Dynamic Evaluation of Discrete Zoning over Time Using Spatial Big Data

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Abstract. Zoning is widely used in land-use control and the criteria for a ‘good’ zoning scheme varies dramatically for different purposes of zoning. Studies during the past decades have presented many theoretical frameworks for the design and evaluation of zoning schemes designed for dynamic urban processes especially the housing market, but challenges remain. Therefore, this paper attempts to explore the robust zoning over time help derive boundaries that better fit with changing housing market. It starts with the preliminary introduction of the zoning and a review of spatial big data and existing studies on evaluating the suitability of zoning schemes over time. Three indicators are adopted to evaluate the current zoning framework. A new index called RHD that can evaluate zoning changing dynamics over time is proposed, followed by the discussion of the empirical findings of the impacts of the zoning on land supply and house prices in the territory. The proposed framework for evaluating zoning can benefit future studies of zoning regarding dynamic housing market in the world.

1. Introduction

Zoning is implemented in dividing a city's land into zones that allow or prohibit certain land uses[1]. Zoning is widely used in land-use control, and zoning related studies have received considerable attention in the past decades[2] in fields including urban planning[3], land-use regulation[4], environmental management[5], transportation planning[6], and housing markets[7,8]. Curtis and MacPherson[10] produced the first rigorously defined geography of housing market areas taking account of three strands of evidence: commuting, migration and house prices[11]. As the world is developing rapidly, more land regulations are needed for efficient use of urban land resources.

The criteria for a ‘good’ zoning scheme vary dramatically for different purposes of zoning[8]. Studies during the past decades have presented many theoretical frameworks for the design and evaluation of zoning schemes, but challenges remain. Bishop (2009)[12] commented that only time and experience can determine what is right and what needs to be adjusted. First, most studies shared a static view of zoning scheme, that is, the suitability of the zoning scheme is mostly determined by the urban context at the time of the designing process. However, zoning plans will not always be as ‘good’ as it seemed during the designing phase[8]. Some frameworks qualitatively included a prospect of future urban changes in the designing process[13]. However, the effectiveness of such approaches can hardly be evaluated. Second, existing assessments mostly depend on experiences of field experts, and there lacks a systematic and quantitative approach for evaluating the suitability of zoning over time and designing time-robust zoning schemes.

One main reason for the lack of dynamic assessment methods for zoning schemes is the challenge
and high cost in collecting sufficient relevant data over a long period of time. Classic data collection methods such as surveying can hardly provide a complete view for the suitability of a zoning scheme, especially the ones covering a wide spatial extent and effecting a large population. Another main reason is the lack of urgency for dynamic assessments of zoning schemes, since zoning schemes can be updated every five or ten years, while the world were not changing as rapidly as nowadays. However, cities are becoming more and more vibrant and dynamic due to the massive industrialization and rapidly developing information technologies[15]. Consequently, the suitability of zoning schemes may degrade rapidly after the designing phase with rapidly changing urban economics and built environment. Such rapid degradation is significant for the zoning schemes, especially designed for dynamic urban processes including urban mobility and housing market.

In recent years, the growing availability of spatial big data and online open urban data have enabled quantitative evaluation and characterization of many urban dynamics[15]. Spatial big data is based on spatial and temporal scales, and their applications are considerably used in urban studies. For example, Han, Yu, and Long (2015)[20] analyzed the functional zones in Beijing by using bus smart card data and points of interest. Moreover, Long and Thill (2015[20]) discovered jobs–housing relationships and profiled underprivileged residents. Spatial data analytics have also been used for house prices, mobile phone use, and health care.

Therefore, this study has three objectives. First, we provide a sophisticated review of spatial big data and existing studies on evaluating the suitability of zoning schemes with a specific focus on the change of zoning suitability over time. Second, we collected 148,871,01 house transaction records in Hong Kong from 1995 – 2019 and analyzed transaction variabilities and house prices in Hong Kong. Third, using this big dataset, we propose a framework composed of three quality indicators for evaluating the zoning system dynamically over time. We finish with discussions and future directions on evaluating good zoning schemes.

2. Literature Review

Zoning, by definition, is the process of diving a city’s land into functional zones[5]. As a tool for land-use control, zoning serves as an underlying structure for efficient and effective land use regulations. Fundamentally, zoning provides managerial convenience in managing geographical areas by defining geographical boundaries to transform a continuous geographical extent into many discrete land parcels, called zones[6]. Each land parcel within a zoning scheme is assumed to be homogeneous, that is, each parcel is geographically continuous, have similar conditions and contexts, and so can be regarded as one combined unit and be managed using identical policies[13].

Zoning is vital and useful in guiding resource management and human activities based on geographical boundaries[12]. Urban land-use planning is the most common example of zoning practices[5]. By dividing a city’s land into functional zones such as residential and industrial land units, certain land uses are promoted or prohibited for each zone[1]. Zoning is widely used to secure areas of environmental or biological services in cities, such as the zoning of national parks in the United States and Australia[10] and the strict national “redline” policy in China for farmland protection against the rapid urbanization. The underlying zoning scheme effectively protects ecosystems and historical inheritances from human disturbance.

What defines the ‘goodness’ or suitability of a zoning scheme given a certain problem and geographical context? Researchers, planners, and decision makers have proposed varying principals in designing and evaluating zoning schemes[10]. Due to the lack of available data sources, many researchers tend to adopt qualitative measures while assessing zoning schemes. Apa (2009)[19] proposed a summary of principles that can make a good zoning scheme:

- Make mixed use areas simpler. Maybe reduce to three sectors: residential zone, mixed use zone and special zone.
- Attainable Housing. Real need is in attached and multi-family units.
- Dynamic development standards. Let some of them adjust automatically as conditions change.
- De-politicizing final approvals. Limiting public hearing debate to listed issues.

Despite a large body of research on the suitability of zoning schemes, very few studies have
studied suitability assessments of zoning scheme over time, mostly due to the large managerial cost associated to changing the zoning scheme. However, since the industrial revolution, cities have been changing at an unprecedented rate; the massive urbanization process has taken place in just thirty years in China, there is increased necessity and urgency to discuss how the fitness of zoning changes over time. In practice, planners have already been updating land use plans every five or ten years, but methods for designing and evaluating a zoning scheme that sustains time is still lacking. Dynamic, flexible, and advanced plans are favored by modern land-use planning[2].

In recent years, the growing availability of online spatial big datasets have enabled dynamic assessments and characterization of zoning and many urban dynamics[15]. Urban open data is used to analyze more sophisticated, large-scale, and dynamic analytic methods to understand urban issues. Spatial big data is based on spatial and temporal scales, and their applications are considerably used in urban studies. Spatial data analytics have also been used for house prices, mobile phone use, and health care. Based on urban datasets, Han, Yu, and Long (2015)[20] analyzed the functional zones in Beijing by using bus smart card data and points of interest. Moreover, Long (2015) discovered jobs–housing relationships and profiled underprivileged residents.

The housing market is a dynamic urban phenomenon on which zoning system variables have a significant effect over time, whether positive or negative[17,18]. On the one hand, planners and city decision-makers decide the amount and location of residential zones available for development each year, which significantly fluctuates local house prices. The past two decades of house prices in Hong Kong makes a piece of obvious evidence for how limited land supply over time leads to unaffordable house prices[7]. Zoning of other categories surrounding each residential zone will also affect house prices due to favoritism of buyers. Approximate to some zones, such as commercial and green lands, are usually favorable to buyers, while approximate to some other zones, such as industrial, can be mostly unfavorable[4]. On the other hand, house agents and buyers have their definitions of house price zones. Such zoning can be viewed as an effort to group areas having similar house prices, and so change alongside with the rapid fluctuations within the house prices. By examining data over a 24-year time period, Mark (1986)[18] concluded that the impacts of zoning and re-zoning on the housing market is evident but diverse and challenging to predict. Others, including Bailey et al. suggested that housing prices varied with the type of zoning classification.

3. Materials and methods
3.1 Study area
Hong Kong, China (Figure 1), world-wide famous for its shortage of land supply and high-density urban constructions, is a compelling area for zoning studies. Empirically, Hong Kong’s zoning scheme and planning regulations have always had a high impact on the local housing market[17]. With fast-changing urban dynamics, the suitability of zoning schemes over time is yet to be quantitatively assessed.

Figure 1. Hong Kong, China, the study area.
3.2 Hong Kong housing transactions data 1995-2019
We retrieved the Hong Kong house transactions dataset opened by Centa Data (http://hk.centadata.com/). The dataset includes house transaction records covering all 18 administrative districts in Hong Kong for a period of 25 years (1995-2019). The dataset includes 148,871,0 records. Each transaction record contains house properties and details about the transaction, such as the area, address, number of rooms of the housing unit to be traded, and the time of the amount of the transaction.

3.3 Dynamic assessment of zoning suitability
For the use in the housing market, each zone should have relatively homogeneous house prices\cite{7}. Adopting the assessment framework by Thorson (1994)\cite{9}, we assess the suitability of zoning for the housing market from two aspects, the so-called inner-variability and inter-variability.

For a zoning scheme, the inner-variability indicator reflects the level of homogeneity within house prices within each zone. A ‘good’ zoning scheme should be able to only group similar house transactions, and so have relatively low inner-variability. The inner-variability can be calculated as,

\[ V_{\text{inner}} = \sigma(P_i) \]

where \( P_i \) is a set of house prices recorded within the \( U_i \), the spatial extent of the \( i \)th spatial unit of the zoning scheme, \( \sigma() \) is the standard deviation operator.

The inner-variability can be sensitive over the number of data points within a spatial unit. Statistics for spatial units having a small number of data points are more vulnerable to be affected by outliers, generating extremely large values. Therefore, we excluded zones having less than three data points from statistical calculations. We also calculated an inner-variability weighted by number of data samples in each spatial unit. The weighted average can be formulated as,

\[ \bar{x} = \sum_i w'_i x_i, \quad w'_i = w_i / \sum_i w_i \]

where \( w'_i \) is the normalized weight. Here, \( w_i \) is measured as the number of data points in \( U_i \).

The inter-variability indicator reflects the level of heterogeneity among the average house prices of each zone. A ‘good’ zoning scheme should be able to only separate groups that are significantly different from each other, and so have relatively high inter-variability. The inter-variability can be calculated as,

\[ V_{\text{inter}} = \sigma(P_i) \]

Many cities have designed specific house market zonings for the use of the housing market\cite{11}. We use the Tertiary Planning Unit (TPU) demarcated by the Planning Department of Hong Kong to demonstrate the effectiveness of the proposed method. The TPU has served as the spatial reference system for critical social services in Hong Kong such as the population census.

4. Results
4.1 House transactions in Hong Kong 1995-2019
Figure 2 (a) shows changes in the annual number of house transactions in Hong Kong from 1995-2019. Despite drastic fluctuations from 1995 to 2000, the annual number of house transactions levelled off from 2001 to 2014 and slightly fluctuated between 500 and 600 units. Between 2017 and 2019, however, as the real estate market was in the doldrums, the trend of transactions has substantially dropped down since 2017.

Figure 2 (b) illustrates changes in annual average house prices during 1995-2019. We observed that except for the peaks in 1997 and 2016, house prices show a general upward trend with an annual average growth rate of 15.13%. The maximum increase in annual average house price was 35.98% from 3793.01 to 5157.67.
Figure 2. (a) Annual number of house transactions. (b) Changes in average house prices by year.

4.2 Dynamic zoning assessment

Figure 3 demonstrates changes in the inner-variability, weighted inner-variability, inter-variability for house prices in each year. For convenience in comparisons, we normalized trends in each time series by transforming the starting points of each curve at 1995. Moreover, we observed that two curves shared similar trends before 2000, while the gap between inner variability and its weighted version has increased since 2000. We also estimated that cold zones would have a higher inner variability (3411.86), while hot zones would have a lower inner variability (3016.96) from 1995 to 2019, and this trend will become more significant over time.

Figure 3. (a) Annual zonal inner variability and inner variability weighted for house prices. (b) Annual zonal inter variability for house prices.

We observed that inter variability, inner variability and its weighted fit well before 2010. Since 2011, however, as house prices increased, inner variability and its weighted were stable, while inter variability still presented an up and down trend, which indicated that the three indicators were not affected by house prices. From 2015 to 2017, house counts increased due to the new houses supply. Thus, the increasing house counts brought an ascending trend to inter variability. While from 2019, the curves of inter variability and house counts dropped down because a small amount of data was adopted. Further, we identified that there is a weak negative correlation (r=-0.22) between house prices and house transactions.
Figure 4. Changes in values of quality indicators for dynamic assessment of housing zoning scheme in Hong Kong.

As we observed the current dynamics by year in the evaluated zoning, we proposed an index: Regional Homogeneity Difference (RHD) Figure 5.

\[
RHD = \frac{\text{inter variability}}{\text{inner variability weighted}}
\] (4)

RHD describes the difference of house prices between regions. RHD also has a high correlation with the average house prices \((r = 0.67)\) so that it can be used to indicate zoning changing with house prices over time.

Figure 5. Regional Homogeneity Difference (RHD).

5. Discussion

5.1 Recommendations for zoning over time

Few empirical researches explored the dynamics of urban zoning framework. Unlike previous studies that treated zoning as static, our study took zoning as a variable structure that varies according to the house prices in different regions and examined the rezoned plan toward the housing market. On account of changeable real estate markets, static zoning cannot fit house prices well. Therefore, dynamic zoning is efficacious and instructive for studying the urban zoning.

Based on our findings, we explicitly investigated the housing market zoning in Hong Kong over time. Cold zones have higher inner variabilities in house prices while hot zones are lower and the gap between them becomes larger over time. Although the existing zoning (TPU) in Hong Kong has been widely used in real districts, to generate a better housing market zoning which is influenced fewer over time, is of great importance.

Our research is oriented toward qualitative analysis. Quantitative studies on zoning strategy have been promoted by the increasing availability of spatial data for the past few years. Having performed further analysis, we proposed a more comprehensive plan fits the housing market area better compared with simple zoning such as TPU. To propose a robust zoning over time, we focused on the following aspects:

1. Suitability for the existing administrative districts.
2. Monitor and track the dynamics of the housing market.
3. Rezoned plan that in line with local regulation plan.
6. Conclusions

Our discussions on the robust zoning over time help derive boundaries that better fit with changing housing market. Taking Hong Kong, China as a case, we first estimated house transactions by real estate records and observed an upward trend of house prices during the study period. We then evaluated current zoning framework using three indicators, zonal inner variability by year, zonal inner variability weighted by year, and inter variability by year. From the calculation, we found that the inner variability in cold zones is higher than hot zones. Therefore, we proposed a new index called RHD that can give a clear result on evaluated zoning changing dynamics over time. Moreover, our results reflect that house prices and house transactions have some unpredictable waves and still need changes monitoring.

Our study of evaluating how zoning fit housing market over time in Hong Kong is especially timely. Compared with the simple rules of planning static zoning, dynamic zoning is far more complex. As the housing market in the world is dynamic and has changed largely in recent decades, many cities need a refresh zoning that can help tackle with dynamic change. However, our primary goal is to present a robust zoning over time, so that the effects of growth area, detailed house marketing assessments and allocation proportion of these factors are not considered. Besides, quantitative models and elaborate analysis were not conducted. The proposed framework for evaluating zoning can be applied in different cities and scenarios in the future and can benefit future studies of zoning regarding dynamic housing market in the world. Based on such an evaluation framework of zoning and reasonable future predictions, optimization methods can be utilized to generate ‘optimal’ spatial layouts of discrete zoning that sustains a long time span of urban growth[15].

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