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## Journal of Land Use, Mobility and Environment

There are a number of different future-city visions being developed around the world at the moment: one of them is Smart Cities: ICT and big data availability may contribute to better understand and plan the city, improving efficiency, equity and quality of life. But these visions of utopia need an urgent reality check: this is one of the future challenges that Smart Cities have to face.

ENERGY, POLLUTION AND THE DEGRADATION OF THE URBAN ENVIRONMENT

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A RANDOM WALK DOWN
MAIN STREET

ABSTRACT

US suburbs have often been characterized by their relatively low walk accessibility compared to more urban environments, and US urban environments have been characterized by low walk accessibility compared to cities in other countries. Lower overall density in the suburbs implies that activities, if spread out, would have a greater distance between them. But why should activities be spread out instead of developed contiguously? This brief research note builds a positive model for the emergence of contiguous development along "Main Street" to illustrate the trade-offs that result in the built environment we observe. It then suggests some policy interventions to place a "thumb on the scale" to choose which parcels will develop in which sequence to achieve socially preferred outcomes.

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有关土地使用、交通和环境的杂志

摘要

美国郊区的特点通常是步行便利性不如更加城市化的环境，而美国城市环境的特点是步行便利性不如其它国家的城市。郊区较低的整体密度意味着，如果要分散进行开发活动的话，活动之间的距离将变得更大。但是，为什么要分散开发而不是进行相邻开发呢？这份简要研究笔记建立了一个针对"主干道"沿线出现的相邻开发的积极模型，从而阐明了造成我们观察到的建成环境的取舍。随后本文将建议进行一些政策干预，从而能"施加影响力"，选择将按照何种方式开发哪些地块，从而实现社会优先的结果。

沿主干道漫步

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1   INTRODUCTION

There are many definitions of "sprawl"; one common feature is the description of "leapfrog" development (Ewing et al., 2003, Galster et al., 2001, Gillham, 2002, Sutton, 2003, Whyte, 1958). Leapfrog development, named after the children's game, consists of pockets of development separated by green fields of undeveloped land. This occurs for a variety of reasons, some random, some to do with preferences for developers or future landowners for land which is adjacent to undeveloped parcels, giving the feeling of more space. In the case of commercial structures, Leapfrog and low density developments provide space for surface parking.

Leapfrog patterns are a temporary phase in process of land development, as the parcels that are leapt over are likely to be developed later as their value increases. But as a temporary phase, it may last a long time, depending on the pace of development and depending on the desire of developers (and their prospective customers) to maximize spaces between subdivisions.

One of the major costs associated with leapfrog development are the added costs of infrastructure provision. More infrastructure is required to connect the same number of people than in a compact arrangement. This has long been identified as a "cost of sprawl" (Harvey and Clark, 1965). Another major disadvantage that leapfrog developments poses is a reduction walk accessibility. Leapfrog development runs against preferences for more walk accessibility to destinations (shops, jobs, schools). Local accessibility is naturally hindered by leapfrog development patterns which increase the space (and thus distance) between development.

The past decade there has seen a resurgence in both the use and the study of alternative forms of transportation, including walking (as well as cycling, car sharing, and public transit, which have similar issues). Though walking is generally regarded as a distinct mode, it also forms an important component of trips made using other modes. This is most apparent in the case of public transit: before boarding and after alighting from a bus, streetcar, or train, every passenger is a pedestrian. For this reason, a deeper understanding of the spatial patterns of walk accessibility can also contribute to planning and research of public transit. Similarly, bike and car-sharing systems generally require walking trips to and from vehicle storage locations, and extended distances pose a disadvantage to bicycling compared to motorized transportation.

Imagine, for instance, trying to walk from Uptown (as shown in the southwest corner of 1) to Downtown (in the northeast corner of the Figure) in Minneapolis. While Uptown and Downtown are locally very walkable, one cannot easily or pleasantly travel between them on foot. In this case, the Lyndale/Hennepin/I-94 junction presents both a physical and a psychological barrier to walking trips due to the discontinuity of pedestrian infrastructure and the low quality of the environment for non-motorized travel. Even without that, however, once developed, now undeveloped surface parking lots create an unpleasant contiguous path on the south end of Downtown.

Even more than cities, suburbs have significant walk accessibility issues. As shown in Figure 2, the Arbor Lakes area of Maple Grove Minnesota has short areas of pleasant walking environment surrounded by surface parking lots. Barriers such as this are, in general, readily apparent when encountered by pedestrians. But because they are difficult to identify systematically and because no standards exist for evaluating their impacts, planning for pedestrian infrastructure is often difficult to justify in comparison to auto infrastructure, for which exists nearly a century of technical methodology and guidance.

Based on casual empiricism (anecdotal evidence), it seems that many US cities could be described as comprising islands of walk accessibility. 3 shows this for the Minneapolis-St. Paul region. While there are pleasant neighborhoods and districts to walk in, there are significant gaps of low walk accessibility that discourage walking between them. This would be even more apparent at the 5 minute or 2 minute level.

As part of a larger research project looking at the influence of site design in encouraging walking using pedestrian volume data from twelve neighborhoods around commercial centers in central Puget Sound region (Hess et al., 1999, Moudon et al., 1997), Hess (1997) used measures of street network connectivity to explain

the differences in pedestrian flows between neighborhoods in the Seattle area. In addition to typical measures, such as the amount of land devoted to right-of-way and walking environments, the length of the sidewalk systems and the amount of land devoted to automobiles, three measures were estimated to understand the street network characteristics. The first measure, called the pedestrian route directness, estimates the ratio of the pedestrian network distance to the straight line distance between the origin and destination. The walking shed or the walking distance contour used to identify the half-mile buffer around a place reachable by walk, is defined as the second measure. The final measure, named effective density, estimates the ratio of number of housing units within the walking shed divided by the area of the buffer.
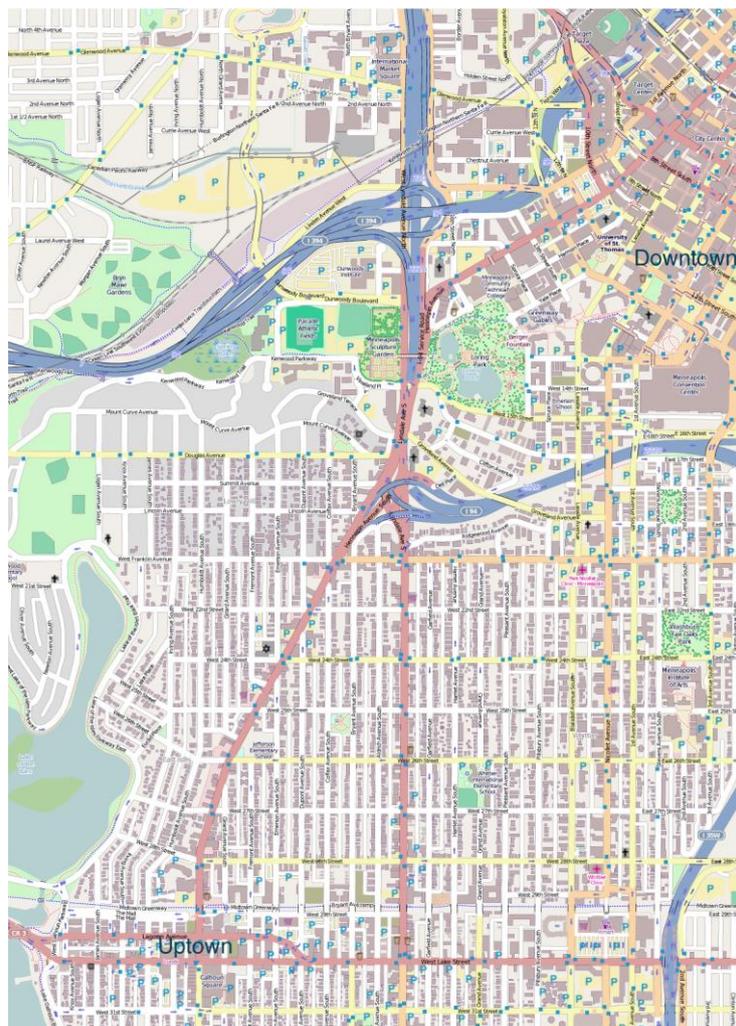
Fig. 1 Street and Building Map of Downtown to Uptown Minneapolis

Dill (2004) presented results from a research project evaluating various measures of network connectivity for the purposes of increasing walking and biking. The research objective was to identify connectivity measures used in various fields such as transportation, urban planning, landscape ecology and geography and evaluate these measures for their potential in promoting walking and biking.

Clearly connectivity is an important aspect of walk accessibility, but adjacent activity is also important, not just for generating demand, but for creating visual interest for those walking past. For instance, we might hypothesize that, all else equal, walkers prefer walking past something interesting than something barren, and thus, all else equal, interesting places will generate more pedestrians.

Though it is frequently discussed, specific definitions of "walkability" vary. There is general agreement, however, that walkability is fundamentally determined by two factors: the availability and quality of pedestrian infrastructure, and the qualities of the environment in which that infrastructure exists. It is intuitive that in isolation, neither of these factors is sufficient to create a fully walkable environment. Candidate variables include:

- Type of infrastructure (sidewalk, unpaved sidewalk, paved trail, unpaved trail, etc.)
- Condition of infrastructure
- Width, traffic volume, and speed of adjacent street, if any
- On-street and off-street parking
- Crash rates
- Roadway intersection geometry and signage
- Presence and type of traffic buffering (boulevard, parking lane, bike lane, etc)
- Tree canopy coverage
- Adjacency to water features
- Characteristics and condition of adjacent landscaping
- Qualities of and distance to adjacent building facade (setback)
- Type and variety of adjacent land uses (walk accessibility to destinations)
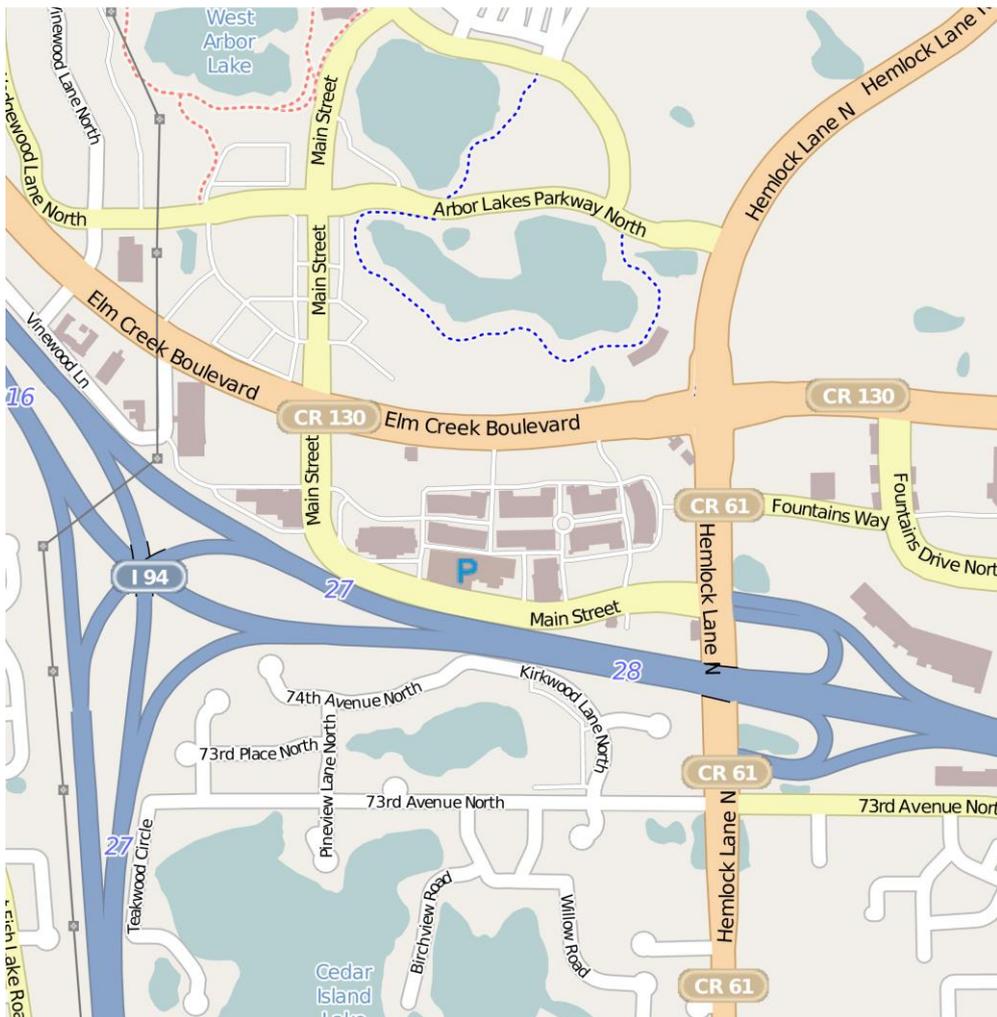
Fig. 2 Street and Building Map of Maple Grove

Considering all of these is the job of an empirical model. The conceptual model presented herein focuses on the last, can destinations be easily reached by walking? To be clear, walk accessibility is just one important aspect of what the literature refers to as walkability. There are many things that are close together, but unpleasant US suburbs have often been characterized by their relatively low walk accessibility compared to more urban environments, and US urban environments have been characterized by low walk accessibility compared to cities in other countries. Lower overall density in the suburbs implies that activities, if spread out, would have a greater distance between them. But why should activities be spread out instead of developed contiguously? This brief research note builds a quite simple model of Main Street to illustrate the trade-offs that result in the built environment we observe, and suggests some policy interventions to place "a thumb on the scale" of the decision about which parcels will develop in which sequence to achieve socially preferred outcomes.
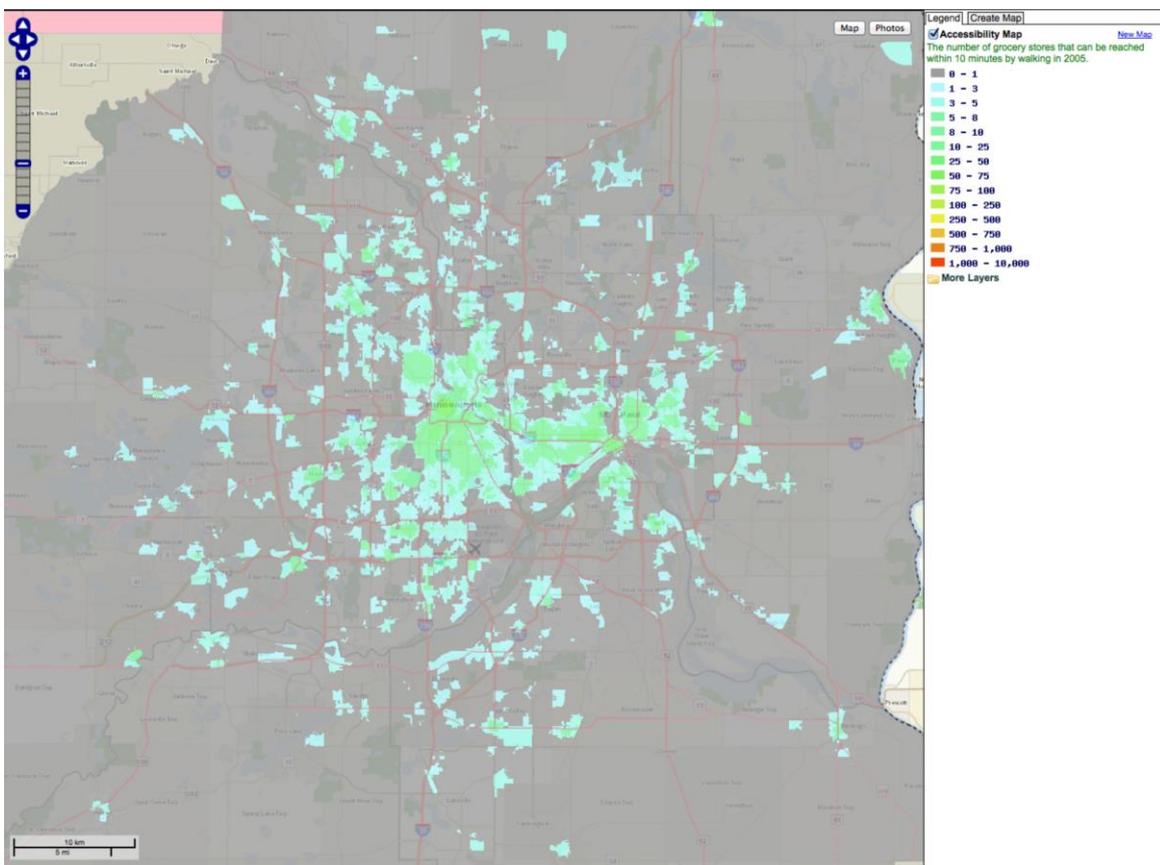
Fig. 3 10 minute Walk Accessibility to Grocery Stores in 2005. (Number of stores that can be reached in 10 minutes by Census Block)

2 MODEL OF MAIN STREET

We start with a linear model (Main Street). We have a community with 9 blocks strung out on a road (north to south). The center block has some exogenous regional accessibility advantage (it is a port, or has more direct access to a regional highway, or some other feature). Accessibility to the rest of the region (Ri) declines with distance from the center. Initially all blocks are undeveloped. Then blocks are developed in sequence. The model runs through the event where eventually all blocks are developed (the model is indifferent to the actual time this takes, only the sequence). In practice there may be long durations between developments (and though we will never see the end of time, there is no guarantee every block will eventually be developed). With long timespans between developments, determining contiguity over the sequence of development is that

much more important to understand the cumulative accessibility over long time spans. If adjacent blocks are developed, then they form a walkable cluster. If non-adjacent blocks are developed, pedestrians must walk at past at least 1 undeveloped block to reach the next development. A walk accessibility score is used which is based on the number of developed adjacent blocks. Simply put, when the market values walk accessibility (L_i) relatively highly compared to space (S_i), then developments will cluster immediately and all development will be in a walkable neighborhood. However when the market does not value walk accessibility, development will be haphazard, and high levels of walk accessibility will not emerge until a large fraction of blocks are developed. If costs of infrastructure (C_i) are relatively high, developers will similarly build contiguously, while if they are low (or borne by others), developers have less incentive to create continuous wholes. This model illustrates the kind of early stage suburban development in many outer ring suburbs. While many have walkable blocks, those blocks remain unconnected, separated either by undeveloped parcels or giant parking lots as an interim land use. The utility (U_i) of developing on a particular parcel is given by its benefits and costs:

$$U_i = \alpha \; R_i + \; \beta S_i + \gamma L_i - C_i + \epsilon$$

α is the value of regional accessibility (R_i), and is highest in the center and lowest at the edges.
β is the value of adjacency to empty space (S_i)
γ is the value of adjacency to neighbors (L_i), and is a measure of local accessibility
ϵ is an error term to account for misperception on the part of developers.
The market finances development in the block with the highest perceived utility $Max(U_i)$.

If infrastructure costs are borne by the developer, building adjacent to existing development minimizes the additional costs of infrastructure. In contrast, if infrastructure is built by the community in advance, this constraint on development is relaxed. If the developer's customers (future landowners) value being near their neighbors (either because they like other people, or because they like the amenities that are associated with other customers, e.g. shops, schools), that positively affects contiguity. In contrast, if future landowners prefer being away from neighbors, because they prefer to be near green space, or because they are simply anti-social, that negatively affects contiguity. While people certainly want to be near jobs and amenities (otherwise why would cities exist), there is evidence that people prefer space to being near neighbors. If people wanted to be near both people and jobs, cities would look like points, with no undeveloped space. This tension is what gives cities an interesting spatial configuration. The simulation applies a logit model of the Utility to each of the remaining available parcels (a Parcel Choice model), and uses a Monte Carlo process to randomly draw one parcel for that iteration. That parcel is developed, and the iteration in incremented. The process is repeated until all parcels are developed. Because in this simulation, $L_i = S_i$, without loss of generality, let $\beta = 0$. In the simulation, we set $\alpha = 1$. To simulate pre-provisioning of infrastructure, $C_i = 0$. Since regional accessibility varies only a little bit over the 4 block distance from the center of the region, the importance of R_i appears most significantly when breaking ties between which parcel to develop when local accessibility and adjacent space are otherwise near equal. In implementation, the error term is simply coded as a random number [0,1]. The error term breaks ties in an otherwise deterministic simulation (should the development occur north or south of Main Street, e.g.). The performance measure is walk accessibility which is defined as
Local accessibility for cell i is given by:

$$L_i = \sum_j O_j \, D_{ij}$$

where:
O_j = 1 if cell j is developed, 0 otherwise D_{ij} = 1 if cell j is within 2 cells of cell i in either direction, 0 otherwise.
The resulting overall time and person-weighted accessibility.

$$A = \sum_{t}\sum_{i}(L_i * O_i)$$

where:

t indicates the iteration round.

3   RESULTS

The results present 3 scenarios ɣ> 0, ɣ= -1, ɣ = -5 in Figure 4. The vertical-axis of the graph is space, with the center (highest regional accessibility point) denoted by 0, and other blocks denoted by number of streets north or south of the center of the town. The horizontal-axis of the graph is time. Each iteration is a round of development. One block is developed each round. Developed blocks are colored red (and have a 1 in them). Undeveloped blocks are colored white (and have a 0 in them).

0	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Iteration 7	Iteration 8	Iteration 9	Iteration 10
4	0	0	0	0	0	0	0	0	1	1
3	0	0	0	0	0	0	1	1	1	1
2	0	0	0	1	1	1	1	1	1	1
1	0	1	1	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	1	1	1
1	0	0	1	1	1	1	1	1	1	1
2	0	0	0	0	1	1	1	1	1	1
3	0	0	0	0	0	1	1	1	1	1
4	0	0	0	0	0	0	0	0	1	1

-1	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Iteration 7	Iteration 8	Iteration 9	Iteration 10
4	0	0	0	0	0	0	0	0	1	1
3	0	0	0	0	0	0	0	1	1	1
2	0	1	1	1	1	1	1	1	1	1
1	0	0	0	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	1	1	1	1	1	1
2	0	0	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	1	1	1	1
4	0	0	0	0	0	1	1	1	1	1

-5	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Iteration 7	Iteration 8	Iteration 9	Iteration 10
4	0	0	0	0	1	1	1	1	1	1
3	0	0	0	0	0	0	0	0	1	1
2	0	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	1	1	1	1	1
0	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	0	1	1	1	1
2	0	0	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0	1	1	1
4	0	0	0	1	1	1	1	1	1	1

Fig. 4 (a) Time-space diagram of Main Street, ɣ> 0. Minimally dispersed development path on Main Street. (b) Time-space diagram of Main Street, ɣ= -1. Mixed development path on Main Street. (c) Time-space diagram of Main Street, ɣ= -5. Maximally dispersed development path on Main Street

By iteration 9, all 9 blocks are developed in all 3 scenarios, and the communities are identical. However in the preceding years the development takes a different path to get there, meaning in the interim years, there are different levels of walk accessibility. For instance if one could walk 2 blocks in 5 minutes, how many of the blocks that you are on, and plus and minus 2 are developed (the operation definition of L_i). From the center block, scenario (a) minimally dispersed in the first iteration you can get to 1 block, the second iteration you can reach 2 blocks, and so on, until the fifth iteration when you can reach a maximum of 5 developed blocks. This is obviously lower at the edges of the developed area.

In contrast, for the maximally dispersed scenario (c), the first iteration still has accessibility of 1, the second iteration has an accessibility of 2, the third has an accessibility of 3, but the fourth still has an accessibility of

3, as does the fifth iteration. Finally in the sixth iteration the accessibility increases to 4 and the seventh it increases to 5. If we employ the idea of person and time-weighted accessibility summed for all developed cells (A), scenario (a) scores 212 while scenario (b) (mixed) scores 206 and scenario (c) scores 188. This 12 percent loss in accessibility may seem small. Clearly it varies by definitions and the spatial extent of the model, but it illustrates how non-contiguous development loses accessibility. When ɣ is strongly positive, local accessibility matters, and development is contiguous. When ɣ is strongly negative, local accessibility is a negative, people do not want to be near neighbors, and development follows a leapfrog pattern until contiguous development is required by land availability considerations. This begins to occur around the middle of the development pattern, as infill nearest to the center takes place first after the checkering pattern is played out. This transition from non-walkable to walkable is a phase shift, and takes several iterations to occur in this geometric configuration. When ɣ is near zero, a mixed pattern occurs.

4   DISCUSSION

We observe discontinuity in our urban environment. The model suggests that is a temporary (though perhaps long-lasting) stage of development which will be filled-in as demand for development increases (exogenously) while space remains finite. However, it also suggests that by increasing the costs of development (by charging development more for infrastructure), by increasing the value of local walk accessibility, or decreasing the preferences for space or parking, we will get a more contiguous built form from the outset.

There are several key points:

1. Pockets of development in places like Maple Grove indicate that individual developers are capable of creating pleasant small walkable places with fine grained streets. The resultant pattern indicates current rules and market preferences don't demand integrating these pockets to create larger walkable districts.

2. Contiguity is an important consideration. If everyone were driving, leapfrog development would not be a problem since there is a small fixed cost of getting in the car and a variable cost of driving. If you want people to walk, it is a problem, since the variable cost increases significantly with distance.

3. Pre-provisioning of infrastructure enables development to occur with more or less equal probability anywhere within the town in the absence of a preference for walk accessibility over space. Were road construction the responsibility of developers, to ensure connectivity, developers would build in a more contiguous fashion.

4. Depending on the rate of development (until all blocks are developed), the town may remain far less walkable if walk access is not valued by the market, or required by the town, until it nears completion.

5. How to ensure walk accessibility in a decentralized piecemeal development process (so it does not take 30 years to complete) is not obvious, but is important. This is where some type of planning is important, either on the part of the master developers who control everything, or the government, or a negotiated compact between the individual property owners. Suppose the individual developers pooled their land and the profits in a joint venture, would the planning outcome have been better?

6. To help avoid discontinuous development, communities can either put the cost of infrastructure back on the developers of parcels, or attempt to regulate not only final densities but also interim sequencing or staging of development. This is particularly relevant when the city-building process is slow, and a lot of land has been devoted to potential future development.

We can think of the transformation from unworkable leapfrog style development to contiguous development as a phase shift. If leapfrog development is preferred early on, (due to preferences for space outweighing preferences for walk accessibility), development is disconnected. But as developments are added, the parcels congeal into an interconnected urban fabric.

There are many directions to extend this model. Thus far, walk accessibility is only considered for adjacent parcels, but one could certainly consider walking to farther parcels, which might enable consideration of a positive feedback system where walk accessibility begets more walk accessibility. (This would especially be valuable on a longer Main Street. We could extend it to a second dimension (east-west as well as north-south) which would enable a richer consideration of neighborhoods. We could consider not simply binary coverage of a block (developed/undeveloped), but consider percentages of development, or allow for varying densities. We could develop trade-off curves between cost, contiguity, and space. But every complication makes the model harder to comprehend, and needs to be justified for some gain in understanding.

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IMAGE SOURCES

Fig. 1, 2: Open- StreetMap.

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