Article

B Planning and Design

Environment and Planning B:
Planning and Design
0(0) 1–22

DOI: 10.1177/0265813516671311
epb.sagepub.com
SAGE

Assessing innovation: Dynamics of high-rise development in an Israeli city

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Abstract

Urban models serve as laboratories, providing researchers with the opportunity to assess the impact of a wide range of social and economic processes on the development of a built environment. Novelty and unexpected changes play an essential role in this development, but these are difficult to formalize and imitate. Typically, urban models simulate innovation by introducing stochastic fluctuations of the pre-established development rules.

This research offers a methodology for assessing innovation in a developing city and examining its impact on urban development. The methodology is implemented in the Israeli city of Netanya, where urban development is analyzed at a resolution of single buildings over a period of three decades.

We recognize two types of innovation: spatial innovation, manifested by leapfrogging residential clusters that establish new development areas; and contextual innovation, manifested by residential clusters that include buildings that are substantially higher than their surroundings. We demonstrate the impact of few innovative residential clusters on urban development in the following decades and highlight the diffusion of innovation in the city.

Keywords

Built environment, urban dynamics, urban simulation, development process, self-organization

Introduction

Can we predict how a city will grow? That is to say, can we foresee in which direction it will expand; what will be the next site to develop; and what type of buildings will be constructed? Theoretical insights and sophisticated modeling tools can be employed to try to answer these questions and to understand the nature of urban growth and the factors affecting it, both in principle and in reality. However, one factor is seldom taken into account—possibly because it fundamentally challenges the idea of modeling—and that is the degree to which a city can

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be innovative. And if so, what is the role of novelty and unexpected change in the development of an urban environment. Cities are assumed to be focal points for social, economic, and cultural innovation (Knudsen et al., 2008); however, there are inherent problems when dealing with the concept of innovation in urban models. Models are inherently limited in their ability to incorporate unexpected development simply because it is unexpected.

The main focus of this research is to evaluate the role of innovation in the ''regular'' development of a built environment, in order to assess the importance of incorporating this attribute in urban models. We consider innovation in one of the major physical components of the city: buildings. Innovation comes in various forms: in the type of building (internal and external design, apartment size, building height); in the type of urban environment (inner city, suburban); and in the type of development (individual buildings, whole neighborhoods).

Models are limited in relation to innovation: they are bound by pre-set rules and forced to assume that innovation is linked to stochastic deviation or, at least, to the ''rule of modifying/breaking-the-rule''. In this paper, we wish to examine the existence of building-related innovation, far from the hub of urban entrepreneurship, where it is least expected; and we establish if it is a significant trait of urban development or if it should be set aside, as often happens in Cellular Automata (CA) and Agent-Based Models (ABM) of cities.

This research investigates the dynamics of residential development in the Israeli city of Netanya, located in the outer ring of the Tel Aviv Metropolitan Area, during the time period 1983–2010. Netanya was chosen for two significant qualities. First, it is outside the metropolitan core and is the image of a stable residential city. As such, it is not attractive to developers interested in experimental innovation and entrepreneurial risk-taking. Rather, the type of development that takes place in the city is adaptation continuation of existing fashions and tested trends. Second, being part of the rapidly increasing metropolitan area, Netanya has been growing immensely over the last three decades, mainly with the development of new residential neighborhoods. Over the years and in accordance with residential development in the Tel Aviv Metropolitan Area, more and more residential developments in Netanya are high-rise buildings. This trend peaked in 2014 when more apartments in the city were being built in high-rise residential buildings (15 floors and up) than any other city in Israel (ICBS, 2015). Therefore, development in Netanya can be described as ''regular'' and, at the same time, it provides an opportunity to track occurrences of innovation in a city that has had considerable growth of the built area.

We analyze the built environment of Netanya from aerial photos and a high-resolution urban GIS database. Based on the empirical results, we present the characteristics of residential dynamics in the city, and explore the role of innovation in residential development. We focus on the relationship between new residential developments and the buildings that surround them. Quantitatively, we analyze the size and location of new development sites in regard to existing built-up areas, and the relation between the height of new and existing buildings. Based on these comparisons, we identify innovative individual buildings and clusters of buildings. We explore innovation diffusion and the overall impact on the development of the city.

From description of structure to dynamics of urban development

Classical models of urban development assume that the spatial structure of cities is an outcome of economic decisions of households that act to maximize their utility. According to Alonso's Bid Rent theory, households locate themselves at a certain distance from the central business district (CBD) based on the utility they receive from the land and other consumer goods within their budget constraints (Alonso, 1964). Land-use prices are described by bid-rent curves, which decrease away from the CBD. Distance from the CBD results in increasing transportation costs that affect the utility of the bidders. The outcome is a spatial structure of concentric land-use rings that reflects the sensitivity of each land-use to the transportation costs. The Muth-Mills housing model expands on the Alonso model to account for density at each location (by introducing a developer who decides the structural density of development) in addition to the rent gradients (Mills, 1967).

Unlike the static Alonso-Muth-Mills model that assumes that the city pattern is always in an equilibrium state, complexity theory sees the city as an ever-developing system (Batty, 2001). Haken's theory of synergetics and Prigogine's theory of dissipative structures were influential in relating to cities as self-organizing systems that emerge from the bottom-up (Portugali, 1997). Urban models demonstrate processes such as bifurcation points, structure emergence, and path dependence in the process of urban development (Allen, 1997; Clarke and Wilson, 1983; Dendrinos, 1992; Portugali and Benenson, 1995); and they relate between micro-interactions of urban agents and components with macro structures that emerge in the city.

CA and ABM became major tools for modeling urban dynamics in the late 1990s. From the very beginning, they were used for simulating the evolving urban landscape as an outcome of locally interacting human agents and infrastructure elements, and to test theories and ideas about the bottom-up emergence of cities. These models are used as experimental laboratories for testing ideas about cities, and are employed to investigate scenarios and perform predictions of urban development in real-world cities (Batty and Xie, 1997; Clarke et al., 1997; de Almeida et al., 2003; Engelen et al., 2002; Itami, 1994; Miller et al., 2004; Silva and Clarke, 2002). Urban CA and ABM demonstrate that similar patterns and, to some extent, predictions of real urban development can be modeled, and therefore corroborate the theory of the city as a complex self-organizing system (Batty, 2008).

Complexity theory considers the spatial pattern of the system as a self-organizing outcome of local interactions between multiple entities that occurs under the influence of global factors (Pascual et al., 2002). Applying this view to the city, we consider the urban built-up pattern as a result of the interaction between multiple independent developers who respond to urban patterns, population and economic demands, and planning limitations. Urban developers lessen their risks by building in areas that are already developed and established, and by replicating existing building styles. Since most developers adopt this approach, competition is harsh. To survive and succeed, developers are obliged to accumulate experience and to try *to foresee the future*, as the profits of their current decisions will be realized only several years later. Therefore, they tend to compare the utility of the development alternatives and choose their next construction sites based, not only on the current behavior of other developers, but also on the anticipated influence of present development on the decisions of others. This view opens the door for innovation: a developer decides to break away from the current trends, by either building far from the currently developed areas or introducing a new form of building that is different from its surroundings.

A remark on self-organization of the built area

The city is a complex system comprised of numerous infrastructure elements—commercial, industrial and residential buildings, roads, electricity, water, sewage and phone networks, parks, parking lots, and public spaces—all interrelated in functionality and location. Though most cities incorporate a plan that regulates city development, the actual implementation of the plan is in the hands of public and private development firms and private individuals who, without central coordination, determine the location, timing, and form of construction. As recent research in the field of urban and regional planning shows (Alfasi et al., 2012; Buitelaar et al., 2011; York et al., 2014; Zhong et al., 2014), comprehensive land-use plans are far from being effective in terms of coercing development patterns. Moreover, flexibility tools enabling bottom-up planning and development are becoming more common (Gielen and Tasan-Kok, 2010; Tasan-Kok, 2008), which means that case-by-case decision making, rather than comprehensive planning, affects the development of a city.

When considering a potential site for development, developers evaluate the existing state of the city while taking into consideration the implications of actions made by other developers who are operating alongside them. This interaction results in an ongoing feedback process between the developers' behavior and the city's dynamics. The collective actions of developers change the state of the city, and the emerging city pattern determines conditions for future developments. Through this feedback process the city self-organizes itself.

While ultimately shaping the global structure of the city, each developer operates within a local orientation. The decision of where to locate a development site is mainly related to the current and anticipated state of a site's surrounding area—the neighborhood. Therefore, the city as a whole develops from the bottom-up. According to this outlook, the emergence of a new, self-organizing order can be characterized by observing the spatial diffusion of form, such as height, style and design of buildings, among development sites.

One of the tools used here to characterize development sites is the power law, usually an indicator of the scaling behavior of complex, self-organizing systems (Marković and Gros, 2014). The power law was first recognized for the relation between the number of cities (y) and population size (p): $y = A^{*}p^{-\alpha}$, where A is a constant defined by the size of the largest city (Auerbach, 1913). Zipf (1949) found that the population (P_i) of a city and its rank (R_i) within cities ordered by population size can also be described by the power law: $P_i = P_1/R_i^{\alpha}$, where P_1 is the population of the largest city. The values of the α exponent for the relation between the size of the city and its rank were evaluated in different countries around the world, showing that α is usually close to 1 (0.7–1.3) with small variations between countries (Pumain, 2004; Rosen and Resnick, 1980). Several explanations were offered for the power law scaling of systems (e.g. see the most popular Gabaix (1999) model of larger cities growing disproportionally fast), but none was fully adopted by researchers. The existence of the power law dependency between size and rank of elements in social systems is often considered as a signature of self-organization (Batty, 2008; Stephen and Dixon, 2009); and we accept this hypothesis. While the power law is mostly studied for systems of cities, few studies indicate that it is also valid on the inter-city scale (Chen and Wang, 2014; Fragkias and Seto, 2009). In this study, we support this claim by showing that the size distribution of the newly developed residential sites follows the power law in each of the three decades investigated.

Research area and methodology

Research area—Netanya

Founded in 1929, Netanya is situated in Israel's central district along the Mediterranean coastline, about 30 km north of the Municipality of Tel Aviv and as part of the outer ring of the Tel Aviv Metropolitan Area. It is the 8th largest city in Israel, with a municipal area of 2895 ha and a population of 189,000 residents. Since 1980, the city population has almost

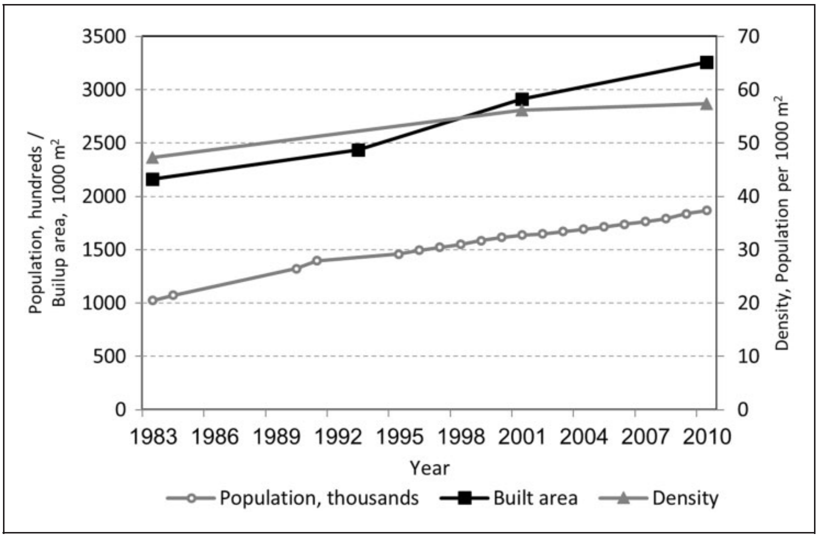

Figure 1. The dynamics of population, built-up area and density in Netanya, 1983–2010.

doubled and the built-up area increased by more than 60% (Figure 1), much of which is due to a large wave of immigration to Israel during the 1990s. Private developers are responsible for 95% of residential development in Netanya.

Over the years, Netanya's skyline has changed and high-rise buildings with more than 15 floors have become the primary type of residential development (Frenkel, 2007). The peak of this type of development was in 2014 when 2443 apartments were being developed in high-rise buildings (Figure 2). This comprised 70% of total residential development in Netanya—more than any other city in Israel (ICBS, 2015).

In addition, new residential neighborhoods emerged outside the existing built area, which expanded the city substantially (Figure 3).

Methodology

Aerial photos of the city of Netanya from 1983, 1993, 2001, and 2010 were used to monitor urban development. The aerial photos were geo-referenced and combined with GIS vector layers of the building footprints from 1995 and 2010. Using the vector layer of the building footprints in 1995 superimposed on the aerial photos taken in 1983 and 1993, we created two additional vector layers that represent building footprints in 1983 and 1993. To do this, we geo-referenced aerial photos, and then manually tested whether buildings that existed in 1995 are presented in the aerial photos of 1993 and 1983. Buildings that did not appear were deleted from the corresponding layers.

Our database, thus, includes four vector layers of building footprints, representing the built area of Netanya in 1983, 1993, 2001, and 2010. The layers include data on the period of buildings' construction, building type and height. These layers were examined using several methods of GIS analysis to describe the dynamics of residential development, which is analyzed based on individual buildings and clusters of continuous development (Fragkias and Seto, 2009).

We investigate development dynamics according to two aspects: the location of new residential development in relation to the existing and newly constructed built-up areas;

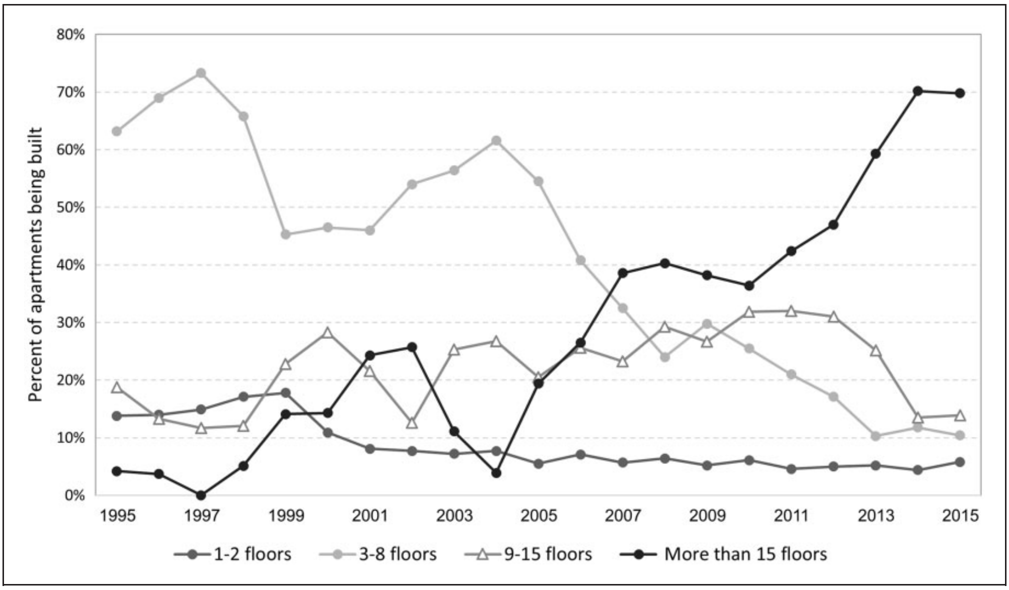

Figure 2. The dynamics of residential construction by building height in Netanya (ICBS, 2015).

and the similarity of the new development, in terms of building height, to existing and newly constructed built-up area. We aim to describe and explore the process of spatial diffusion of height in the city and to evaluate the impact of new innovative buildings, in terms of height, on the future development of the city.

Our data include individual buildings with no specific information on the residential projects with which they are associated. Therefore, we rely on the adjacency between buildings developed in the same period; and we assume that observed clusters of residential development represent projects that were planned as a single continuous entity.

Clusters of residential development are identified for each period as follows: We consider all residential buildings constructed in a given period, build a 30-m buffer around each, and unite overlapping buffers. The resulting continuous parts are defined as clusters of residential development.

The 30-m buffer around a building is based on the average distance between adjacent buildings in Netanya's residential neighborhoods. Note that the maximal distance between buildings within a development cluster is 60 m. This is also the minimal distance between buildings in two different clusters.

Spatial location relative to the built area: we classify the development clusters of a certain period according to their location relative to the existing buildup area[1] at the beginning of the period. Classification includes three categories:

(1) ***Completely inside***—Cluster area completely overlaps with the built-up area.
(2) ***On the fringe***—Cluster area partially overlaps with the built-up area and extends beyond it.
(3) ***Completely outside***—Cluster area is fully outside the built-up area.

Cluster's height characteristics: we characterize clusters of development by their maximal height which is defined as the height of the highest building in the cluster. Since we assume that the cluster was planned as a single project, the highest building is representative of the maximal height the planner/developer saw fit for the area. A building's height is defined by

Figure 3. Urban development in Netanya, 1983–2010.

number of floors. The cluster's maximal height is compared to other clusters and individual buildings in the city to determine whether they are similar or different.

Height similarity: Cluster/Building X is classified as similar in height to cluster/building Y if their height difference does not exceed a third of the height of building Y.

Results

Power law distribution of a cluster size as a sign of self-organization

To characterize the dynamics of development in Netanya, we ranked, for each period, the development clusters according to their area (A) and constructed the log-log relationship between the area (A_i) of the cluster (i) and its rank (R_i). As can be seen in Figure 4, this

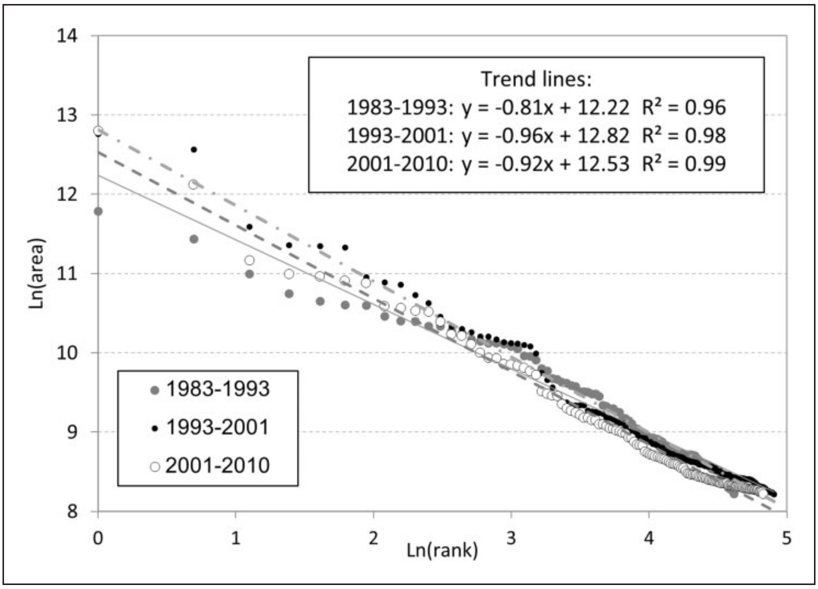

Figure 4. Rank-size log-log scatterplot of residential development clusters, by development periods.

relationship is close to linear for each of the three investigated periods, with the power law exponent 0.81, 0.96, 0.92 for the clusters of buildings constructed between 1983–1993, 1993–2001, and 2001–2010, respectively. In all three periods, the estimate exponent is significantly lower than 1 at $p < 0.001$.[2] We consider this as a confirmation of the self-organization of the residential clusters during each period.

Note that, in accordance with the power law, an essential portion of the developed area is covered by a few large development clusters. In 1983–1993, the 10 largest development clusters comprised 36% of the total development and in 1993–2001 and 2001–2010 they comprised 50%.

Location of development clusters relative to the previous built-up area

As can be seen in Figures 5 and 6, most residential development takes place on the fringe of the built area. Development clusters on the fringe comprise, depending on the period, 65–75% of all development.

The average size of the clusters located on the fringe is larger than the average size of the clusters located completely inside or outside the built-up area (Figure 7). During 1993–2001, the average area of clusters located on the fringe grew to 3.8 ha, twice as much as the cluster area of the previous time period 1983–1993. Then it declined to 3 ha in 2001–2010.

Clusters inside the built-up area comprise, depending on the period, 20–32% of total development (Figure 6). Their average size is the lowest compared to clusters located on the fringe and outside the built-up area and they get smaller in time—0.9 ha during 1983–1993, and 0.6 ha during 2001–2010. Clusters outside the built-up area comprise the smallest portion of total development, 3–14% (Figure 6). However, on average, they are larger than the clusters in the built-up area. The average area of clusters outside the built-up area remains 1.3 and 1.0 ha during the first two development periods, and grows to 2 ha during the second.

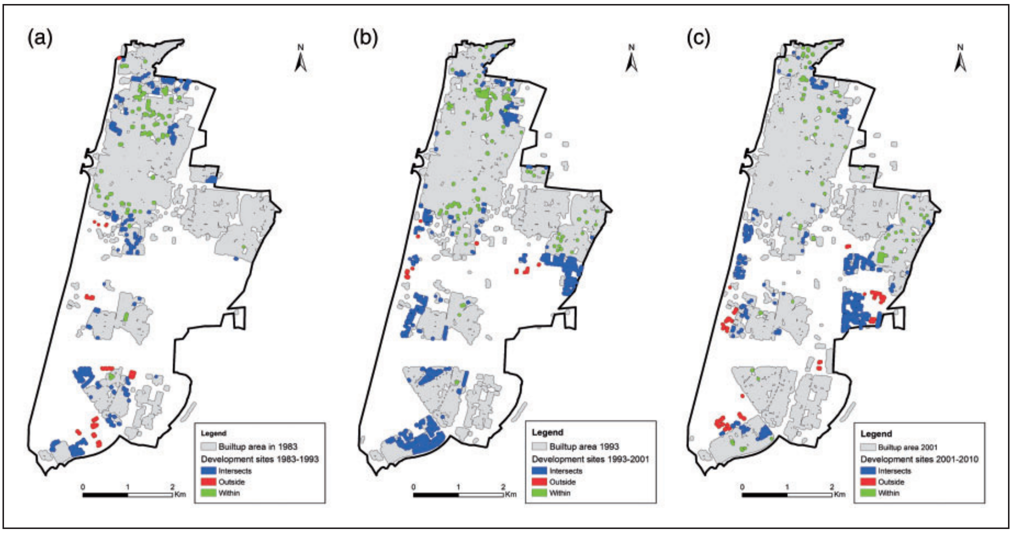

Figure 5. Location of residential development clusters relative to the built-up area, by development period: (a) 1983–1993, (b) 1993–2001, and (c) 2001–2011.

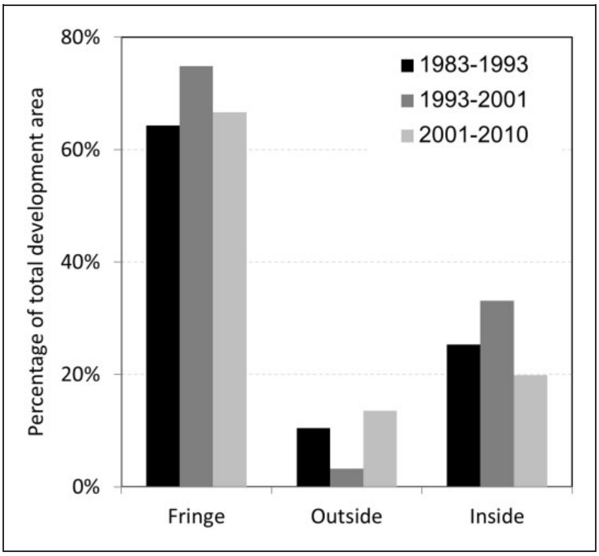

Figure 6. Fraction of the total area developed during a period according to location relative to the existing built-up area at the beginning of a period.

Maximal height of development clusters. The maximal height of buildings in development clusters, which defines the maximal height of the clusters, changes throughout the research period in two opposing ways. On the one hand, the number of clusters with the maximal height of more than 13 floors almost doubled, growing from 6% in 1983–1993 and 1993–2001 to 11% in 2001–2010. On the other hand, the number of development clusters

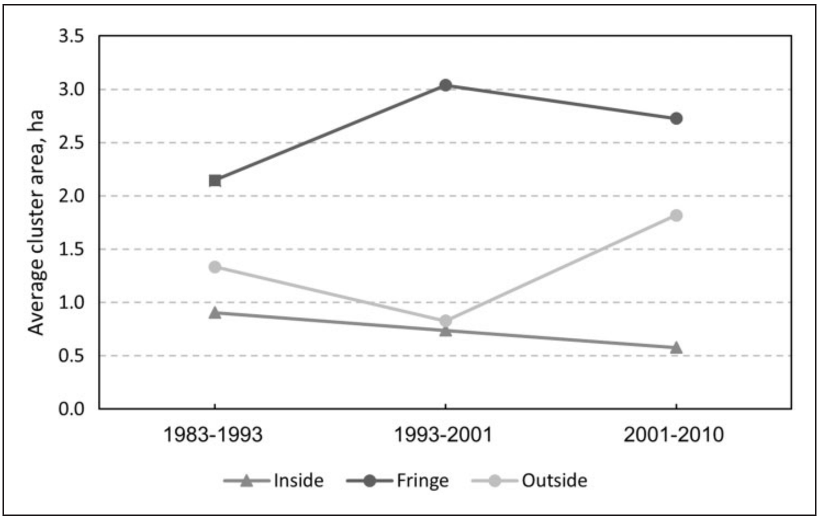

Figure 7. Average area of residential development cluster by location, for each development period.

with maximal height of 1-2 floors consistently grew during the periods. During 1983–1993, only 11% of all clusters had a maximal height of 1–2 floors, while in the following periods they comprise 28% and then 40% of all development clusters.

We consider the shift from mid-height construction to high-rise and low-rise buildings as a reflection of the suburbanization of Netanya, occurring as a result of its location in the outer ring of Tel-Aviv Metropolitan Area, and signifying the emergence of a new type of suburb, one that is made up of high-rise buildings alongside single-family low-rise housing. This suburban pattern of "towers in the park" is evident throughout the Tel Aviv Metropolitan Area (Mandelbaum, 2015), and the evolution of this pattern is clear in Netanya. In the section that follows, we investigate high-rise clusters. We analyze their spatial dynamics on a local scale and track the emergence and entrenchment of this spatial pattern.

Leapfrogging: Expanding the built-up area

Development clusters located completely outside the previously built-up area can be considered as a type of spatial innovation in the development of a city, as they leapfrog beyond the existing built-up borders and determine new paths for urban expansion.

Innovative leapfrog development does not follow a constant trend over the years. Although leapfrogging clusters constantly stretch further (out of the existing built-up area) and comprise larger parts of developments, they present a wave-like behavior: the city expands outwards during 1983–1993, then retreats during 1993–2001, and then expands further outwards during 2001–2010 (Table 1).

We found no significant correlation between the size of the development cluster and the distance from the built-up area (Figure 8).

Most leapfrog clusters are located up to 250 m from the build-up area, only six leapfrogged to a longer distance. The most distant outside clusters are observed in 2001–2010, when the average size of the leapfrogged clusters is also the largest of the three periods (Figure 8).

Table 1. Distance to the built-up area for construction clusters located completely outside the built-up area.

Development period	1983–1993	1993–2001	2001–2010
Number of clusters outside the built-up area	12	9	15
Average distance to the built-up area (m)	158	122	163
Maximum distance to the built-up area (m)	483	250	615
Minimum distance to the built-up area (m)	9	17	2

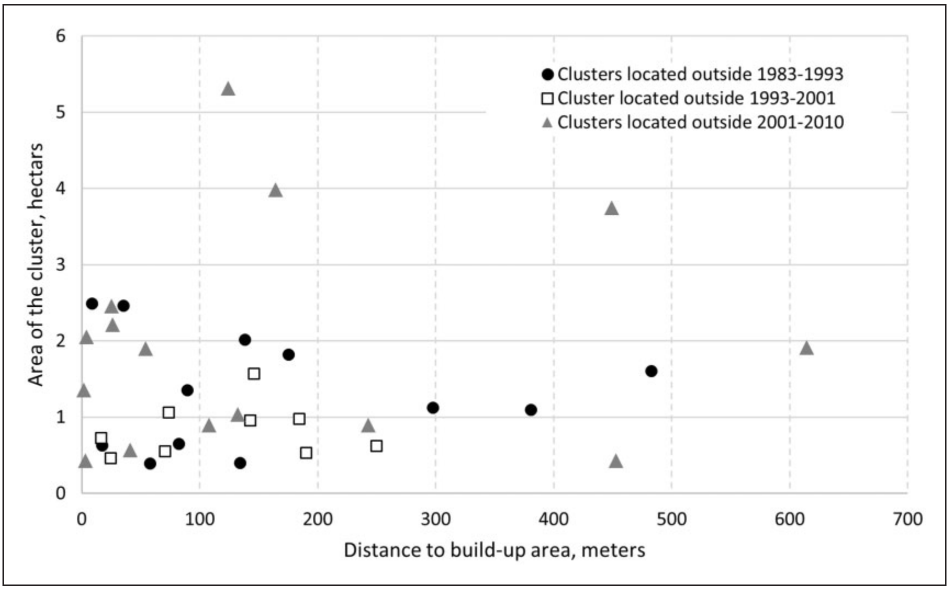

Figure 8. Size of leapfrogged clusters versus distance from the built-up area, by development period.

To determine whether the clusters that were developed outside the build-up area attracted more development in the next development periods, we measure the number of clusters developed at a distance of up to 250 m around each of the clusters during the periods that follow. All clusters developed outside the build-up area during 1983–1993 had residential clusters that were developed in their vicinity (a radius of 250 m) in the two periods that follow (1993–2001 and 2001–2010). Three of the outside clusters had between 3 and 5 residential clusters developed in close vicinity, while the other nine had between 6 and 9 residential clusters. The average distance of the new development to the closest cluster was 40 m, and most outside clusters had a residential cluster that developed directly next to them.

As for the clusters developed outside the built-up area in 1993–2001, all had a residential cluster that developed attached to them in the period that followed.

Three of them had between 1 and 2 residential clusters developed in their vicinity in the period that followed (2001–2010) and seven clusters had between 3 and 5 residential clusters.

This analysis shows that leapfrog residential clusters serve as a new attraction for further development.

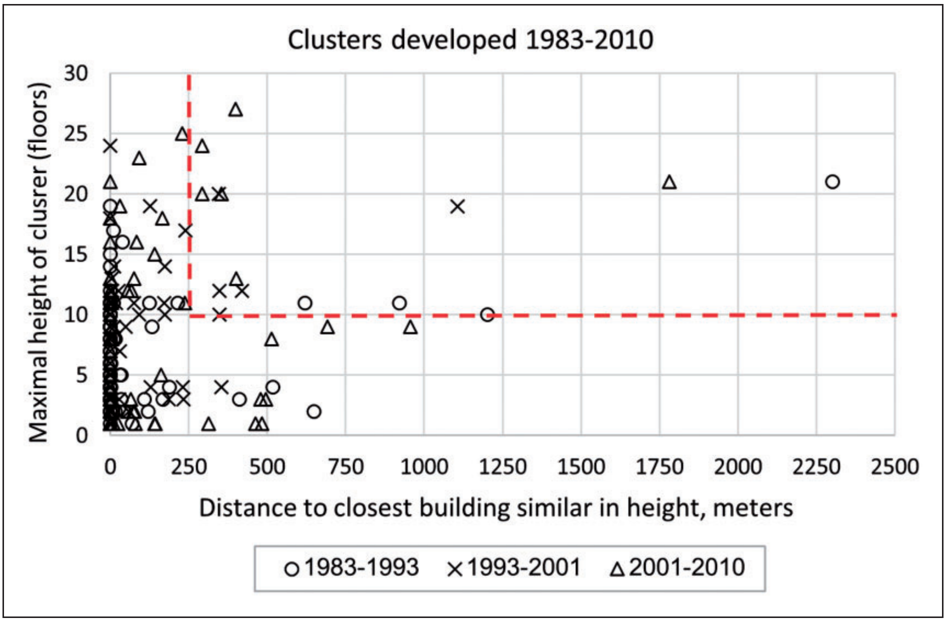

Figure 9. Distance between a cluster and the closest building of similar height that exists at the beginning of the period. The red dashed line marks a distance of 250 m and a height of 10 floors.

Bringing the message of height to new places

We broadly define innovation as a certain characteristic that is introduced into an area in the city where it had not existed before. We name this contextual innovation, and it is added to the spatial innovation presented by leapfrogging. The characteristic we consider in this paper is building height and in what follows, we estimate the degree of innovation of a development cluster according to the distance between the development cluster and the closest similar building (in terms of height) that existed at the beginning of a period (Figure 9). If this distance is small, then the cluster continues the height tendency that already exists in a given area, and therefore the development is not innovative. However, if the distance is large, then the development cluster establishes a new height tendency and can be considered innovative, meaning it is the first to introduce high-rise buildings to its vicinity.

A cluster is classified as innovative if it satisfies two conditions:

(1) The cluster's maximal height is 10 floors or more. Such height represents the upper decile of height for all buildings developed between 1983 and 2010.
(2) The closest building with a similar height to the cluster's maximal height is at a distance of 250 m or more. Such distance is the upper decile of the shortest distance to a similar building among all development clusters for all periods.

Figure 9 presents the characteristics of height and shortest distance to similar buildings for all development clusters. The red dash lines mark the threshold values for innovative clusters, and the clusters that satisfy those thresholds are defined as innovative (Figure 9 and Table 2).

Table 2. Clusters' statistics.

Development period	Number of clusters	Innovative clusters
1983–1993	100	4 (4%)
1993–2001	132	5 (4%)
2001–2010	129	6 (4.5%)

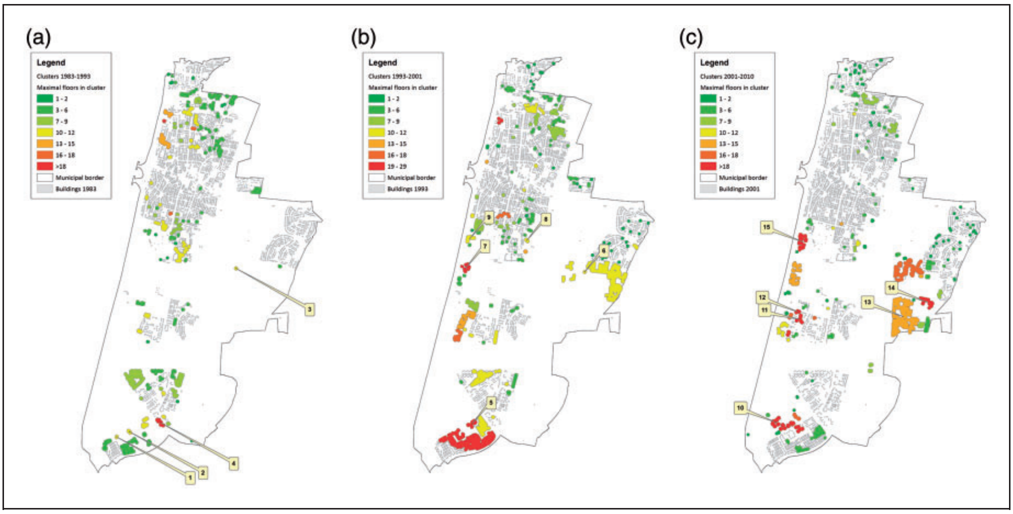

Figure 10. Netanya residential development clusters by period: 1983–1993 (a), 1993–2001 (b) and 2001–2010 (c). The colors of the clusters mark the maximal building height in the cluster (in floors). Innovative clusters are labeled with the number that matches their number in Table 3.

Not surprisingly, height-innovative clusters are few. Throughout the research time (1983–2010), only 27 out of 361 (7.5%) clusters were developed at a distance of more than 250 m from a building of similar height that existed in the vicinity before development and only 15 (4%) included buildings of 10 floors and more (Figure 10). This shows that new development clusters tend to conform to the existing built environment and, more particularly, to imitate building height existing in the vicinity. Most of the city's development took place in this manner, as new residential clusters perpetuated the existing built environment and replicated the height of existing building in the area. Thus, for most of the built area, new high-rise buildings rose steadily from one period to the next.

Few clusters are identified as contextually innovative, when we look at their locations (Figure 10) and attributes (Table 3). The location of the innovative clusters on the map showed that, in fact, the scale of innovation was even smaller than the one reflected from counting the clusters.

In the first period (1983–1993), where only four innovative clusters were registered, we found that three of them (clusters 1, 2, 4, Table 3 and Figure 10) were in fact a fraction of a single plan, dedicated to enlarging Ramat Poleg, a well-established neighborhood of single-family homes located at the southern end of Netanya. While most of the extensive development of Ramat Poleg was conducted by similar low-rise homes, few high-rise buildings were located there. Each of the innovative clusters there is comprised of 1–2

Table 3. Characteristics of innovative clusters.

#	Area (m^2)	Highest building in the cluster, floors	No. of building in the cluster	No. of buildings in the cluster similar in height to the highest building	Distance to closest building[a] similar in height located outside the cluster (m)	Distance to closest cluster[b] similar in height (m)	Location relative to the built area
Innovative clusters 1983–1993							
1	6917	11	2	2	922	219	Outside
2	11,192	11	2	2	621	219	Outside
3	26,331	21	6	3	2301	4741	Fringe
4	6270	10	1	1	1202	1127	Outside
Innovative clusters 1993–2001							
5	31,157	20	10	1	346	112	Outside
6	6187	10	1	1	347	50	Outside
7	34,823	19	10	2	1105	865	Outside
8	10,223	12	2	2	348	156	Fringe
9	27,209	12	16	2	420	112	Outside
Innovative clusters 2001–2010							
10	39,836	27	7	3	400	6	Outside
11	27,302	24	5	3	292	5	Inside
12	13,197	20	3	3	293	5	Fringe
13	363,860	13	105	63	401	1	Outside
14	53,127	21	19	5	1781	481	Outside
15	68,448	20	21	2	353	248	Fringe

[a] Buildings existed at the beginning of the period.

[b] Clusters developed during the same period.

buildings of 10–11 floors. These clusters were the first to introduce the ''towers in the park'' pattern in Ramat Poleg, and to the city of Netanya as a whole, and they were planned and authorized. In the next period (1993–2001), the Ramat Poleg area continued to develop, as more high-rise buildings were constructed next to low-rise developments. One of the innovative clusters there was built in 1993–2001 (no. 5) and includes a building of 20 floors among others of 10–12 floors.

Another innovative cluster (no. 3, Table 3) was located at the eastern part of the city, in an area that later grew to be Kiryat Ha'Sharon, developing in relative proximity to an existing low-rise suburban neighborhood. This innovative cluster includes three residential buildings of about 20 floors. Following that, this suburban neighborhood contained mainly 10 floors buildings as well as a few significantly higher ones. It is this cluster that introduced high residential towers as an option for suburban, luxury housing as most development occurred in the periods that followed. As the development around this cluster shows (see below), the novelty was accepted and entrenched, and the construction of high-rise residential buildings in the area continued.

During the next period (1993–2001), few more innovative clusters developed. Two new suburban neighborhoods containing a mixture of high-rise luxury buildings next to low-rise single-family homes were developed, both at the west end of the city, near the beach (clusters 7 and 9). Each of these clusters includes two high buildings beside other, significantly lower buildings. These locations did not develop massively over the next period, though small and medium size development continued.

The last period of our research (2001–2010) sees the entrenchment of the high-rise trend, along with introducing six innovative developments. We see these innovations as an expression of four development plans: The construction of Ir-Yamim near Ramat Poleg (no. 10 in Table 3), at the south-west end of the city: a completely new urban quarter made up of high-rise buildings alone. While this new urban quarter is not far from Ramat Poleg, the innovation lies in bringing luxury high-rise buildings of 27 floors to a leapfrogged area. This type of development is also reflected in the rapid and upward development of Kiryat Ha'Sharon, which is made up primarily of high-rise buildings (no. 13–14 in Table 3). The other innovative clusters developed in 2001–2010 extended existing built areas by adding significantly high high-rise buildings. This is the case with enlarging Neot Shaked neighborhood (no. 11–12), and extending the built area near the coast (no. 15). Both mix few high-rise buildings of 20 floors and lower ones, thus introducing high-rise housing to already functioning living areas.

The diffusion of height innovation

To determine whether the introduction of innovation provides a new development mode for the simultaneous and future development, and whether the innovative development is later diffused to the surroundings, we measure the number of buildings similar in height to the innovative cluster at a distance of up to 250 m that were constructed during the periods that followed (Figure 11).

Since we have three development periods, the impact on future development can be assessed only for the first two periods, 1983–1993 and 1993–2001. Therefore, we compare the distance between innovative clusters developed during 1983–1993 to the clusters developed during 1993–2001 and 2001–2010, while innovative clusters developed in 1993–2001 are compared to clusters developed in during 2001–2010.

In the surrounding area of the innovative clusters (radius of 250 m), we observe multiple developments of buildings similar in height to the innovative cluster that were constructed in

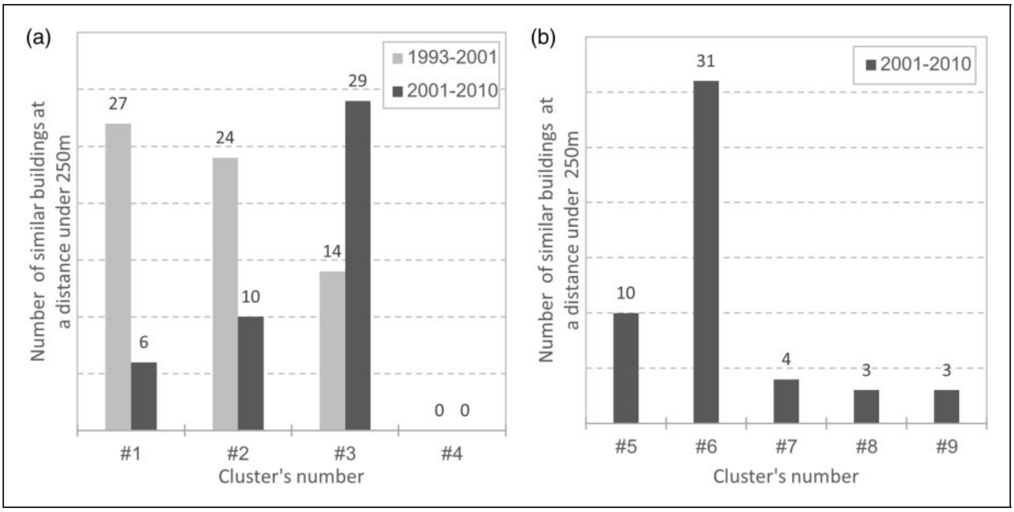

Figure 11. Number of buildings at a distance of up to 250 m, similar to the maximal height of the innovative cluster, for innovative clusters developed in 1983–1993 (a) and in 1993–2001 (b).

the periods that followed, with the exception of one cluster (number 4 in Figure 11) that had no similar development of buildings. The diffusion of a new height model in the period that followed is apparent, for example, cluster number 1 (Figure 11) had 27 similar buildings that were developed in the vicinity in the following development period.

In the case of cluster number 3 (Figure 11), the impact of the height innovation can be seen even further in time, when during 1993–2001, 14 similar buildings were developed in the vicinity of the cluster and during the next period (2001–2010), 29 similar buildings were developed in the area.

Discussion

General insights

The classical literature assumes that high-rise buildings reflect land-use prices. Since the latter is organized in bid-rent curves decreasing from the CBD, a high-rise building is expected to emerge near the center and reflect the decline of rent values from the center outwards. However, while this pattern was evident in North-American cities for many years, this is changing; and, the degree to which it reflects cities in other places of the world is doubtful (see: Barr and Cohen, 2014; Frenkel, 2007; Porat et al., 2012). We claim that by looking at high-rise buildings as a reflection of style, in addition to rent-bid values, and tracing these dynamics from the viewpoint of the innovative developer, can highlight the role of innovation in "regular" urban development. Particularly, our research demonstrates two overlapping mechanisms of the diffusion of innovation in space: spatial innovation of leapfrogging development sites, and contextual innovation reflected by high-rise buildings.

The investigated area is located within the municipal borders of Netanya, where land-use development is regulated by district and local outline plans. While the outline plans determine the overall borders and assign the permitted land-use for development, it is developers who determine the size, location and timing of their development sites within the restrictions of the outline plans. We consider the power law distribution of development cluster size in Netanya as a reflection of a self-organization process of the built environment

(Pascual et al., 2002). As we already know, strong top-down intervention may cause the power law distribution to appear deviated, as shown by Fragkias and Seto (2009). The power law distribution of clusters in Netanya supports the assumption of a bottom-up development process of the city, which stems mainly from decisions by developers who operate in the city and less by the organized regulative powers of the outline plans.

Netanya developed immensely during the research period. The fringe of the built-up area attracts most of the new development, and development clusters on the fringe are always relatively larger than development clusters in the inner city and those that leapfrog beyond the built-up area. The infill of the built area continues over all periods, and makes up the second largest portion of development, although the average area of such sites is the smallest and, as expected, decreases over time. Leapfrog development comprises the smallest portion of development, while such development clusters are larger than those of the infill development and their size increases in time.

Although leapfrog clusters constantly reach further distances and comprise larger parts of development, they present a wave-like behavior during the three decades covered by our research. During the first decade the city expands outwards; then during following decade, it infills; and then it expands again to further distances in the last decade. This development process has been observed in other cities (Martellozzo and Clarke, 2011).

Most of the new residential clusters constructed in already developed areas in Netanya replicate the height that prevails in the close vicinity. Most of the innovation (10 out of 15 clusters) was located outside the already built areas, and only one, during the last period, was located inside it, showing that residential buildings tend to be a replication of the existing way of living. The emergence of high-rise buildings occurs gradually, with each period introducing slightly higher buildings that were not defined as innovative at the time.

However, our research enables us to trace a few, yet influential, innovative clusters that introduced high-rise residential buildings where no other similar buildings existed before. These innovations changed the way in which the built environment developed. The most prominent were a few high-rise residential buildings constructed as part of the massive enlargement of Ramat-Poleg, a detached suburb of single-family homes. Most of the construction in Ramat Poleg replicated the existing low-rise housing, yet these buildings of up to 10 floors, constructed far from the CBD, created a new suburban pattern which we identify as "towers in a park"—high-rise residential buildings modeled in a modernist fashion aspired by the legacy of Le Corbusier, the famous Swiss-French architecture. Similarly, a few significant high-rise buildings were built in other remote places, thus creating new suburban neighborhoods that match this pattern.

The entrenchment of innovation. The introduction of innovation can affect the potential of an area for future development by influencing decisions taken by developers and creating positive feedback where innovation is later replicated by other developers within the neighborhood. In addition, innovation can turn into a model, spread or leapfrog to other places, and be replicated as a whole in existing and new neighborhoods. As our Netanya analysis shows, innovation was entrenched in both ways. Firstly, our analysis suggests that a few rare cases of height innovation located beyond the built-up area during 1983–1993 and 1993–2001 were expanded during the periods that followed. Similarly, new suburban neighborhoods, comprised of high-rise buildings—with and without low-rise single-family homes in the same neighborhood—continued to occur after 1993, and in greater volume, with higher buildings and larger clusters. Secondly, it shows that significantly high residential buildings were introduced on the fringe of existing neighborhoods, thus changing the view and type of living.

The above findings suggest that throughout the research period, we witness the introduction and then the gradual entrenchment of height innovation and particularly the ‘‘towers in a park’’ pattern. As time progressed, types of construction that were defined as innovative became a common pattern. On the one hand, innovative clusters grew larger and higher with time, as Table 3 shows, and on the other hand, more high-rise clusters—not necessarily innovative—were introduced into existing neighborhoods (Figure 10). A diffusion of the innovative trends is reflected from the gradual change in building height: with time, the share of significantly high-rise buildings goes up and turns into a common way of building. In addition, a gradual entrenchment of spatial pattern takes place, and the ‘‘towers in a park’’ pattern turns into a common model—in completely new neighborhoods as well as in the expanded existing built areas.

The accumulation of innovation in time bears significant influence on the urban structure. From the spatial aspect, once new foci of development were created beyond the existing fringe during 1983–1993 and 1993–2001, this development was later reinforced when it attracted new development and established new paths of expansion (Figure 5). For example, the outer (red) clusters at the southern end of Netanya on the map of 1983–1993 (Figure 5a) turned into a built-up fringe in 1993–2001 and became a continuous built-up area in 2001–2010. What started as a small and remote initiative, a seemingly unexpected development, became a major determinant of the entire city map. The development of undeveloped areas beyond the current built-up borders tends to be in large clusters. This might be related to development of large neighborhoods by large-scale development firms.

Urban change

Although cities are usually acknowledged as innovative and dynamic, we know that most development in cities cannot be described as ‘‘innovative’’. Rather, new development is mostly repetitive and takes place on the fringe of the already developed areas. In fact, this way of building, clearly evident in Netanya, is the essence of urban modeling as we know it today. Urban simulations rightfully assume that development is, for the most part, recurrent, and therefore easy to express with CA and ABM models, which incorporate the influence of topography, infrastructure and natural barriers. Innovation is essentially hard to model. Innovation can be spatial, in that it can impact the location of new development. Innovation can also be contextual and affect the type, style and contents of urban development. Typically, CA and ABM models incorporate leapfrogging as a stochastic allocation of areas that are far from the current built-up areas but have high potential for development (see White et al., 2015); whereas the contextual aspect of building height has been scarcely included in the repertoire of land-use and land-cover change modeling (Broitman and Czamanski, 2012; Lin et al., 2014).

Our research shows that a few innovative clusters can create a significant change in the urban structure and affect the way in which a city develops. In Netanya, spatial innovation was evident in suburban development at the southern and eastern ends of the city, where no similar development had taken place. This contextual development is reflected in the introduction of luxury high-rise residential buildings as a suburban option. The innovative clusters were made of both types of innovation—spatial and contextual combined—and were responsible for initiating a crucial change in the way in which the built environment developed.

Initially, it seems that the risk involved with development of innovative high-rise buildings near existing single-family neighborhoods was great and only a few developers in Netanya were willing to introduce it. But following the completion of initial innovative developments, one in Ramat Poleg and the other in Kiryat Ha'Sharon, the risk related to such projects, as experienced by other developers, was lessened and developers dared to push for more high-rise developments in new and existing areas. New areas were chosen for such development in 1993–2001 and particularly 2001–2010, when they were no longer considered a high-risk challenge. The height of buildings in such innovative clusters almost doubled, from around 10 floors to around 20 floors, and then almost tripled to 27 floors. In addition, the size of such innovative clusters grew larger. Innovation was thus accepted and a new type of development became a part of the system. One can further speculate whether this type of development will become a form of a collective memory of developers, planners, or both. Importantly, though, innovation is essentially unpredictable and as a result, hard, and possibly unfeasible, to model.

Conclusions

A city's spatial order is defined by the use, form and building height. For the most part, developers preserve this order, by locating new buildings at the intersection between built and undeveloped areas and by replicating existing building patterns. At the same time, the option of changing the spatial order is tempting for developers, especially for profitability reasons. For instance, abnormal profits are achieved by developers who purchase low-cost land in undeveloped areas and gain construction permits or extended building rights from planning commissions (Christensen, 2014). In Netanya, we looked at innovative development that contradicts existing structure in two aspects: The spatial—location of development clusters—and the contextual—height similarity of buildings within an area. The dynamics of Netanya's built-up pattern reveals an essential innovation component that started in 1983–1993, was accepted during 1993–2001, and became a fashion in 2001–2010. High-resolution spatial data of Netanya over 30 years of development were critical for arriving at this conclusion, as it allowed us to analyze the development with the scale and perspective of developer decisions: the individual building and the surrounding neighborhood.

As discussed above, although only a small portion of the urban development is defined as innovative, it is very influential and can impact the way in which the city grows. The empirical estimate of the laws that define location, volume, and context of the innovation, as well as the impact of innovations on urban development, should be incorporated into urban modeling and simulation. Modeling can contribute to anticipating the degree to which innovation is entrenched, and to foreseeing the way it further affects the built environment.

To conclude, we assume that high-resolution spatio-temporal information on urban spatial patterns, building usage, population, and transport will reveal more innovative aspects of urban dynamics. Hopefully, this will bring us to an operational answer regarding a critical question posed many years ago (Hagerstrand, 1967): whether innovations can be identified at early stages and the degree to which their dynamics can then be predicted and, thus, simulated, or should innovative development be discovered only in retrospect?

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Notes

1. The extent of the buildup area for each of the periods is the area formed by merging the 30 m buffer of every building that existed in Netanya in the beginning of the period.
2. Based on a t-test, the regression coefficient in all three periods is significantly different from 1, sig = 0.001.

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