d_i}{E}\right] S_0}$$

Where NADC$_n$ is the normalized average distance to center for scenario n, based on the reference scenario $S_0$, $e_i$ is the number of jobs at zone i, $d_i$ is the distance of zone i to the inner-city centroid and E is the total metropolitan number of jobs. The measure ranges from 0, which entails low centrality, and 1, which entails high centrality.

Accessibility measures provide a joint indicator for transport costs and land use patterns. Accessibility can be defined as “the ease with which any land-use activity can be reached from a location using a particular transport system” (Geurs and van Wee, 2004, p. 128). The potential accessibility measure (PA) indicates the number of activities reachable discounted by transport costs. PA captures the effect of both transport network ($C_{ij}$) and spatial pattern ($D_j$), as shown on the formula below. In this study, activities are considered to be only jobs, therefore PA measures job accessibility.

$$PA_{iv} = \sum_{j \neq i} D_j \cdot e^{(\beta c_{ijv} + \beta_{ov})}$$

Where $PA_{iv}$ is a potential accessibility measure from zone i with mode v to all other zones j, $D_j$ is the number of jobs in zone j and $c_{ij}$ is the transport cost between zones i and j. The second measure is infrastructure-based accessibility (IBA). IBA is an inverse measure of generalized travel costs for each zone with a certain mode (used for example in Wang et al., 2018), therefore capturing only network effects ($C_{ij}$). The IBA indicator provides a bridge between transport results and potential accessibility results. The IBA formulation is as follows:

$$IBA_{iv} = \sum_{j \neq i} e^{(\beta c_{ijv} + \beta_{ov})}$$

Where $IBA_{iv}$ is the infrastructure-based accessibility measure for zone i and mode v, $\beta$ is the cost sensitivity parameter and $\beta_{ov}$ is the alternative specific parameter of cost sensitivity for mode v, having car as reference.

### 4. Scenario design

A zero scenario containing urban growth by expansion is compared with DLU scenarios containing intensification. DLU scenarios achieve a higher growth in the same period of time and locate growth on existing built areas. Growth rates for residents and jobs are assumed as 15% for the zero scenario and 25% for DLU (Table 1). DLU scenarios are defined by combining two levels of randomness (random and direct) and magnitude (small and large), leading to four scenarios.
Scenarios are denominated organic development (small and random), urban acupuncture (small and directed), powerful bottom up (large and random) and urban strategy (large and directed).

The zero scenario (traditional expansion) develops as fringe expansion, which is the usual form of urban growth. In the organic development scenario (S1), small dynamic developments occur dispersely in the territory, that targets individual homeowners or small local real estate developers. The urban acupuncture scenario (S2) uses small and medium developments to renew specific urban locations. In S3, development is random because actors lead the process instead of public policies, building mixed use complexes across the city. The urban strategy scenario (S4) has dynamic land use developments as a major urban planning strategy, in which comprehensive dynamic zones are defined by public planning with strict control on size and type of developments.

5. Analysis and results

The scoping of analysis and geographical references used for the presentation of results are firstly explained in the introduction of this section. In sequence, results are presented for spatial centrality, OD matrix, modal split, traffic flows, infrastructure-based accessibility (IBA) and potential accessibility (PA).

The trip analysis here performed focuses on internal trips within the city of Eindhoven only, in accordance to the same boundaries for the land use scenarios. However, traffic results do include through trips, external trips coming from outside Eindhoven and trips leaving Eindhoven towards external zones.. Furthermore, geographical references are used in the analysis for transport results (Figure 2). The first geographical reference is two city areas (inner city and outer ring), used for definition of trip directions, and the second geographical reference is the division of five city areas named according to cardinal directions, which is especially used for congestion analysis.

5.1. Spatial centrality

The normalized average distance for CBD was calculated for scenarios. The values are 0 for S0, 0.22 for S1, 0.56 for S2, 0.03 for S3 and 0.37 for S4. S2 has the highest spatial centrality followed by S4 and then S1, while S3 approached the largest possible concentration in urban edge, which is observed for S0. We can observe that directed scenarios have higher spatial centrality than random scenarios, which is embedded in the scenario design. However, there is a significant difference between spatial centrality in S2 and S4.

5.2. OD matrix and modal split

Trip distribution according to directions (based on the division of inner-city and outer ring) and modes is shown in Figure 3. The figure shows the absolute difference of trips between each of the DLU scenarios as S0. We can observe that results across DLU scenarios vary mainly for internal outer ring trips and internal inner-city trips. Internal trips to the outer ring are more numerous in random scenarios, while internal trips to the inner-city are more numerous in directed scenarios.

Looking at modal split, on average the largest share of trips is made by bike (55%), followed by car (40%) and public transport (5%). Bike share is higher for directed scenarios and car share is higher for random scenarios. In directed scenarios bike trips increased mainly in trips internal to the inner-city. PT ridership maintained the same share across scenarios, showing that PT seems to
Table 1. Growth rate and number of residents and jobs added per land use scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Growth (%)</th>
<th>Residents Added</th>
<th>Residents Total</th>
<th>Office jobs Added</th>
<th>Office jobs Total</th>
<th>Retail jobs Added</th>
<th>Retail jobs Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref. 2010</td>
<td>0</td>
<td>0</td>
<td>216,016</td>
<td>0</td>
<td>132,090</td>
<td>0</td>
<td>14,126</td>
</tr>
<tr>
<td>Zero (S0)</td>
<td>15</td>
<td>32,400</td>
<td>248,416</td>
<td>21,932</td>
<td>154,022</td>
<td>2,119</td>
<td>16,245</td>
</tr>
<tr>
<td>DLU (S1, S2, S3, S4)</td>
<td>25</td>
<td>54,000</td>
<td>270,016</td>
<td>36,554</td>
<td>168,644</td>
<td>3,531</td>
<td>17,657</td>
</tr>
</tbody>
</table>

Traditional expansion

Figure 1. Growth distributions per land use scenario.
be relatively insensitive to scenario variables.

5.3. Traffic flows

The relative distribution of car traffic for DLU scenarios in comparison to S0 is presented in Figure 4. The figure was obtained by comparing the volume-capacity ratio (v/c) of DLU scenarios to the v/c of S0. In this way we can observe more clearly the difference between scenarios. The blue bars show locations where traffic in S0 is higher, while red bars show locations where DLU is higher. We can observe that the blue bars are the same in the four maps, since development in S0 is concentrated in locations that did not receive comparable development in any DLU scenario. The red bars show that random scenarios have a spread traffic pattern while directed scenarios contain concentrated traffic. In the case of S2, traffic is concentrated in the inner-city and east area, having the east area larger traffic volumes. S4 showed traffic concentrated in the inner-city, W and SW areas.

Congestion levels are qualitatively evaluated in Table 2. Congestion in S0 is higher in location
Figure 4. V/c ratio difference between DLU scenarios and S0.

Table 2. Quantitative evaluation of congestion pattern.

<table>
<thead>
<tr>
<th>Area</th>
<th>S0</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner-city</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>N</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>W</td>
<td>+++</td>
<td>++</td>
<td>o</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>SW</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>SE</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>E</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
</tbody>
</table>

+++ Very high
++ High
+ Medium
o None
and size than DLU, because of the high density and low capacity of road infrastructure. We can see that most congestion locations are equal across DLU scenarios. Congestion locations show that all forms of developments are possible in the inner-city without generation of congestion. In the outer ring area, concentration of traffic is governed by the randomness variable. The level of congestion in those points increases proportionally to the magnitude variable, if at the outer ring area, but at the inner-city magnitude has no effect on congestion levels.

5.4. Accessibility

IBA results are shown on the two first rows of Figure 5. We can observe that car IBA is the highest for S0 followed by S2, then S1 and S3, and lastly S4. PT has better accessibility for the north center axis, where the largest bus line operates. The whole inner-city has a high accessibility level. For the other areas accessibility increases in a diffuse pattern. In case of bike, accessibility decreases in a clear radial pattern following the ring-radial structure of the city.

PA results can be seen in the three last rows in Figure 6. Based on the maps, we can observe that car PA is higher in all DLU scenarios in comparison to traditional expansion. The accessibility is higher in small scenarios (S1 and S2) than for large scenarios (S3 and S4). PT potential accessibility is slightly higher S2, but overall all DLU scenarios are similar. PT potential accessibility maintains the axis pattern (north-center line) observed in the IBA analysis. Bike PA, on the other hand, has a radial pattern. Looking at the net results from the three modes, we can see that car accessibility has the sharpest differences between scenarios, while PT accessibility is equal and bike follows the results of car accessibility in a shorter variation range. Therefore, car accessibility can represent accessibility across all modes.

6. Policy implications

The smart growth strategy aims to increase the share of PT and active modes, decrease congestion and increase accessibility (Duffhues and Bertolini, 2016; Handy, 2005). Transport and spatial planning could use DLU to contribute to these goals by applying the following policies. Policy 1 focus on spatial planning, Policy 2 on modal shares and Policy 3 on road infrastructure. Each policy is presented and followed by an explanation.

Policy 1: Concentrate dynamic land use in the inner-city area

Concentrating dynamic land use in the inner city area can be beneficial for congestion control and higher accessibility levels. As observed from Table 2, congestion did not increase at the inner-city for any of DLU scenarios, regardless of the amount of activities added. Scenarios with larger concentration had a higher shift to cycling, as seen on Figure 4. Potential accessibility was the highest for S2, as seen on Figure 6, which is the most centralized scenario.

Policy 2: Encourage cycling in the inner-city area

Bike share in the inner-city increased for directed scenarios. Given that the inner-city appears to be attractive for cycling when integrated to land use concentration, cycling policies can push for an even larger shift to cycling. However, the study shows no evidence that cycling policies
Figure 5. Accessibility results.

Infra-based accessibility (IBA)

PT* (left)
Bike* (right)

Potential accessibility (PA)

Car

S0 S1 S2 S3 S4

IBA
Very low
Low
Medium
High
Very high

PA
Very low
Low
Medium
High
Very high

* PT and bike have a single map because their assignment is uncongested.
in combination with a low land use concentration would be effective, as observed in the random scenarios.

**Policy 3: Upgrade road infrastructure located in outer ring areas**

As observed in Table 2, congestion is concentrated in outer ring areas. Figure 4 shows that traffic distribution follows the spatial distribution. In the case of directed scenarios, development locations are known. Two policies could be applied: (1) developments in outer ring areas can be located in areas with better infrastructure capacity, or (2) road infrastructure upgrade can take place where developments are expected. Therefore, directed scenarios demand an integrated transport and spatial planning. In the case of random scenarios, development locations are not known or known with a certain probability, and therefore the complete road infrastructure is considered for upgrade. With respect to magnitude of developments, larger developments would demand larger road infrastructure upgrade.

7. Conclusions and recommendations

DLU reduced congestion levels in comparison with traditional expansion. This is an unexpected result, as urban intensification policies are expected to increase congestion (Melia et al., 2011; Ferreira and Batey, 2011). Shift to bike and available infrastructure capacity were observed as the main factors for this result. By controlling congestion and increasing agglomeration of activities, DLU was able to improve potential accessibility. When looking at the spatial distribution of the most successful DLU scenarios, we can conclude that these benefits are closely connected to the centrality of spatial patterns. In other words, DLU in central areas is more beneficial than in the outer ring area. The results suggest that the benefits of centrality can hold when applied in other case studies, however with limited benefits in comparison to the results for Eindhoven since the city contains a ring-radial pattern that rewards developments in the central area.

Accessibility outcomes show, on the contrary of the expected, that random scenarios not always have lower accessibility than directed scenarios. The organic and uncontrolled form of development in S1 was able to provide a higher accessibility level in comparison to the direct scenario S4. However, accessibility in S1 relies mostly on car accessibility, which conflicts with sustainable development goals.

A substantial increase of bike share was observed for directed scenarios when development occurs in central areas. This result follows the expectation that concentrated land use can increase share of active modes (Naess et al., 2011; Duffhues and Bertolini, 2016; Hull, 2011; Banister, 2008). However, scenario S1 had a substantial amount of development in central areas, and however its bike shares decreased. A pitfall here exists to consider that any form of urban intensification policy will lead to an increase in active modes. S1 shows that a certain level of intensification must be reached so that bike effects can be observed, as argued by Naess et al. (2011).

The PT share was relatively constant across all scenarios, which suggests that the analysis carried might not have been able to capture effects on public transport. The scope of analysis for trips within Eindhoven might have played a role in this result, given that PT in Eindhoven has a more significant role in regional level. We expect that a regional analysis would increase PT share and accessibility particularly in the central area. Therefore, PT policies associated to DLU are a point for further research.
A crucial message that can be concluded from this research is that planning must acknowledge urban flexibility as relevant for future transport and spatial policies.

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