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Land-Use Morphology and Density Patterns of New Residential Construction

Understanding the determinants of residential construction has been a highly topical field of research in urban economics and housing market policy research, as it is the invariable central mechanism any housing market or environment is shaped by. While much effort has been dedicated to national or statewide analyses of how zoning and land-use regulations impact residential construction, little conclusive research has been done on how zoning shapes patterns of residential construction on the metropolitan level. However, better understanding this dynamic process of residential construction in the special context of even a single metropolitan city is surely valuable, and the smaller, more controlled setting is less subject to confounding factors such as variation in topography or the supply elasticity of the housing market. The goal of this paper is to analyze the relationship between zoning regulations (in particular, density and land-usage type regulations) and patterns of new residential construction, meaning the erection of entirely new single or multi-family buildings. Research is guided by the following question: How do zoning regulations impact totals of residential construction? More specifically, what is the relationship between the land-use zoning morphology of San Francisco and its density patterns of new residential construction?

To analyze density requirements, the most appropriate unit of analysis is comparing metropolitan areas, as density requirements within a single metropolitan area in general remain constant. In this paper, we look at how the density requirements of minimum acres per unit and minimum lot size impact totals of residential construction across 21 California cities, making use of construction building permit data and the Terner California Land Use Survey. The results of

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the non-spatial analysis of California cities show no correlation between density requirements and permitting totals.

The paper then changes scale and transitions to a spatial analysis of exclusively San Francisco, which ranks in the Wharton Land Use Stringency Index as the city with the most highly regulated zoning environment, making it a particularly interesting city to analyze. We make use of San Francisco construction point data and land-use zoning districts to conduct descriptive statistics, exploratory spatial mapping, and a LISA analysis of the relationship between land-use zoning and density patterns of new residential construction.

The results of the spatial analysis of San Francisco highlights a distinct theme - slightly over fifty percent of residential land is apportioned to single-family districts, which tend to be the largest contiguous districts, but single-family districts are also the least dense areas of new residential construction, accounting for under 20% of total new residential construction. In fact, a brief comparison of the land-use zoning map of San Francisco and density of residential construction map shows that as the highly segregated land-use zoning morphology progresses from predominantly single to duplex/triplex to multi-family (going from the South to North of San Francisco), districts with higher density levels of construction become more common. However, there is not a significant overall spatial correlation between land-use type zoning and density patterns of new residential construction as revealed by the LISA analysis. This may be a result of the vast difference in areal magnitude between some zoning districts (sometimes to the order of a hundred), which allows for choropleth maps that reveal distinct spatial trends, but do not allow for strong statistical spatial correlation.

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Literature Review

Research on residential construction is well developed, and several potential determinants of residential construction have been explored. This literature review identifies the following major candidate determinants that have been explored thus far in the literature: rent, construction costs, topography, and residential construction, and observes that the field has converged on the importance of two key determinants of residential construction - topography and land-use regulation. The literature review then goes on to explore research on land-use regulation and the spatial methodology surrounding this area, with a concluding paragraph discussing how the author's proposed research question might add value to the current state of research.

The determining process of where developers decide to build houses or apartments is a multifaceted process, and research in urban economics has been open-minded to several possible factors. While basic urban economic logic suggests that developers will build at higher density where land is expensive, research on apartment development in California found a lack of correlation between rents and multifamily permits (Murray and Schuetz, 2019). In a 2006 paper by Gyourko and Daiz, construction costs, another plausible factor for determining patterns of residential construction, was found not to explain variation in construction costs, although it is worth noting that construction costs remain important for overall levels of construction activity, and is a focal area of research in the Terner Center for Housing Innovation's *The Costs of Building Housing* series.

While substantial research points to rents and construction costs not being able to explain variation in residential construction, there is a strong consensus that topography and regulation are the key determinants of residential construction (Adler and Colburn, 2022; Saiz, 2010). In a

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seminal paper on housing supply elasticity in 2010, Saiz utilized GIS techniques to estimate the level of restrictive topography surrounding metropolitan areas in the United States, and found that the presence of steep-sloped terrain and bodies of water effectively curtailed residential development. However, as contextualized by Adler and Colburn twelve years later, the restrictive effect of topography on residential construction remains constant, and so changes in supply elasticity within a metropolitan area have to be attributed to land-use regulation.

Land-use regulation and zoning is by far the most extensively researched determinant of residential construction, and has been found to have the strongest explanatory power for variation in residential construction with relaxed zoning resulting in more permits, and in particular multifamily permits (Calder, 2017; Monkonnen et al., 2020; Scheutz, 2019; Song, 2021). Substantial research has also found strong correlation between stringent land use regulation and affordable housing, although the relationship between regulation and price is often a black box and is beyond the scope of this literature review, which focuses on the intermediate mechanism of construction (Ikeda and Washington, 2019). Scheutz, a senior fellow at Brookings Metro, argues that a well-functioning land-use regulatory environment can be appraised by three key questions: Is the housing market producing enough additional housing to meet increased demand? Within a metropolitan area, is new housing being built in the locations where people most want to live (i.e. locations with the highest demand)? And does the housing market provide a diverse range of housing choices that match household budgets, size, and other characteristics (Scheutz, 2019)? However, Scheutz also recognizes that zoning rules on paper don't always match development on the ground, as local governments can grant variances to encourage development of a project technically against regulations, while hostile local opposition can block

the construction of units technically allowed under zoning laws (Scheutz, 2019). A seminal work on the logic of hostile local opposition is Fischel's *Homevoter Hypothesis,* which highlights that homes are often the largest financial asset of homeowners, who view multifamily development on neighboring land as a threat of capital loss to their major asset, although the evidence on this relationship is mixed at best (Fischel, 2003).

Before addressing the literature on specific individual zoning regulations, there is also an important emphasis on the two-dimensions of land-use zoning - process and prohibition. While prohibition, namely specific zoning laws, have been substantially more investigated, several researchers point to the practical importance of the complex regulatory process (Gyourko et al., 2019; Monkonnen et al., 2020). In a 2019 study, Gyourko, Hartley, and Krimmel find that the average time span between submitting a project for approval and receiving a decision is 3.4 months, while Monkonnen notes that the often absurdly complex regulatory process may deter developers from even attempting to build. Another potentially confounding factor is length construction period - in a summary report on America's housing in 2022, the Joint Center for Housing Studies at Harvard found that supply chain delays have resulted in 1.64 million homes still under construction (JCHS, 2022). All in all, while there is strong research on specific zoning regulations which will be addressed next, the regulatory approval process and construction process further complicate patterns of residential construction.

Research on specific zoning regulations, can be classified into two sub-categories: land-type regulations and density regulations. The primary focus of research on land-type regulations in relation to residential construction is the all-important division between land zoned for single-family versus multi-family development. The Joint Center for Housing Studies' 2019

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report on America's rental housing found very stark spatial clusters of single-family homes (JCHS, 2019). Theirs results showed that rental units make up 80 percent of the housing stock in just five percent of census tracts, while conversely owner-occupied homes accounted for 80 percent of the housing stock in 31 percent of tracts, emphasizes the prioritization of single-family development in large swaths of land in the United States. However, land-use regulations in isolation are insufficient to explain residential construction patterns, as density regulations greatly influence how much single or multi-family zoning can be built on particular zoning types of land.

The manner in which cities regulate the density of single-family and multi-family development, respectively, is substantially different (Murray and Scheutz, 2019). For single-family homes, minimum lot area restrictions were found to be the most common dimensional requirement in zoning (Song, 2021). Song found that 16% of single-family homes bunch within 5% of minimum lot areas, implying that minimum lot area restrictions exert a heavy influence on housing characteristics. On the other hand, when looking at California apartment development, Murray and Scheutz found that while minimum lot size is the cornerstone density metric for single-family zoning, it is a less important metric for regulation of multifamily development. They identified two key multifamily density metrics - the maximum number of units allowed per acre, and maximum building height. In particular, Murray and Schuetz found that most jurisdictions restrict apartment buildings to less than four stories, which is quite notably restrictive in the context that multifamily construction has been shifted to large buildings containing twenty or more units (JCHS, 2019).

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Finally, the importance of methodology in the literature on zoning regulations cannot be overstated. A fundamental difficulty with research on zoning regulations is that there is no comprehensive national database, as localities across the nation each have distinct zoning laws. As such, several attempts have been made to construct proxy measures for zoning stringency, such as the Wharton Land Use Stringency Index, which used survey data from around the country to develop a national index (Gyourko et al., 2019), as well as using property records to predict what zoning regulations look like (Nechamkin and McDonald, 2019). When attempting to create national databases for particular zoning regulations such as minimum lot area, innovative attempts have been made such as Song's bunching algorithm, which used a structural break algorithm to detect the point and which developers were packing houses, and proxied that point as the likely minimum lot area. Data engineering in respect to zoning regulations remains an active and relevant part of zoning regulations research as a whole.

There is little explicitly spatial research on zoning regulations and residential construction as it relates to American cities, but expanding to research conducted on European cities, an longitudinal spatial analysis of residential construction in Greece analyzed spatial trends over the period 1990-2017 (Cecchini, Zambon, and Salvati, 2019). The authors gathered elementary building permit data as the primary heuristic of total levels of building activity, and used a mix of descriptive mapping and k-means clustering to identify four centers of building activity in Greece, and observed how the morphology of these clusters changed over time. However, Cecchini et al.'s work is still conducted on a national areal scale, and methods for spatially analyzing residential construction on smaller levels such as within a single municipality are currently sparse.

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In summary, research on the relationship of specific density zoning requirements and residential construction is still developing and has not reached a stasis that synthesizes density zoning requirements for single-family and multi-family residential construction. As such, research that holistically considers zoning requirements in a single metropolitan area, taking into account how the environment shapes both multifamily and single family development, rather than considering each type of residential development in a vacuum, may add value to the burgeoning research on the spatial interaction of zoning and residential construction. Hence, after first conducting more general statistical analyses on the correlation of various zoning requirements with residential construction for several California metropolitan areas, I transition to a more in-depth spatial investigation of San Francisco relying on spatial methods such as descriptive mapping and LISA analysis of density patterns of residential construction.

Analysis of density requirements and construction in California cities

We now briefly discuss the primary data sources used in the analysis of California cities. When analyzing the impact of zoning requirements on residential construction, two main categories of data are needed - a measure for residential construction, and measures for various zoning requirements. In this analysis, I measure residential construction by the number of new permits issued in a metropolitan area, which I obtain from the Building Permits Survey (BPS), a part of the Census' New Residential Construction Series. The BPS is conducted monthly and annually, and I use the annual data for 2018 as it best coincides with the time frame of my other data sources. The BPS provides overall totals of new permits issued during 2018, as well as subtotals for single family units and multifamily units.

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As mentioned in the literature review, the far more difficult aspect of data collection is effectively measuring zoning requirements. The most recent and comprehensive attempt at this is the Terner California Residential Land Use Survey, created by Mawhorter and Reid, which was informed by previous surveys of land use regulation such as Raising the Roof (Landis, 2000), the Brookings National Survey on Local Residential Development Regulation (Pendall, Puentes, and Martin, 2006), and the Wharton Survey on Residential Land Use Regulation (Gyourko, Saiz, and Summers 2008) among other precedents (Mawhorter and Reid, 2018).

The Terner Land Use Survey contains a variety of zoning measures on 271 California municipalities, as well as traditional respondent data such as personal perceptions of factors such as uncertainty in permitting, but I focus on the following measures: single family minimum lot size (sq. ft), multifamily minimum lot size (sq. ft), single family maximum units per acre, and multifamily maximum units per acre. In addition to these four density measures, the Terner Land Use Survey also provides, for each municipality, a breakdown of the amount of land designated for single family land, multi-family residential land, and non-residential land, giving each respective category a value of little (6-25%), some (26-50%), a lot (51-75%), most (76-95%), or almost all (96-100%). This serves as an important contextual characterization of each municipality that can be used to find outliers within particular categories (for example, a category can be "some" single family land, "some" multi family land, and "little" non-residential land).

As the Terner Land Use Survey is most convenient for answering my research question of how zoning requirements impact residential construction, my study area is MSAs in the state of California. After filtering the Building Permits Survey to only California Metropolitan Areas,

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joining the BPS and Terner Land Use Survey data by metropolitan statistical area, and accounting for missing values, I obtain a dataframe accounting for 21 metropolitan statistical areas in California, which is a reasonably thorough coverage of California as the state has 26 metropolitan statistical areas in total (U.s. Census, 2020).

The bulk of the analysis consists of looking at the relationship between the four zoning density requirements mentioned earlier, in comparison to single-family and multi-family permitting totals by metropolitan area. The issue of normalizing the permitting totals is substantial, as it makes little sense to compare zoning requirements and permitting totals without accounting for some sort of population measure. There are several possible approaches, such as normalizing by total population, normalizing by change in population, and likely many other reasonable methods. As there is little literature that suggests the best way to normalize permitting totals, I divide permitting totals by total population (measured in thousands), to get a ratio of number of permits per thousand people for the metropolitan statistical areas. I also normalize the single family and multi-family permit totals by population, which effectively allows one to see whether a city permits more multifamily or single family construction. For example, San Jose has a relatively balanced permitting split, where out of approximately 8 total permits per thousand people, there are approximately 4 single family permits per thousand people and 4 multifamily permits per thousand people, while Bakersfield's permitting split is extremely skewed towards single family development, where out of approximate 6.5 total permits per thousand people, there are approximately 6 total single family permits per thousand people and 6 total multifamily permits per thousand people.

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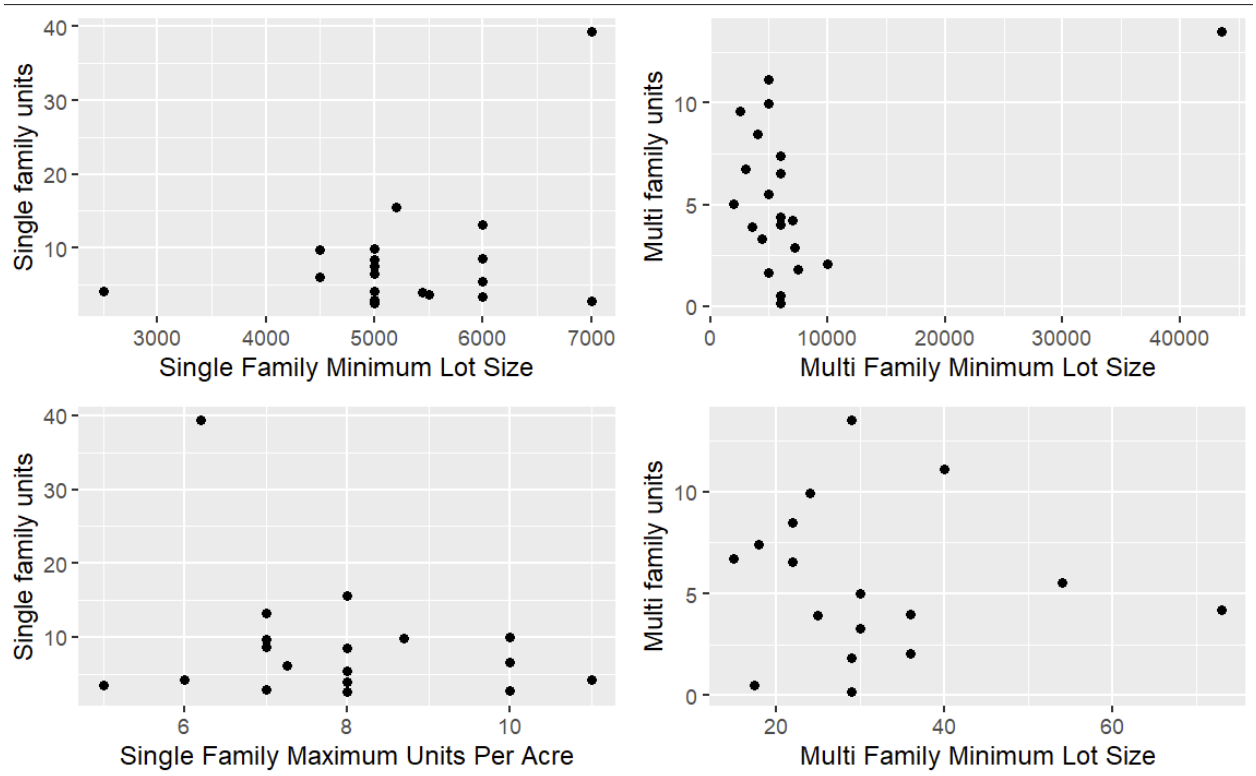
When using metropolitan areas as statistical units, spatial analysis may be prone to several confounding variables due to the restrictive topography of California with its coastal water, and so the analysis is exclusively non-spatial. I run four correlations on a dataset of 21 major California metropolitan areas, correlating single family minimum lot size/single family maximum units per acre with single family permitting totals (2 separate correlations), and multi family minimum lot size/multifamily maximum units per acre with multi family permitting totals.

The four resulting scatterplots are shown below:



There is little to zero correlation between any of the density zoning requirements and total number of single-family or multi-family units of new residential construction (per. 1000 people) across the California municipalities. Hence, individual density zoning requirements lack

the explanatory power to compare new residential construction totals across municipalities, highlighting the complexity of the process of new residential construction. While it is possible that further statistical tests might yield stronger results, this is quite unlikely, as similar methods of linear and multivariate regression conducted in the literature to try and explain development have only found inconclusive results, such as in Murray and Scheutz, 2019, in which the authors conclude that rent does *not* predict apartment development. More conclusive research, such as in Song's analysis of Pittsburgh in 2021 in which she identified a significant influence of minimum lot size on developer behavior, rely on a deeper investigation of a single municipality, and so a more thorough spatial analysis on San Francisco is the focus of the rest of the paper.

Analysis of land-use zoning morphology and density patterns of new construction in San Francisco

For the analysis done on the single metropolitan area of San Francisco, we transition away from specific density zoning to land type-zoning. We first discuss the background of San Francisco as the study area for the analysis.

San Francisco has a particularly notable housing market and environment ranking as the most regulated metropolitan area in the United Nations in the Wharton Land Use Survey (Gyourko, Hartley, and Krimmel 2019). San Francisco had a regulatory index value of more than one standard deviation above the national average. In their 2019 working paper, Gyourko et al. also note that San Francisco's extreme regulation is not simply due to a few ultra-restrictive outlier communities, but instead that there seems to be a high average level of regulation with a tight variance. As such, San Francisco is a useful choice for an analysis only focusing on

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land-use type regulations (in particular the distinction between a land parcel being single-family residential, multi-family residential, or non-residential), as there will be little confounding effect from other zoning regulations since they have little variance.

I use the permitting statistics calculated for San Francisco to provide useful background contextualization for the spatial analysis. I observe San Francisco has a permitting split skewed towards multifamily development, with approximately 4 single family permits per thousand people versus approximately 9 multi-family permits per thousand people. Thus, in addition to an exploratory spatial data analysis of San Francisco's residential construction patterns, a guiding question to try and understand the spatial morphology of San-Francisco's land type regulation is how it may foster a zoning environment conducive to multi-family residential development (the findings are in fact counterintuitive), and I now expand more on the spatial methods and data.

I gathered data primarily from the San Francisco Open Data Portal - for land-use type zoning I use the official Zoning Map provided by the San Francisco Planning Department. The Zoning Map dataset provides information on the type of land-use for 1645 land parcels (referred to as zoning districts by the San Francisco Planning Department) that comprise all of San Francisco, and I filter the dataset to include only residential zoning districts, and the final dataset contains 845 residential districts. The areal magnitude of the residential districts greatly differ, and in particular the single-family districts tend to be much larger than the multi-family districts. An example classification the zoning map gives a zoning district is residential-house-one-family. To categorize the zoning districts, I classify them via a categorical variable with three options - single, for exclusively single-family homes, duplex/triplex, and multi, for larger apartment buildings of four or more units. This simple classification scheme better allows me to identify

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distinctive clusters of single family zoning, or of multi-family zoning, to better understand the morphology of land-use zoning in San Francisco.

The second piece of spatial data I gathered are San Francisco's Development Pipeline Quarterly Snapshots, which are geocoded point data of housing/commercial projects or permits provided on the San Francisco Open Data Portal by the San Francisco Planning Department. The data accumulates quarterly, so that each successive quarter contains all the observations of the past quarter plus new observations during the current quarter. I use the quarter four snapshot of 2021 and the quarter four snapshot of 2022, so that the dataset contains observations over the course of the two year period 2021-2022. The quarterly snapshots contain virtually all building permits that pass through the San Francisco planning office, even for simple construction such as the remodeling of a single unit. As the goal of my research is to measure the relationship between land-use zoning and *new residential construction,* certain types of construction such as remodeling, ADUs, or adding units to already existing buildings are excluded, and the final dataset I create with only new residential construction permits contains 1645 permit point data, which I then aggregate to the 845 zoning districts.

We now provide some descriptive statistics of the final data. For the zoning districts data sets, by summing up the total area of single-family districts (resp. duplex/triplex districts, resp. Multi-family districts) and dividing by the total area of residential districts in San Francisco, we obtain the proportion of land zoned for each type of residential development. We find 52.2% of residential zoning districts are allotted for single-family districts, 30.4% for duplex/triplex districts, and 17.4% for multi-family districts. However, summary statistics from the building permit data aggregated to the zoning districts show that of the 1645 permit point data, 18.1% are

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located in single-family districts, 39.8% are located in duplex/triplex districts, and 42.1% are located in multi-family districts. These two sets of summary statistics already paint a powerful narrative - from the perspective of maximizing density of residential construction, San Francisco's zoning morphology makes little sense, as even though over half of zoning districts are allotted for single-family homes, only 18% of total construction is single-family. The summary statistics also suggest that a spatial pattern of higher density clusters in duplex/triplex and multi-family districts will be more pronounced than in single-family districts, and this is indeed what the following spatial results visualize.

The bulk of the spatial analysis of San Francisco consists of two parts: firstly, exploratory mapping of the land-use zoning morphology and density point patterns of new residential construction in San Francisco, and secondly, a univariate LISA analysis of the number of permits per km variable.

Beginning with the exploratory mapping of the land-use type zoning, I create a choropleth map based on the categorical variable of whether a zoning district is designated as single-family, duplex/triplex, or multi-family, shown below:

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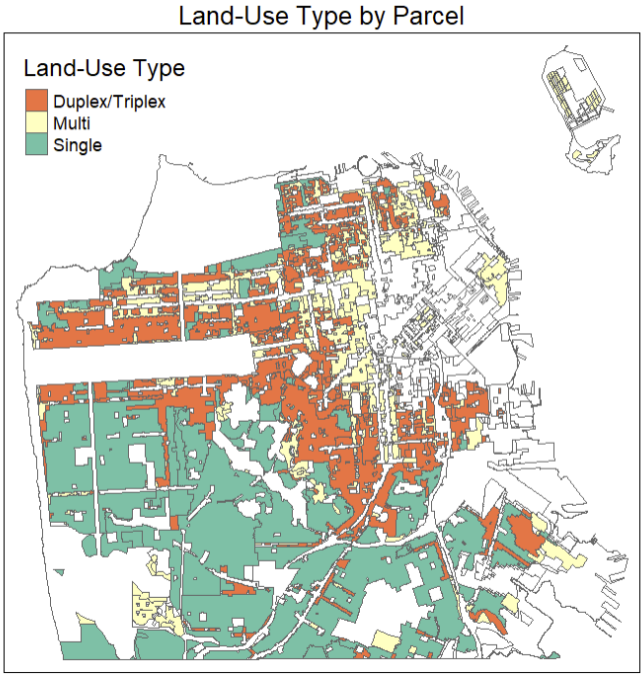
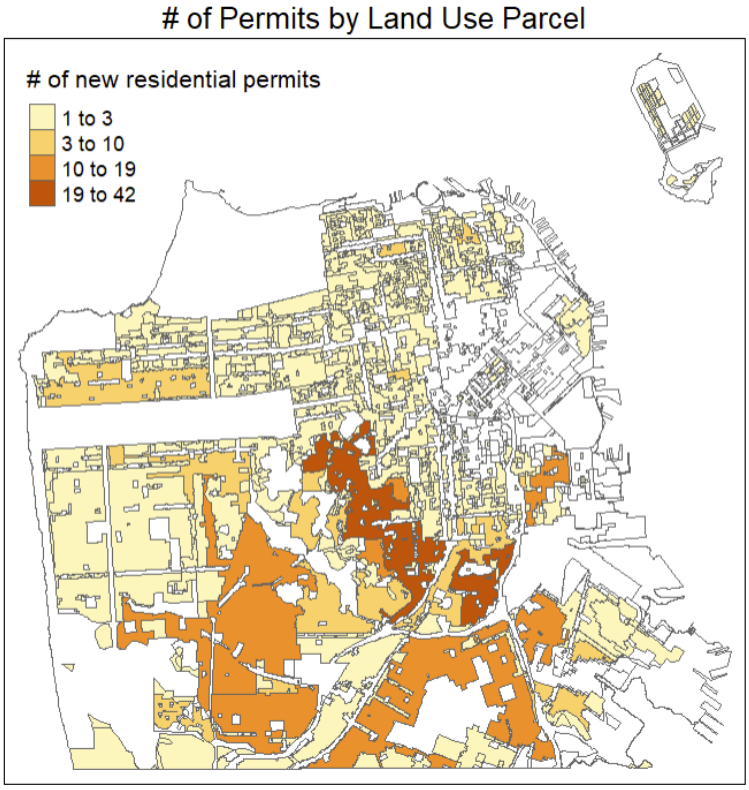


The two immediate observations one can make from the map are the highly homogenous spatial morphology of land-use type zoning, and the drastic differences in areal magnitude between single-family and multi-family districts. The map reveals an extremely segregated land-use type zoning morphology that moves from South to North, with all of single-family zoning districts located in the South of San Francisco, followed above by a strip of duplex/triplex zoning districts, and finally the vast majority of multi-family zoning districts are clustered in the North of San Francisco. The single-family zoning districts are often large and contiguous, while the areas of San Francisco containing multi-family zoning districts are partitioned into many miniscule zoning districts, and overall one can see there is substantially more land that is zoned for single-family homes. At first glance, this finding seems to run counterintuitive to the permitting statistics found earlier that skewed toward multifamily

development, and this contradiction is resolved when looking at the density maps, which we discuss next.

As mentioned earlier, the areal magnitude of the zoning districts varies greatly, and so an initial choropleth count map of the number of permits per zoning district, shown below, can give the misleading perception that the extremely large single-family and duplex/triplex zoning districts contain the most new residential construction:



In the above map, the largest zoning districts fall within the highest quartile of 19 to 42 building permits. However, once the total counts are standardized by area of the zoning districts as shown below**,** the density patterns of number of new residential permits *per kilometer* tell an entirely different story:

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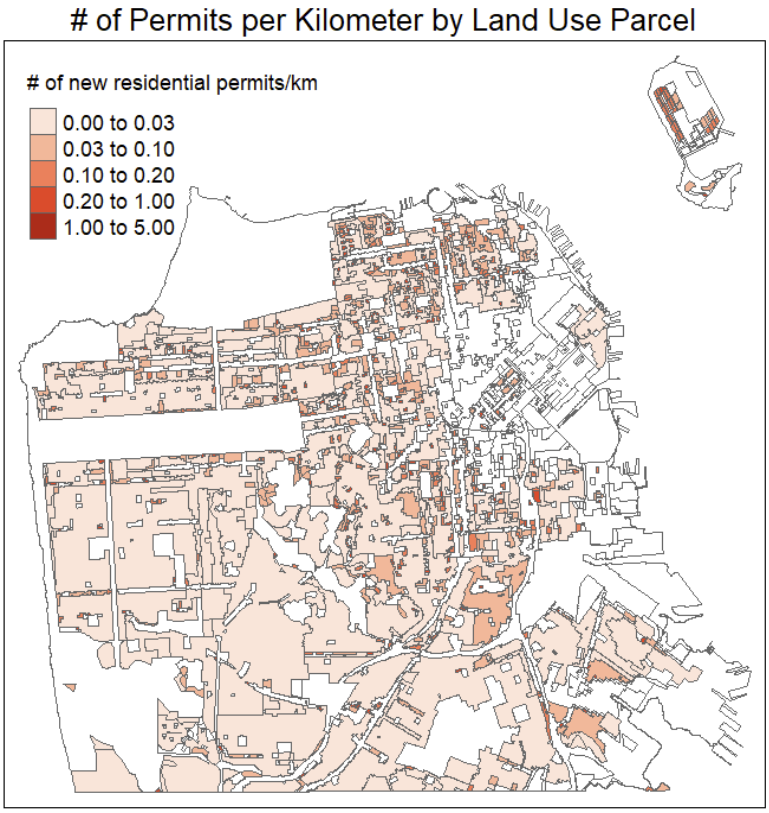

We see that the vast majority of the single family zoning districts (see first map in this sectoin) fall into the least dense quantile, while the darker shades of red that signify districts with denser residential construction number are increasingly found as one moves towards the middle and top of the map, which are the duplex/triplex and multi-family statistics. This pattern of density increasing as the districts transition from single to multi-family is strong spatial confirmation of the summary statistics discussed earlier, but due to the large variation in areal magnitude, it is difficult to visually conclude anything further. Hence, we now transition to a LISA analysis to better understand where clusters of high-density/low-density construction are.

Shown below are the cluster map and the significance map of a univariate LISA analysis on density of construction (permits per km), both of which are quite sparse:

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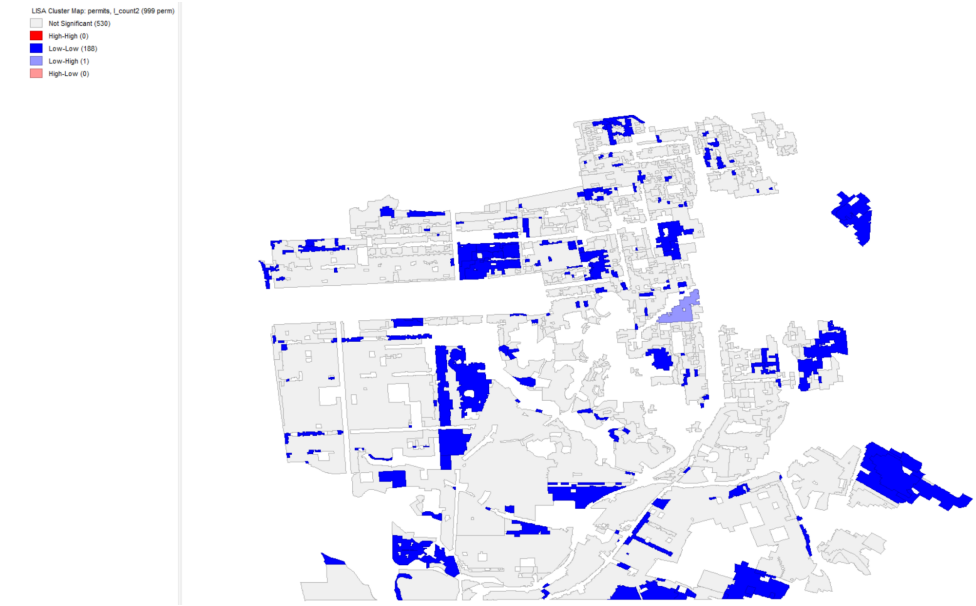

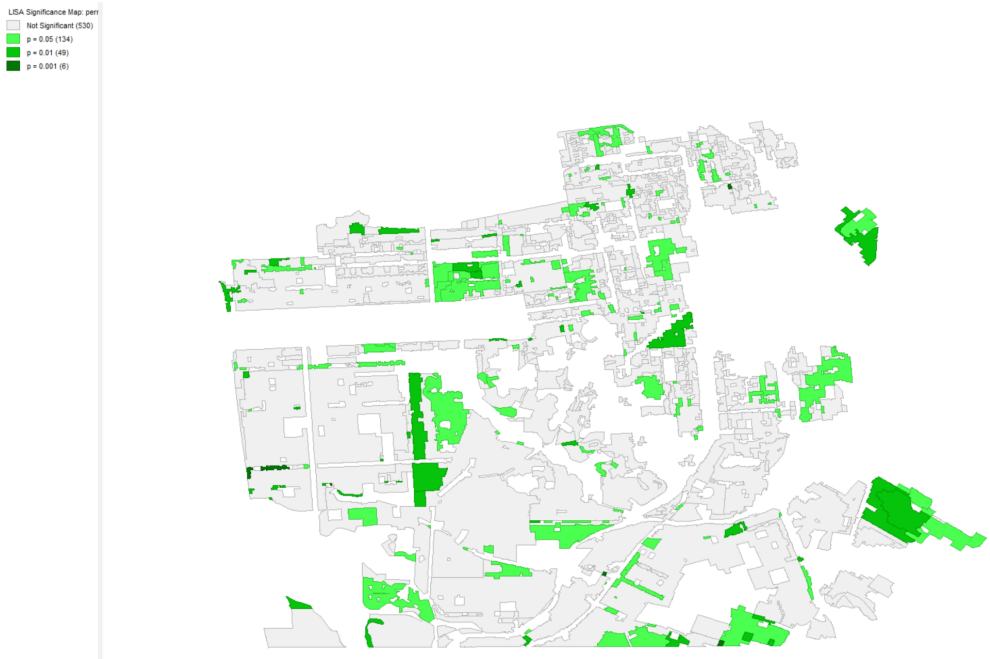

The only conclusive outcome of the LISA analysis is a small number of low-low clusters of construction density, but these clusters are scattered across all of San Francisco and do not seem to be part of any clear spatial pattern. Indeed, the bivariate Moran's I maps and scatterplot (not

included as there is not much to see) confirmed that there is no spatial correlation between land-use type and permits per km/construction density. Hence, although the initial exploratory statistics and mapping of land-use zoning morphology and construction density showed some distinctive trends such as the counterintuitive narrative of the majority of land being zoned for single-family, but a lack of construction density within single-family zones as compared to multi-family zones, the results show no conclusive overarching spatial relationship between the two variables of focus.

Conclusion

In summary, the two scales of analysis presented in this paper both had inconclusive statistical outcomes - there is no broad statement that can be made about how zoning requirements impact residential construction via a single statistical test. However, the descriptive and exploratory spatial mapping of San Francisco in high detail, breaking measures of zoning and residential construction down to their most elementary units of land parcels and permit point data, show that an individual city can certainly have distinctive relationships between zoning and construction. Our study of San Francisco showed that the spatial morphology of land-use zoning is segregated and prioritizes zoning land for single-family development. However, the majority of new residential construction still occurs in duplex/triplex and larger multi-family districts, as the density point patterns of new construction permits are concentrated in these districts. Hence, this paper highlights the methodological value of spatial analysis on single metropolitan areas when dealing with as complicated a process as residential construction, as broad-scale statistical tests for spatial or non-spatial often do not yield positive results as seen in the literature, but there

are still important trends to be picked up on that can help to better understand a city's housing environment and how it relates to patterns of residential construction.

We now return to the portion of the literature review on the three key questions to appraise a well-functioning housing market proposed by Scheutz, a senior fellow at Brookings Metro: Is the housing market producing enough additional housing to meet increased demand? Within a metropolitan area, is new housing being built in the locations where people most want to live (i.e. locations with the highest demand)? And does the housing market provide a diverse range of housing choices that match household budgets, size, and other characteristics (Scheutz, 2019)? Scheutz's questions characterize a well functioning housing market as an elastic, flexible environment in which residents have a high degree of mobility and freedom in choosing where they want to live. On the other hand, the portrait our spatial analysis of San Francisco paints is quite restrictive and maladaptive to Scheutz's criteria, as the largest zoning districts are the least dense, and as density requirements are constant across San Francisco, this is presumably because development is discouraged or suboptimal for developers in these districts. This could be a result of many factors, and plausible candidate explanations are the complex regulatory process of San Francisco, local opposition to increased density in single-family districts due to phenomena such as the Homevoter Hypothesis mentioned in the literature review, and many more.

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