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Urban Morphology and Housing Stock Granularity: A Cross-Scalar Analysis

Cem S. Kayatekin [1], Lorenzo Uribe[2]

[1]*Assistant Professor, IE School of Architecture and Design, Segovia, Spain*

[2]*Junior Architect, OMA, Rotterdam, Netherlands*

Abstract

Do urban morphological parameters trickle down to impact the diversity and granularity of a district's housing stock? Do urban morphological parameters impact housing rental values? These are the main questions underpinning this mixed-method study of four districts across Madrid and Barcelona—two districts developed in a bottom-up manner and exhibiting high morphological heterogeneity, and two developed in a top-down manner and exhibiting high morphological homogeneity. The large-scale statistical analyses conducted from October 2021 to May 2022 via the course of this research delves into the cross-district variations and commonalities of residential values, dwelling unit sizes, plot sizes, block sizes, and street widths. Three findings of import are uncovered—(1) possessing an intricate urban-morphological (or housing stock) granularity does not come hand-in-hand with having high urban morphological (or housing stock) diversity; (2) despite not possessing a higher diversity of urban morphological elements, the bottom-up districts still behaved as slightly-divergent and more-affordable real estate bubbles when compared to the top-down neighborhoods; and (3) across all the districts examined, smaller-scale plots consistently supported more than their expected share of smaller-scale dwelling units.

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Keywords

Urban morphology; Housing stock; Cross-solar analysis; Granularity

1. Introduction

How does a district's urban morphology impact the affordability and diversity of the neighborhood housing stock? This is the question at the heart of this paper.

As the background section will attempt to show, there is a substantial amount of literature focusing on how urban morphology can be (or has been) shaped in order to influence a neighborhood's housing stock, or more broadly, its residential fabric. However, there is a noteworthy scarcity of literature investigating the potential cross-scalar relationships between urban morphology and housing stock affordability and variety—two critical housing parameters actively supported by various contemporary urban initiatives, most notably the 15-minute city framework being adopted by a range of significant cities worldwide (Pozoukidou and Chatziyiannaki 2001, 9)

Within urban history and theory, there are in turn two discursive poles concerning this topic. On one end of the discursive spectrum, there is the hypothesis that repetitive and homogeneous urban-morphological conditions (i.e., a grid) offer the most *egalitarian* building stock for residential and non-residential activities (Kostof 1991, 100). On the other end of the spectrum, there is the hypothesis that urban morphological heterogeneity will support the formation and maintenance of wide ranges of footholds for residential and non-residential activities within the built environment (Kostof 1991, 75).

Both of these hypotheses however remain untested.

Operating within this discursive gap, this research attempts to gain insight into how the urban-morphological heterogeneity or homogeneity of selected districts (two in Madrid, two in Barcelona) impact the affordability and diversity of the neighborhood housing stock. This line of inquiry is focused around four domains:

- The precise physical differences between the morphologically heterogeneous versus homogeneous neighborhoods being studied.
- The differences observed throughout each district's rental residential real estate market.
- The differences in the affordability and diversity of the housing stock of each district
- The cross-scalar relationships that may potentially weave together some of the layers noted above.

1.1 Background

How can urban morphology be shaped in order to influence a district's housing stock? More specifically, in order to influence the variety and affordability of its housing stock? In order to understand the scope of the discourse relevant to this topic, an array of searches for academic journal articles was conducted.

A first search for literature with the terms *urban* (or *city*), *morphology*, and *inclusivity* (or *inclusion*) in their titles produced one article. This piece, Tadi et al. (2015), is framed primarily around the topic of urban energy / environmental performance. While the text does spend some time delving into the relationship between urban morphology and urban inclusivity/inclusion, this subject is addressed more from the lens of social cohesion, public space, mixed-use spaces, etc., as opposed to housing stock specifics.

A second search for literature with the terms *urban* (or *city*), *morphology*, and *diversity* in their titles was slightly more productive, producing eight articles. Six of these however were not relevant to the work at hand, as they focused on: (1) diversity of flora and fauna (five articles); and (2) energy consumption (one article). The remaining two pieces included Marcus and Bobovka (2019) which delves into the relationship between urban land divisions and urban economic diversity, and Da Silva and Samora (2020) which focuses on the morphological diversity inherent to informal settlements in Brazil. The latter work of Da Silva and Samora (2020) is less applicable to the subject at hand due to its sole focus on morphological parameters, however, the former article (Marcus and Bobovka 2019) is of clear relevance.

One of the main questions investigated by Marcus and Bobovka (2019, 2) is whether plot diversity impacts the economic diversity of a neighborhood. That is, whether high plot diversity supports high economic diversity; and low plot diversity in turn low economic diversity. While the results uncovered therein are "still far from conclusive" (Marcus and Bobovka 2019, 19), the text does note that there is a clear and important connection between plot diversity and economic diversity. Important to note however, that Marcus and Bobovka (2019) look at the diversity of economic actors, but not the diversity of shop sizes or shop rental rates, which would have been more comparable to what this paper is investigating.

A third search was conducted for literature with the terms *urban* (or *city*), *morphology,* and *housing* in their title. This produced seventeen pieces. Thirteen of these were not relevant to the work at hand, as they focused on: (1) daylighting, thermal comfort, or energy performance dynamics (four articles); (2) the architectural oeuvre of a specific architect or city assessed as historic or cultural heritage (four articles); (3) crime, antisocial behavior, community cohesion (three articles); and (4) top-down policy initiatives to alter certain neighborhoods' density metrics (two pieces). The remaining four pieces that appeared to be of greater relevance to this work included: Da Filicaia (2007), Xiao (2016), Zhang et al (2019), and Kostourou (2021)

Da Filicaia (2007), looking at three neighborhoods in London, focuses on the relationship between urban morphology and income brackets. A key finding here is that dead-end urban morphological conditions (i.e.., cul de sacs), establish niches within the urban fabric that are isolated from the broader urban network; and that these niches tended to support a residential population from the lower economic echelons, at least for the geography (i.e., three neighborhoods within London) and for the period of time (i.e., the early 2000's) around which the research is focused (Da Filicaia 2007, 61-65). Although dealing with a somewhat specific urban condition (i.e., cul de sacs) this finding begins to hint at a possible relationship between urban morphology and residential real estate values.

Xiao (2016) offers an in-depth literature review of the research being done around urban conditions impacting residential real estate values—namely scholarship looking at variables ranging from accessibility networks, proximity to urban externalities and infrastructures, environmental parameters, and neighborhood quality. What begins to become clearer with regard to the broader literature, via looking at Xiao (2016), is that much of the research being done around urban morphology and housing stock seems to be focused on developing more robust predictive real estate models that can take into account wide ranges of urban dynamics. Within these types of studies, block and street patterns, and their actual spatial parameters (as opposed to accessibility/mobility characteristics), seem to be used primarily to frame historiographic or qualitative descriptive backgrounds for the neighborhoods being studied.

Zhang et al. (2019) delve into the proximity of housing stock to certain urban infrastructures, e.g., "water bodies, green space, transit systems, or [Central Business Districts]" (Zhang et al 2019, 15) and their positive or negative impact on housing values. The urban morphology (in terms of street and block patterns) of the geography being studied (Wuhan City, China), while noted, is once more not the focus of the piece, but rather serves as a qualitative backdrop for the areas being studied.

And lastly, Kostourou (2021) offers a cleaner link to the question at hand. The text focuses on built-environmental conditions, and how initial pilot-scale and building-scale design decisions impact the incremental densification of an urban locale. The analyses are conducted around parameters of plot area, plot geometry, building volume, footprint, gross floor area, etc. (Kostourou 2021, 63). While the dwelling units inside the residential buildings are not examined to the same depth as building- and plot-scale parameters, Kostourou (2021) does offer a robust analysis of how the shaping of built-environmental conditions can impact, over the short- and long-term, the residential character of a neighborhood.

These were the three searches, conducted among a wide range of others, that produced the results most relevant to the research question at hand. One point to note—searches for *urban form* as opposed to *urban morphology* in conjunction with the keywords noted above, initially seemed to produce quite a high amount of literature. However, upon closer inspection, a nearly ubiquitous pattern was observed, was that urban form primarily was used as shorthand to denote varying scales of urban density, and their associated overarching built-environmental qualities—sprawling suburban settlements versus high-density urban cores, being the two ends of that urban form spectrum. The intricacies of urban morphology, and the associated cross-scalar focus on plot, street, and block patterns, were not taken into consideration with the same rigor as those that appeared under the *urban morphology* searches noted above.

After this approach was exhausted to its full potential, the bibliographies of the relevant articles were mined to try to obtain further pieces of import. Through this process, the work of Siksna (1997), Marcus (2005), Ryan (2008), Doherty et al. (2009), Ko (2014), Rode et al. (2014), Danenberg et al. (2018), Long et al. (2019), Meng and Xing (2019), Narvaez (2019), Li et al. (2020), Thai et al. (2020), and Lucato (2020) were homed in upon.

While these discursive pieces offer some cleaner connections to the topic at hand, the relationship between urban morphology and housing stock diversity is once more not addressed directly. Rather, this remaining discursive landscape seems to broadly fall under two areas of inquiry: (1) the relationship between urban plot patterns/morphologies and urban economic diversity; and (2) the intricacies of "urban vibrancy" within urban neighborhoods, a term linked back to the work of Jacobs (1961).

In the first area of inquiry, one can locate Marcus (2005), Danenberg et al. (2018), and Thai et al. (2020). These works look at (1) the relationship between urban plot density and the density of economic actors (Marcus 2005); (2) the role played by the subdivisibility and diversity of plots in supporting urban economic diversity (Danenberg et al. 2018); and (3) differences in urban businesses in street-facing versus courtyard-facing conditions in Hanoi (Thai et al. 2020). Kropf (2011) can also be placed within this discursive landscape, as it pushes the methodological framework for analyzing urban plot systems in the context of such research questions.

Siksna (1997) also falls within this area of discourse, taking a highly specific stance with regard to urban-morphological elements and their idealized dimensions. The author asserts a precise optimal block size for a pedestrian-friendly city—i.e., square blocks that have a width and length of 60-70m (Siksna 1997, 29). Plot sizes are idealized at 15-20m widths and 30-40m depths, or around 450 – 800 sq.m. in area. These plot sizes are argued to be

optimal for producing small-to-mid-scale "traditional and contemporary building forms" and for developers to amalgamate multiple lots together as required (Siksna 1997, 29). Ryan (2008) although not giving such specific dimensions, reaffirms the idealized smaller-scale block size, pointing to the negative impacts triggered by the superblock typologies utilized to remake the urban fabric of Detroit in the 20th Century.

Rode et al. (2014, 156) for instance suggest creating compact urban blocks or tall multi-family building typologies to better support thermal efficiency at the unit scale. Ko (2014, 342) echoes these points but also stresses the importance of maximizing northern and southern exposures of plots in order to maximize potential solar gain as well as solar control.

Once more with this literature, the ideal of the small-to-moderate block re-emerges. Idealized plot sizes are not noted, however, in the case of Ko (2014), the importance of controlling plot orientation is brought to the forefront. Doherty et al. (2009) also echo the energy- and thermal efficiency of compact small-to-moderate urban blocks, however underscore that this type of urban morphology should not be imposed upon cultures whose social networks are accustomed to less dense settlement structures—i.e., the less-dense suburban structure ubiquitously observed throughout Australia.

Within the works of Long et al. (2019), Meng and Xing (2019), and Li et al. (2020), in turn, the topic of 'urban vibrancy' is the underpinning area of investigation. A key dilemma framed by Li et al. (2020, 3) is that "no definition of urban vibrancy is uniformly accepted among scholars and authorities." Yet some cornerstones of a vibrant neighborhood are understood to include: "small-to-moderate blocks with dense street networks, diverse and intense construction, multilevel/multiple city configurations [...] [and] intensity of human activities in urban space" (Li et al. 2020, 3). Diversity of housing stock, although presumably falling under the umbrella of *diverse and intense construction*, does not seem to be directly accounted for.

The works of Narvaez (2019) and Lucato (2020) were the two pieces that didn't fall within the above two discursive umbrellas. Narvaez (2019) offers a combined analysis of urban block systems and accessibility/mobility network analysis, confirming the strong relationship between accessibility and real estate values. Lucato (2020) in turn frames a historico-cultural counterpoint to this argument, noting that welfare estates in Madrid exhibit high accessibility but support lower property values due to their underpinning nature as affordable housing structures.

In looking at the literature in its entirety, three summarizing points can be drawn: (1) a substantial portion of the discourse, anchored around a network-analysis methodology (oftentimes linking back to space syntax), is primarily geared towards the assessment of real estate values or economic activities in relation to mobility/accessibility networks, and proximity to positive/negative externalities; (2) while the spatial intricacies of streets, buildings, plots, and blocks are accounted for to some degree, these parameters are largely overshadowed by the methodological structure, and the data that said structure is focused around, noted in the prior point; and (3) while some work does delve into the dynamics of the housing stock, those that attempt this inquiry in a cross scalar manner (e.g., working across the block-plot-unit spectrum in a rigorous manner) are few and far in between (Kostourou 2021 being the primary example noted in this literature review).

Looking across this literature, certain urban-morphological qualities are consistently underscored in relation to supporting idealized built environmental dynamics. Although not directly addressing housing options and variability, these urban morphological qualities include small-to-moderate blocks, fine-grained plots, and fine-grained street patterns.

This paper is geared towards addressing the discursive gap noted herein while keeping these urban-morphological parameters in mind.

2. Methodology

Within this study, four neighborhoods in Madrid and Barcelona (two per city) were analyzed in terms of parameters concerning urban morphology, the rental real estate market, and housing stock.

The districts were selected based on their possession of widely differing (as widely as was possible) urban morphological qualities. Two districts (one in Madrid and one in Barcelona) were selected for their more

homogeneous urban morphological character, and two (again one in each city) were selected for their more heterogeneous urban morphological character. The price of housing (sold/purchased), most recently coded by the two municipalities in 2019, was used as a control variable so as to compare neighborhoods of comparable income levels. Conventionally, median family incomes would have been a more useful measure, however, this data was not readily available via municipal archives for all districts.

While socio-political narratives were not a discursive layer of focus within this study, it was still deemed important to filter out potentially conflicting urban development trajectories in the selection of these districts. Both of the morphologically heterogeneous districts were developed in a bottom-up manner beyond the confines of a top-down urban plan set in motion via centralized urban authorities; and similarly, both morphologically homogeneous districts were heavily shaped via preconceived top-down plans. For the remainder of the paper, the term *bottom-up* will be used (interchangeably with *morphologically heterogeneous*) to denote the morphologically heterogeneous districts; and *top-down* (interchangeably with *morphologically-homogeneous*) to denote the morphologically-homogeneous districts.

The districts selected were Bellas Vistas (bottom-up, Madrid), Palos de la Frontera (top-down, Madrid), Vila de Gracia (bottom-up, Barcelona), and Nova Esquerra de l'Eixample (top-down, Barcelona) The price of housing (sold/purchased) for these areas, obtained via the digital municipal archives of Madrid and Barcelona, were 3,943 euros / sq.m. (Palos de la Frontera) and 3,365 euros / sq.m. (Bellas Vistas) for Madrid; and 4,198 euros / sq.m. (Nova Esquerra) and 4,836 euros / sq.m. (Vila de Gracia) for Barcelona. While a nearly identical range of real estate values would have been ideal, this was the closest fitting pairing of morphologically divergent districts noted in these two cities.

Figure 1a, b, c, d. Satellite photos at 5,700 ft. altitude taken via Google Earth, of Madrid's top-down Palos de la Frontera (Figure 1a, top left) and bottom-up Bellas Vistas (Figure 1b, top right); and Barcelona's top-down Nova Esquerra de l'Eixample (Figure 1c, bottom left) along with bottom-up Vila de Gracia (Figure 1d, bottom right).

Historically, both Madrid and Barcelona set in motion comprehensive urban plans in the mid-nineteenth century. These are known as the *Plan Castro* in Madrid, and the *Cerda Plan* in Barcelona. The two top-down districts in

Barcelona were portions of the cities directly shaped via these two comprehensive plans. The two bottom-up districts being studied were either: formed in a concurrent timeline to the urban plan but in a bottom-up manner outside of the plan's boundaries, as in the case of Bellas Vistas; or seeded prior to the urban plan's conception, as in the case of Vila de Gracia (Ayuntamiento de Madrid, 2022; Ajuntament de Barcelona, 2022)

In terms of urban morphological data, block widths, block lengths, block areas, plot areas, and street widths were documented and coded. The publicly-accessible and digitized national cadastral map of Spain maintained via *la Sede Electrónica del Catastro,* was the main resource utilized for this process.

For the rental real estate market, Idealista, one of the two most actively used real estate websites in Spain (the other being Fotocasa), was mined for dwelling units for rent during October - December 2021. A total of 755 rental units were found and coded: 137 in Palos de la Frontera (Madrid), 132 in Bellas Vistas (Madrid), 206 in Nova Esquerra de l'Eixample (Barcelona), and 280 for Vila de Gracia (Barcelona). For each unit, the following information was mined and coded: location, area (sq.m.), number of bedrooms, rental price, and whether the units faced the street front (i.e., listed as "exterior") or an internal courtyard (i.e., listed as "interior").

The rental price and area were the primary variables used in the results and findings section. Whereas the location, number of bedrooms, and internal/external orientation were used in order to ensure comparable assortments of rental units were being analyzed across the districts. This required the omission of 12 units from Vila de Gracia, 7 from Nova Esquerra, 3 from Palos de la Frontera, and 4 from Bellas Vistas. After this filtering, all of the rental unit assortments fell within +-4% range of each other. More precisely, 91.3% (+/-3.2%) were found on non-main-street/boulevard and non-block-corner conditions; 6.4% (+/-2.8%) were found on main-street/boulevard conditions; and 2.3% (+/-0.8%) were found on block-corner conditions.

For the housing stock specifics, the digital archives of the Sede Electronica del Catastro were the resource utilized. For each neighborhood, randomized systematic sampling was used, with a sample size calculated to achieve a 95% confidence interval, with a 5% margin of error. The final sample sizes required to achieve this level of confidence were: 66 out of 79 blocks for Bellas Vistas (randomized systematic sampling required, in this case, the systematic skipping of every 6th block to achieve the desired sample count), 45 out of the 50 blocks of Palos de la Frontera, 137 out of the 211 blocks of Vila de Gracia, and 59 out of the 68 blocks of Nova Esquerra de l'Eixample. For these blocks, all of the plot areas and dwelling unit areas were manually coded (in April-July 2022), as there was no means of downloading the information en masse via said archives. These datasets amounted to 780 plots and 8,193 units for Bellas Vistas; 507 plots and 12,204 units for Palos de la Frontera; 2,525 plots and 14,941 units for Vila de Gracia; and 1,181 plots and 20,959 units for Nova Esquerra. This data collection and coding phase took place from October 2021 – May 2022.

Beyond data analyses involving distribution curves; minimum, maximum, median, and mode values; calculations of quintiles, etc., the Simpson Diversity Index (SDI) was used in order to quantify and compare the diversity of dwelling unit sizes, plot sizes, block sizes, and street widths in each neighborhood. The use of SDI calculations was based on the work of Marcus and Bobkova (2019), although within that work it was used to quantify the diversity of economic actors, as opposed to spatial conditions.

In order to conduct SDI calculations, for each variable, size-based categories were first established. For instance, for block sizes, categories based on increments of 1,000 sq.m. were set up—e.g., blocks with an area of 0-1,000sq.m. fell within one category, blocks with an area of 1,001-2,000sq.m. another category, and so on. The SDI value was then calculated based on these 31 categories. While the details are explained further wherever the SDI appears in the subsequent sections, a close variation of this method was the basis utilized throughout the paper.

The use of this metric was not pre-structured into the initial research design but rather was introduced during the data analysis stage, in order to try to check and quantify the suppositions of a neighborhood being more or less diverse than its counterparts when looking at distribution curves. The formula used for calculating this metric is:

$$D = 1 - (\sum n(n-1)/N(N-1))$$

Within this formula, n represents the number of individuals of a single category (e.g. blocks of a neighborhood that are between 3,000-4,000 sq.m. in area) and N represents the total number of all elements (e.g., all the blocks in said neighborhood). The maximum value of the Simpson Diversity Index is 1.0 (indicating infinite diversity), and the lowest value is 0.0 (indicating no diversity).

3. Results

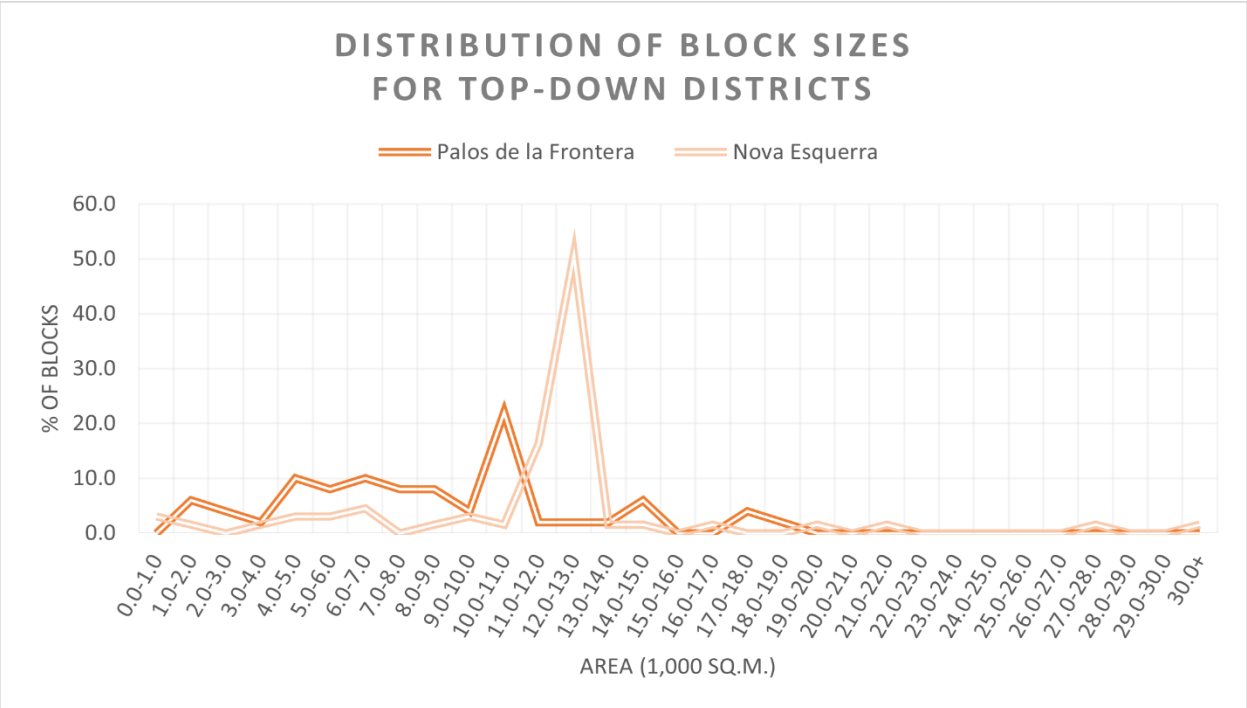
The results that follow are framed around the following four domains:

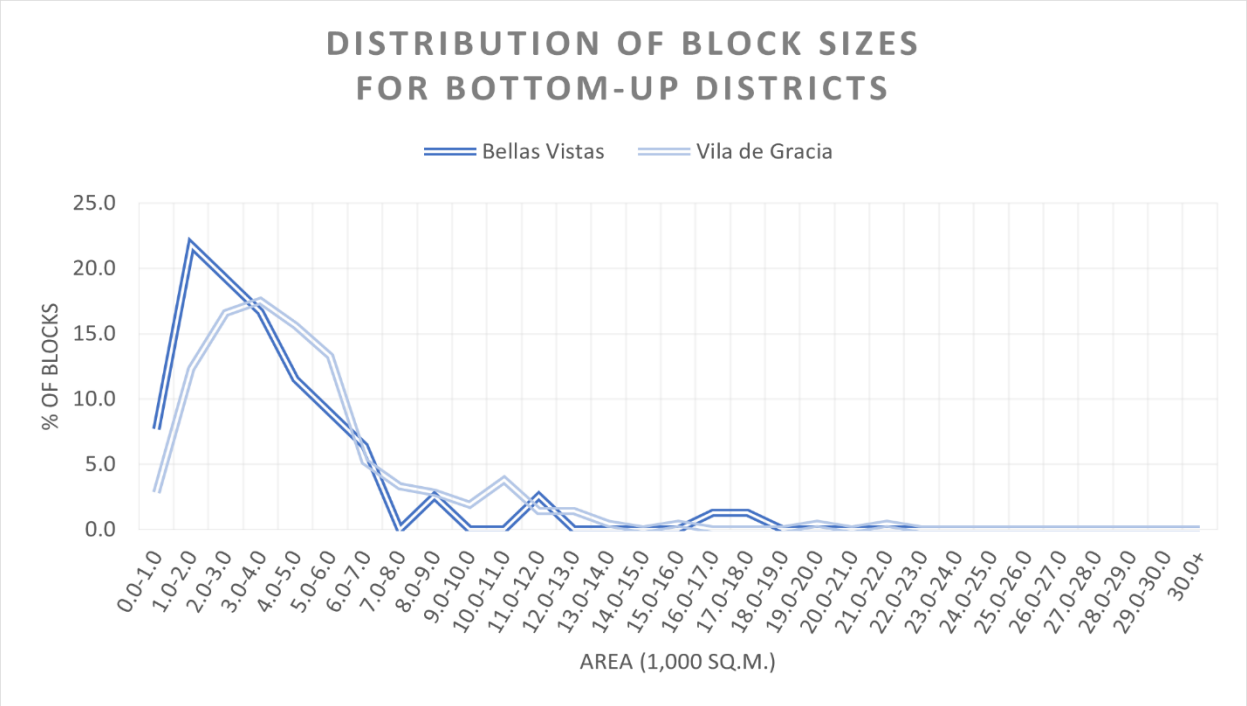
- The urban morphological differences between the neighborhoods being studied, and whether there are common patterns that emerge across the bottom-up and top-down pairs of districts.
- The differences in rental residential real estate markets in said districts.
- The differences in the ranges and distributions of dwelling unit sizes supported in the bottom-up versus top-down neighborhoods.
- The cross-scalar relationships weaving together some of the layers and parameters noted in the above three areas.

3.1 Urban Morphology

In assessing the urban-morphological differences between the four neighborhoods, analyses were centered around three variables—block sizes, plot sizes, and street widths. For these variables, data is presented in the form of (1) distribution graphs; (2) differences in minimum, maximum, and median values; (3) differences in urban-morphological diversity, with diversity being calculated around the Simpson Diversity Index (SDI) values; and (4) differences in urban-morphological granularity—that is, whether districts supported relatively higher or lower densities of the morphological elements in question.

3.1.1 Blocks





Figures 2a, b. Distribution curves showing block sizes for top-down (Figure 2a, top image) and bottom-up (Figure 2b, bottom image)) districts in Madrid and Barcelona.

The minimum block sizes in the bottom-up districts were 245sq.m. (Bellas Vistas) and 457sq.m. (Vila de Gracia), while for the top-down they were 1,574sq.m. (Palos de la Frontera) and 732sq.m. (Nova Esquerra). This indicates that the top-down districts in Madrid had a minimum block size of 542.4% larger than the bottom-up, and in Barcelona, the top-down had a minimum block size of 60.2% larger than the bottom-up.

The maximum block sizes in the bottom-up districts were 17,200 sq.m. (Bellas Vistas) and 21,400sq.m. (Vila de Gracia), while for the top-down they were 18,500sq.m. (Palos de la Frontera) and 59,700sq.m. (Nova Esquerra). This indicates that the top-down districts in Madrid had a maximum block size of 8.6% larger than the bottom-up, and in Barcelona, the top-down had a maximum block size of 179.0% larger than the bottom-up.

The median block sizes in the bottom-up districts were 3,206 sq.m. (Bellas Vistas) and 4,048sq.m. (Vila de Gracia), while for the top-down they were 8,295sq.m. (Palos de la Frontera) and 12,500sq.m. (Nova Esquerra). This indicates that the top-down districts in Madrid had a median block size 158.7% larger than the bottom-up, and in Barcelona, the top-down had a median block size 208.8% larger than the bottom-up.

Across the board in both cities, whether it be minimum, maximum, or median values, the top-down had larger blocks when compared to the bottom-up.

What of the diversity of block sizes?

In order to calculate the Simpson Diversity Index (SDI), blocks were first categorized by size. These size categories were based on increments of 1,000 sq.m., meaning that blocks with an area of 0-1,000 sq.m. fell within one category, blocks with an area of 1,001-2,000 sq.m. another category, and so on. A total of 31 categories were created, the final one being blocks greater than 30,000 sq.m. in area. The SDI value was then calculated based on these categories.

The SDI values observed in the bottom-up districts, with regard to block sizes, were 0.87 (Bellas Vistas) and 0.88 (Vila de Gracia), while for the top-down they were 0.92 (Palos de la Frontera) and 0.72 (Nova Esquerra). This indicates that in Barcelona, the bottom-up district is 22.2% more diverse in terms of block sizes than the top-down. However, this is not reflected in Madrid. Unexpectedly, while the SDI values for Palos de la Frontera and Bellas Vistas were relatively close, the top-down actually supported a 5.7% higher diversity of block sizes than the bottom-up.

With the Madrid districts leaning one way and the Barcelona districts the other, the case of top-down versus bottom-up variations in urban morphological diversity at the scale of the block, in this case, remains inconclusive.

The final metric of import for this section concerns urban-morphological grain or granularity.

What does granularity entail?

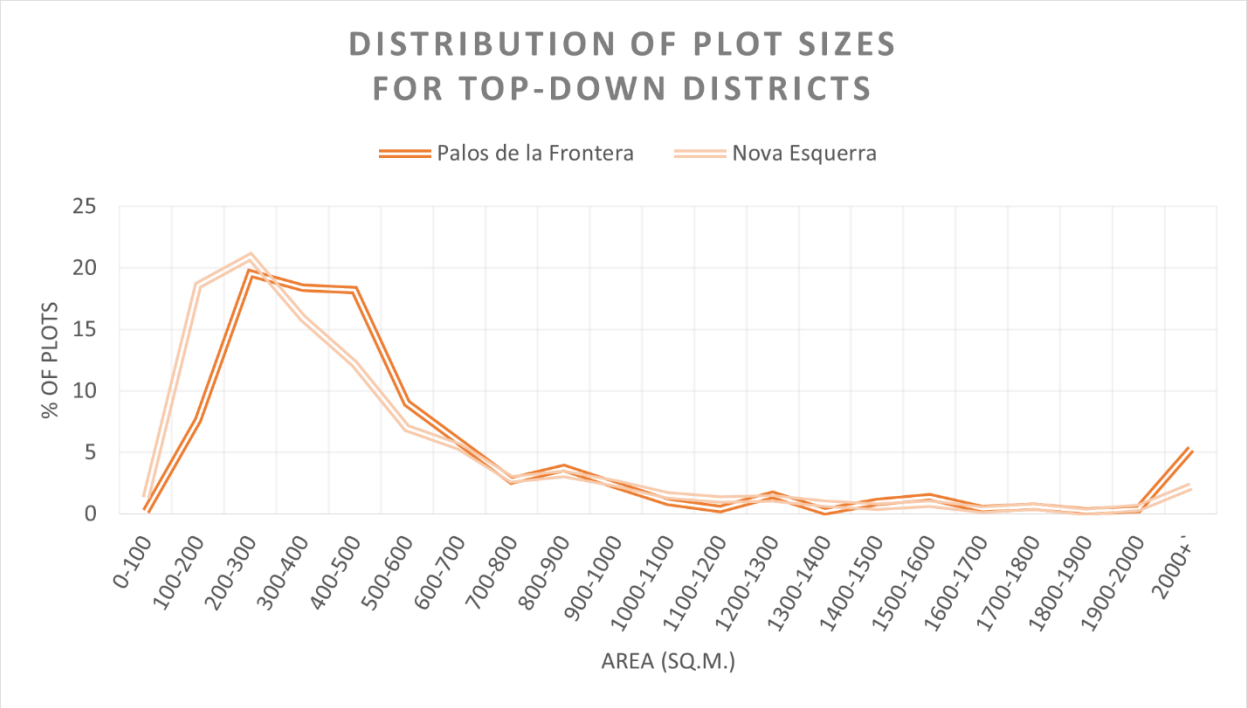
Plots and blocks are inherently two-dimensional morphological elements. A plot cannot be placed on top of another plot, nor a block on top of another block. A 10,000 sq.m. district with a high density of blocks and plots, when compared to a 10,000 sq.m. district with a low density of blocks and plots, would exhibit a more intricate urban-morphological granularity. Plots and blocks, in order to achieve higher densities, would naturally have to be smaller than those in the other less-dense districts. Hence the *grain* of the first district would be of a finer nature. Another suitable synonym for this could be urban-morphological intricacy.

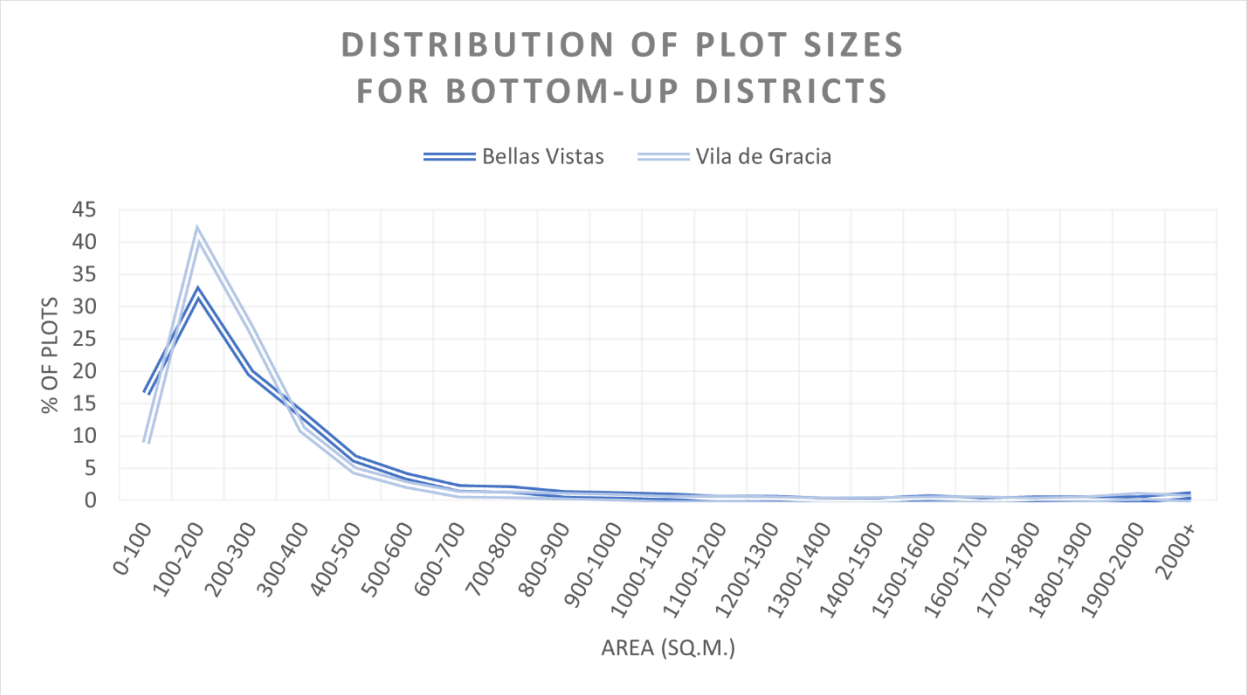
However, having a high density of elements and having a highly intricate urban fabric are not always synonymous. This equivalency does not carry so cleanly into the third dimension. Unlike plots and blocks, dwelling units can be stacked on top of other units. A district with a homogeneous grid of very tall residential buildings, with minimal setbacks between neighboring buildings, with each building supporting thousands of units—this district would exhibit a highly dense housing stock. However, if all the dwelling units were large-scale units (e.g., over 200 sq.m.), then this district, while still being high-density, would not exhibit intricate granularity in its housing stock.

With regard to block-scale granularity, within the areas of the districts studied, the bottom-up contained 79 blocks (Bellas Vistas) and 211 blocks (Vila de Gracia), whereas the top-down contained 50 blocks (Palos de la Frontera) and 68 blocks (Nova Esquerra). With differences in overall geographic area corrected for, this indicates that the top-down district in Madrid had 55.1% fewer blocks than the bottom-up, and in Barcelona, the top-down had 60.4% fewer blocks than the bottom-up.

The bottom-up districts therefore exhibited a much higher density of blocks, in both cities. Put another way, the bottom-up consistently exhibited a more intricate (but not more diverse) urban morphological granularity with respect to block sizes.

3.1.2 Plots





Figures 3a, b. Distribution curves showing plot sizes for top-down (Figure 3a, top image) and bottom-up (Figure 3b, bottom image) districts in Madrid and Barcelona.

The minimum plot sizes in the bottom-up districts were 39sq.m. (Bellas Vistas) and 18sq.m. (Vila de Gracia), while for the top-down they were 75sq.m. (Palos de la Frontera) and 44sq.m. (Nova Esquerra). This indicates that the top-down districts in Madrid had a minimum plot size of 92.3% larger than the bottom-up, and in Barcelona, the top-down had a minimum plot size of 144.4% larger than the bottom-up.

The maximum plot sizes in the bottom-up districts were 3,549 sq.m. (Bellas Vistas) and 2,976sq.m. (Vila de Gracia), while for the top-down they were 10,376sq.m. (Palos de la Frontera) and 21,176sq.m. (Nova Esquerra). This indicates that the top-down districts in Madrid had a maximum plot size of 192.4% larger than the bottom-up, and in Barcelona, the top-down had a maximum plot size of 611.6% larger than the bottom-up.

The median plot sizes in the bottom-up districts were 207 sq.m. (Bellas Vistas) and 199sq.m. (Vila de Gracia), while for the top-down they were 417 sq.m. (Palos de la Frontera) and 356sq.m. (Nova Esquerra). This indicates that the top-down districts in Madrid had a median plot size that was 101.4% larger than the bottom-up, and in Barcelona, the top-down had a median plot size 78.9% larger than the bottom-up.

In order to calculate the Simpson Diversity Index (SDI), plots were first categorized by size. These size categories were based on increments of 100sq.m., meaning that plots with an area of 0-100sq.m. fell within one category, plots with an area of 101-200sq.m. another category, and so on. A total of 21 categories were created, the final one being plots greater than 2,000 sq.m. in area. The SDI value was then calculated based on these categories.

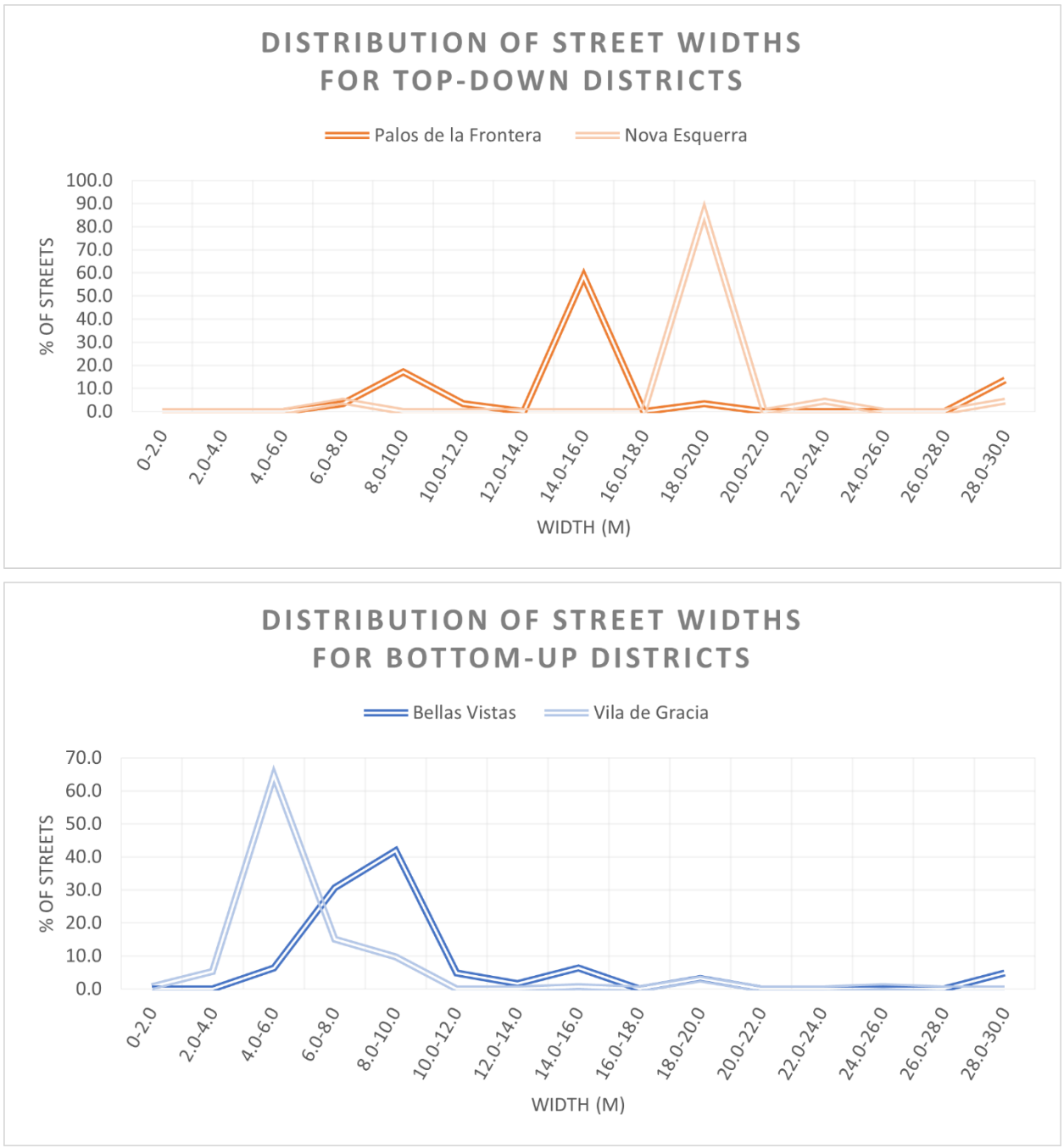
The SDI values in the bottom-up districts were 0.80 (Bellas Vistas) and 0.73 (Vila de Gracia), while for the top-down they were 0.87 (Palos de la Frontera) and 0.87 (Nova Esquerra). This indicates that the top-down district in Madrid had 8.2% higher diversity of plot sizes than the bottom-up, and the top-down in Barcelona had 18.0% higher diversity than the bottom-up.

With regard to granularity, the total number of plots observed in the bottom-up districts was 780 (Bellas Vistas) and 2,525 (Vila de Gracia), while for the top-down they were 507 (Palos de la Frontera) and 1,181 (Nova Esquerra). With differences in overall geographic area corrected for, this indicates that the top-down district in Madrid had 53.4% fewer plots than the bottom-up, and in Barcelona, the top-down had 42.5% fewer plots than the bottom-up.

At the scale of the plot therefore, the data shows that while bottom-up districts supported smaller plot sizes across the board (minimum, maximum, and median) when compared to the top-down, unexpectedly the top-down consistently supported higher levels of plot-size diversity than their bottom-up counterparts. This indicates that at the plot scale,

bottom-up districts had less diverse but more intricate urban morphology—underscoring the discrepancy between urban morphological diversity and granularity noted in the prior section.

3.1.3 Streets



Figures 4a, b. Distribution curves showing block sizes for top-down (Figure 4a, top image) and bottom-up (Figure 4b, bottom image) districts in Madrid and Barcelona

Street widths are of particular importance to understanding the variations of public space that permeate throughout a neighborhood. Their dimensions have significant influence over outdoor environmental qualities of light, air, and noise—qualities that exert influence over the indoor environmental quality of dwelling units.

The minimum street widths observed in the bottom-up districts were 5m (Bellas Vistas) and 2m. (Vila de Gracia), while for the top-down they were 8m (both Palos de la Frontera and Nova Esquerra). The maximum street widths observed in the bottom-up districts were 40m (Bellas Vistas) and 26m (Vila de Gracia), while for the top-down they were 40m (Palos de la Frontera) and 50m (Nova Esquerra). The median street widths observed in the bottom-up

districts were 9m (Bellas Vistas) and 6m (Vila de Gracia), while for the top-down they were 15m (Palos de la Frontera) and 26m (Nova Esquerra).

Aside from the maximum street widths being equivalent in Bellas Vistas and Palos de la Frontera, once more the top-down had larger street widths when compared to their bottom-up counterparts (across minimum, maximum, and median values).

In order to calculate diversity, street widths were sorted into categories according to size, starting with widths of 0-2m, and increasing in increments of 2m, with the final category being 30m+ wide streets. With these categories, the SDI values in the bottom-up districts were 0.73 (Bellas Vistas) and 0.55 (Vila de Gracia), and for the top-down districts 0.63 (Palos de la Frontera) and 0.26 (Nova Esquerra). This indicates that the bottom-up districts supported 16.3% (Madrid) and 111.8% (Barcelona) higher levels of street-width diversity when compared to their top-down counterparts.

With regard to granularity, the total number of streets observed in the bottom-up districts was 66 (Bellas Vistas) and 133 (Vila de Gracia), while for the top-down they were 35 (Palos de la Frontera) and 26 (Nova Esquerra). With differences in overall geographic area corrected for, this indicates that the top-down district in Madrid had 62.4% fewer streets than the bottom-up, and in Barcelona, the top-down had 75.9% fewer streets than the bottom-up.

Unlike the prior calculations regarding blocks and plots, the morphological behavior of streets is fairly consistent across the board. The bottom-up supported smaller street widths (with regard to minimums, maximums, and medians), more diverse street widths, as well as a more intricate street network.

3.1.4 Synthesis

Taking these three layers of urban morphological analyses into consideration—concerning block sizes, plot sizes, and street widths—what emerges?

Aside from one result (maximum street widths in the top-down and bottom-up districts of Madrid being equal), the top-down districts consistently supported larger morphological elements when compared to the bottom-up (for minimum, maximum, as well as median values). The top-down supported 57.8% fewer blocks, 48.0% fewer plots, and 69.2% fewer streets, on average, when compared to their bottom-up counterparts. This clearly indicates that the bottom-up districts exhibited a more intricate morphological grain across scales.

Diversity is a more complicated picture. With block sizes, the findings were split—the bottom-up outperforming the top-down in Barcelona, and vice versa in Madrid. With plot sizes, the top-down was found to support a higher diversity than the bottom-up, in both Madrid and Barcelona. And with street widths, the bottom-up consistently exhibited higher diversity than the top-down, in both cities.

These findings underscore that there is a clear and significant discrepancy between urban morphological diversity, and urban-morphological grain (i.e., urban morphological intricacy). Namely, that diversity does not come hand-in-hand with intricacy, and vice versa.

3.2 Rental Real Estate Values

Do the bottom-up neighborhoods sampled support different rental residential real estate markets when compared to their top-down counterparts?

The hypothesized answer to this query was in the affirmative. The bottom-up neighborhoods studied were expected to behave as anomalous real estate bubbles within the urban fabric, offering a significantly wider, and on the lower end of the spectrum, more affordable, range of rental rates (euros / sq.m. / month) when compared to their top-down counterparts. This speculation leaned on the cross-scalar supposition that: (1) bottom-up districts will tend to exhibit a higher diversity of public space conditions; (2) this heightened diversity of public-space conditions will create diversities of outside-environmental qualities of light, air, views, noise, privacy, etc.; and (3) this will help to shape a wider range of appealing and unappealing real-estate conditions, directly impacting the range of rental rates throughout the neighborhood.

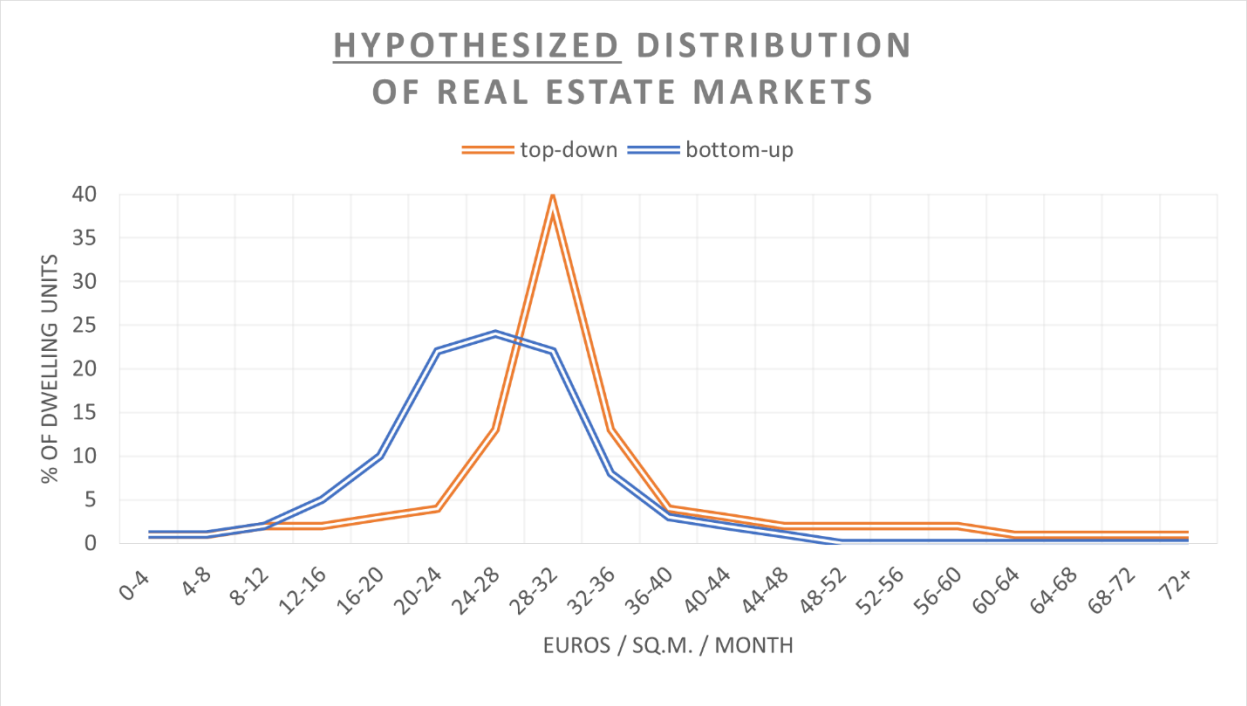


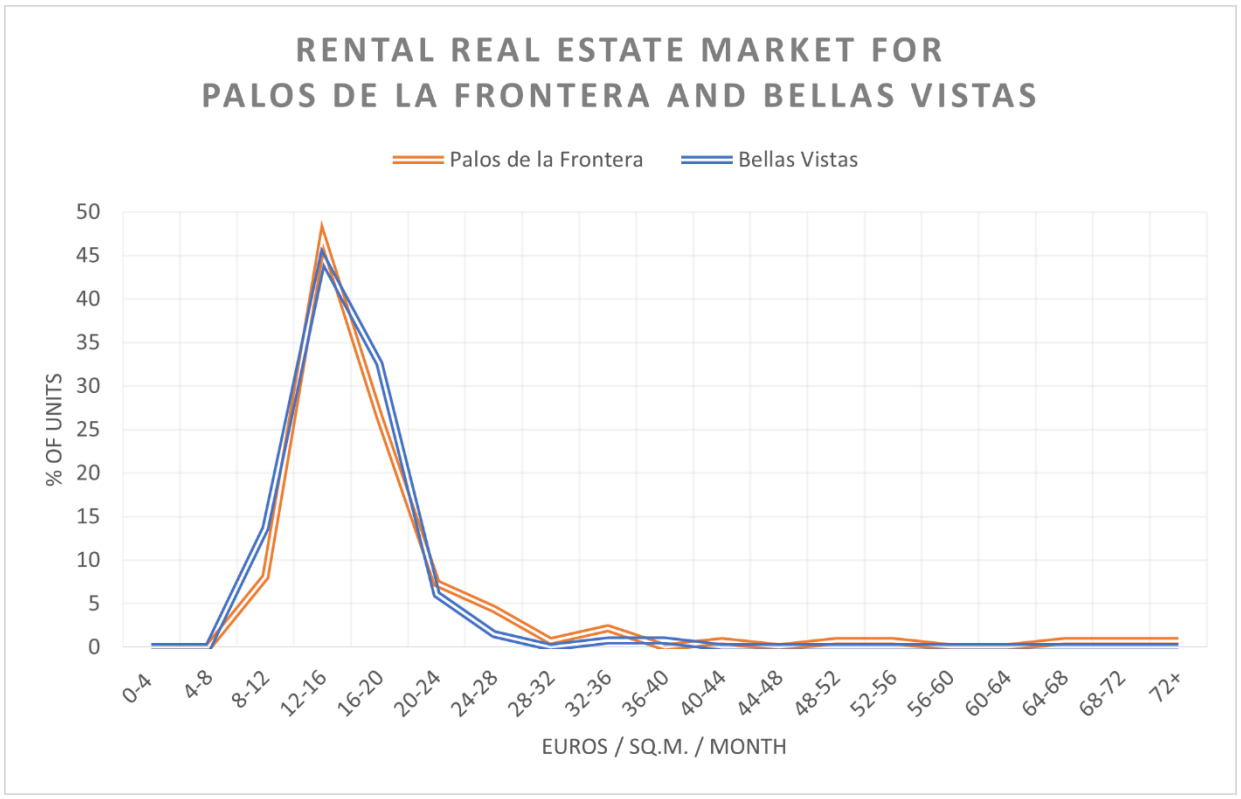
Figure 5: Hypothesized distribution curves of the real estate values of the top-down versus bottom-up districts.

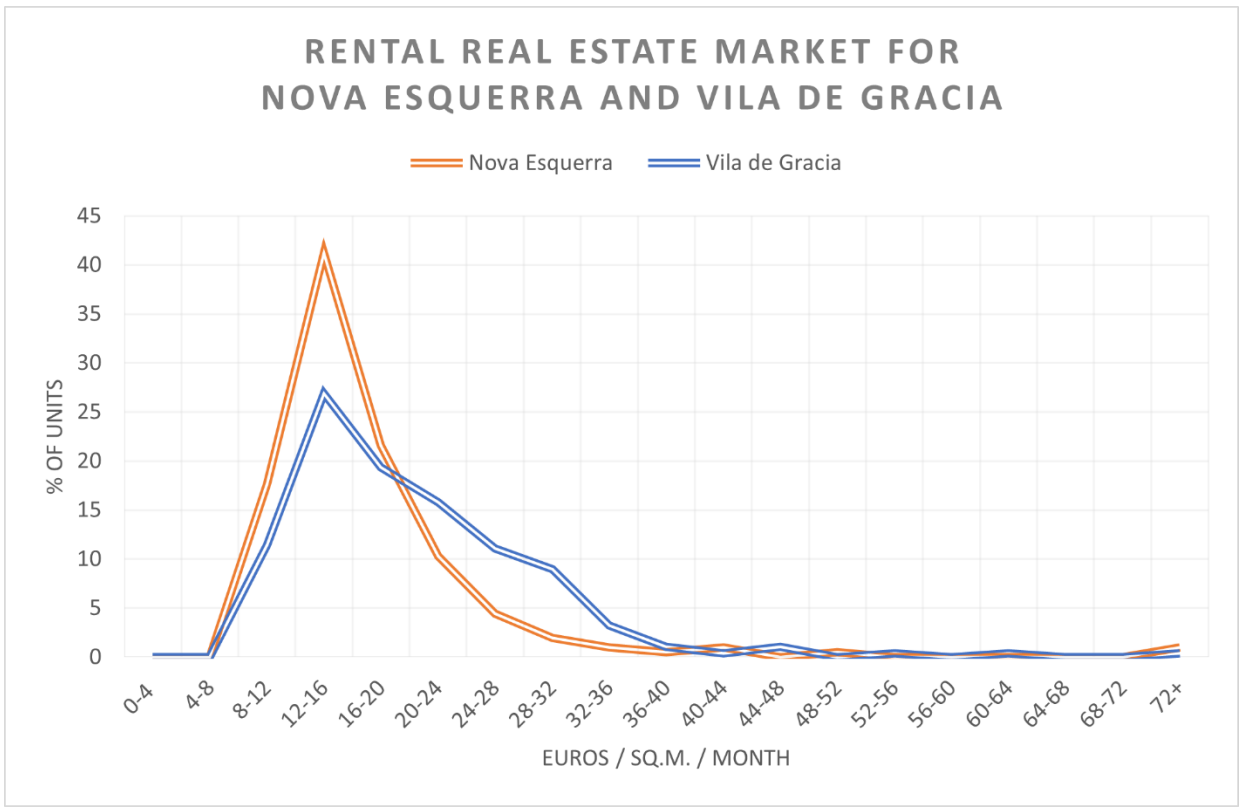
The minimum rents in the bottom-up districts were 9.8 euros / sq.m. / month (Bellas Vistas) and 8.1 euros / sq.m. / month (Vila de Gracia), while for the top-down they were 10.0 euros / sq.m. / month (Palos de la Frontera) and 9.2 euros / sq.m. / month (Nova Esquerra). This indicates the top-down districts in Madrid had a minimum rent 2.5% higher than the bottom-up, and in Barcelona, the top-down had a minimum rent 13.9% higher than the bottom-up.

The maximum rents in the bottom-up districts were 37.8 euros / sq.m. / month (Bellas Vistas) and 72.5 euros / sq.m. / month (Vila de Gracia), while for the top-down they were 87.5 euros / sq.m. / month (Palos de la Frontera) and 89.2 euros / sq.m. / month (Nova Esquerra). This indicates the top-down districts in Madrid had a maximum rent 131.6% higher than the bottom-up, and in Barcelona, the top-down had a maximum rent 23.4% higher than the bottom-up.

The median rents in the bottom-up districts were 15.1 euros / sq.m. / month (Bellas Vistas) and 18.7 euros / sq.m. / month (Vila de Gracia), while for the top-down they were 15.8 euros / sq.m. / month (Palos de la Frontera) and 14.9 euros / sq.m. / month (Nova Esquerra). This indicates the top-down districts in Madrid had a median rent that was 4.9% higher than the bottom-up, and for Barcelona, the top-down had a median rent 20.3% lower than the bottom-up.

Looking at minimum, maximum, and median values, the rent per square meter rates of dwelling units in bottom-up districts were consistently lower than those found within top-down districts. This was particularly exaggerated around maximum values, wherein the top-down district in Madrid had a maximum rent 131.6% higher than the bottom-up, and the top-down in Barcelona had a maximum rent 23.4% higher than the bottom-up. These results indicate that bottom-up districts offered more affordable footholds throughout both cities when compared to their top-down counterparts.





Figures 6a, b. Distribution curves showing real estate values of Palos de la Frontera (top-down) and Bellas Vistas (bottom-up) in Figure 6a (top image); and Nova Esquerra (top-down) and Vila de Gracia (bottom-up) in Figure 6b (bottom image)

Beyond minimums, maximums, and medians, however, the distribution curves visualize another metric that is critical to capturing the real estate picture in full—namely, the mode. The mode marks the most frequently repeated real estate value range in the market. For all the districts, the mode rental range was 12-16 euros / sq.m. / month. For the bottom-up districts, 45% (Bellas Vistas) and 27% (Vila de Gracia) of all rentals fell within this range; and for the top-down districts, 47% (Palos de la Frontera) and 41% of all rentals fell within this range.

The second-most frequent range was 16-20 euros / sq.m. / month. For the bottom-up districts, 33% (Bellas Vistas) and 19% (Vila de Gracia) of all rentals fell within this second range; and for the top-down districts, 26% (Palos de la Frontera) and 22% (Nova de Esquerra) of all rentals fell within this second range.

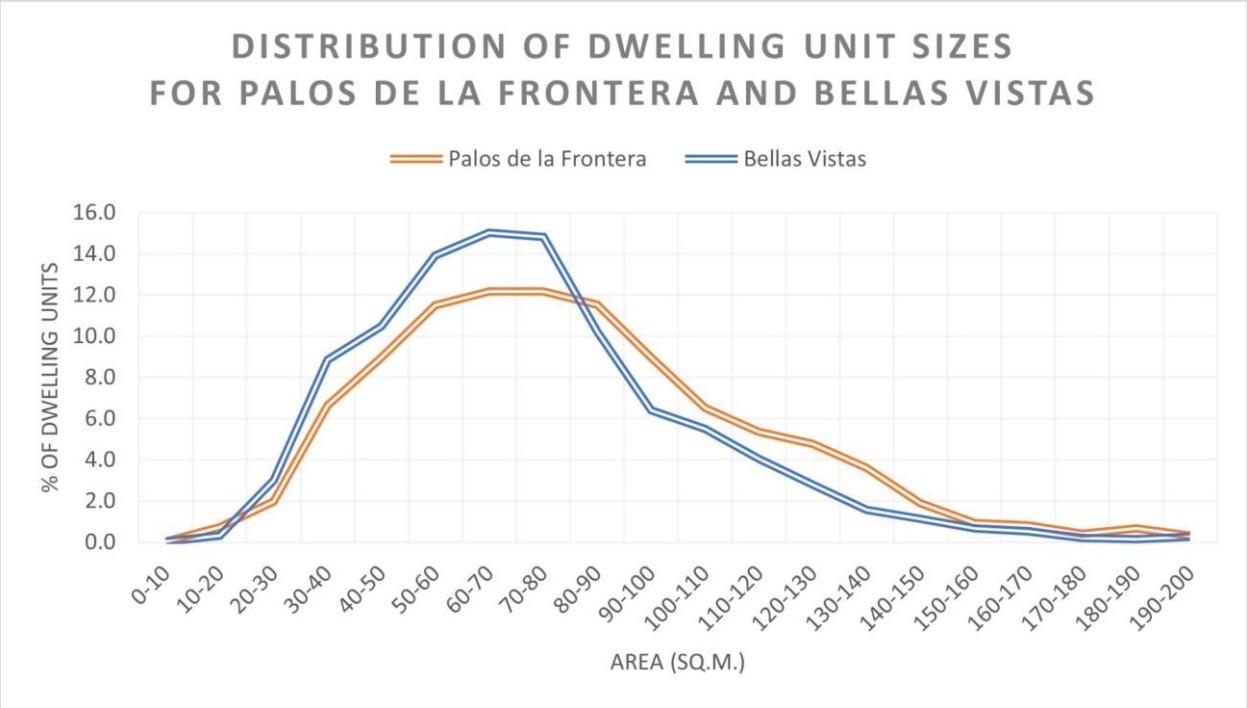
Diversity calculations also echo this point of comparable real estate behaviors across districts. In order to calculate SDI values, categories based on price / sq.m / month were established, starting with 0-4 euros / sq.m. / month, and increasing in 4 euro / sq.m. / month increments. This created a total of 19 categories, the final one being 72+ euros / sq.m. / month. The calculated SDI values for the bottom-up-districts were 0.89 (Bellas Vistas) and 0.92 (Vila de Gracia), and for the top-down districts, 0.93 (Palos de la Frontera) and 0.94 (Nova Esquerra). Here the top-down (again unexpectedly) outperforms the bottom-up in terms of diversity of rental rates, however in this case the differences are quite minimal. In Madrid, the top-down had an SDI of just 3.9% higher than the bottom-up, and in Barcelona, the top-down had an SDI value of just 2.5% higher than the bottom-up.

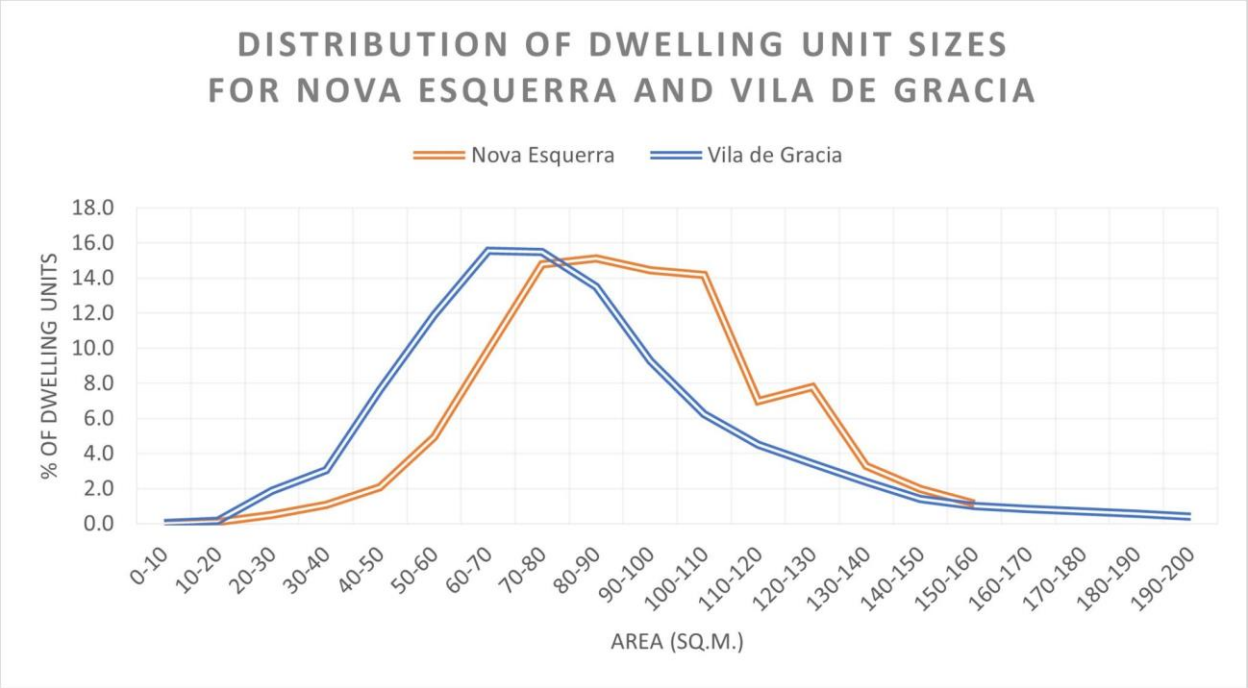
Based on these findings, the initial hypothesis is simultaneously challenged and supported. Minimum, maximum, and median values indicate a slightly more affordable behavior of the real estate market in bottom-up districts when compared to the top-down districts. However, the distribution curves and mode calculations indicate identical most frequent rent per month values. Similarly, SDI values indicate comparable diversity levels of rental values.

The bottom-up districts therefore seemed to support real estate markets that were slightly more affordable, slightly less diverse, and with the highest portion of their units falling in the same cost range (12-16 euros / sq.m. / month) as their planned counterparts.

3.3 Housing Stock

Do the bottom-up and top-down neighborhoods studied support different compositions of dwelling unit sizes across their housing stocks?





Figures 7a, b. Distribution curves showing dwelling unit areas of the housing stock of Palos de la Frontera (top-down) and Bellas Vistas (bottom-up) in Figure 7a (top image); and Nova Esquerra (top-down) and Vila de Gracia (bottom-up) in Figure 7b (bottom image).

As opposed to minimum and maximum values used in prior sections, due to the sheer size of housing data, the use of quintiles proves to be more effective in first presenting the housing data succinctly.

Within dwelling units of bottom-up districts, the upper delimiter of the first quintile range was 47 sq.m. (Bellas Vistas) and 57sq.m. (Vila de Gracia), whereas with top-down districts this delimiter was 51 sq.m. (Palos de la Frontera) and 71sq.m. (Nova Esquerra.

Within dwelling units of bottom-up districts, the upper delimiter of the second quintile range was 62 sq.m. (Bellas Vistas) and 71sq.m. (Vila de Gracia), whereas with top-down districts this delimiter was 69 sq.m. (Palos de la Frontera) and 85sq.m. (Nova Esquerra).

Within dwelling units of bottom-up districts, the upper delimiter of the third quintile range was 76 sq.m. (Bellas Vistas) and 85 sq.m. (Vila de Gracia), whereas with top-down districts this delimiter was 85 sq.m. (Palos de la Frontera) and 99sq.m. (Nova Esquerra).

Within dwelling units of bottom-up districts, the upper delimiter of the fourth quintile range was 97 sq.m. (Bellas Vistas) and 111sq.m. (Vila de Gracia), whereas with top-down districts this delimiter was 109 sq.m. (Palos de la Frontera) and 116sq.m. (Nova Esquerra).

Based on these quintiles, the bottom-up districts are seen to consistently support smaller-scale dwelling units in comparison to their top-down counterparts—indicating a finer-grain housing stock, or more intricate housing stock granularity.

Median values further confirm this point. The median dwelling unit area for the bottom-up districts was 69 sq.m. (Bellas Vistas) and 78sq.m. (Vila de Gracia), compared to the top-down district median values of 76 sq.m. (Palos de la Frontera) and 96sq.m. (Nova Esquerra). This indicates that the bottom-up median dwelling units were 10.0% (Madrid) and 23.1% (Barcelona) smaller than their top-down counterparts.

Does this finer-grain however carry over to values of density?

The total dwelling unit counts for the bottom-up districts were 8,193 (Bellas Vistas) and 14,941 (Vila de Gracia), and for the top-down districts 12,204 (Palos de la Frontera) and 20,959 (Nova Esquerra). With differences in overall geographic area corrected for, this indicates that the top-down district in Madrid supported 5.6% more dwelling units than the bottom-up, and in Barcelona, the top-down supported 69.7% more dwelling units than the bottom-up.

Do these variations in dwelling unit density carry over to actual population density?

Based on 2022 municipal demographic data, the density for the bottom-up districts was 416.6 persons/hectare (Bellas Vistas) and 398.2 persons/hectare (Vila de Gracia), and for the top-down they were 421.5 persons/hectare (Palos de la Frontera) and 433.3 persons/hectare (Nova Esquerra). This indicates that the top-down districts were slightly denser than the bottom-up—by 1.2% in the case of Madrid and 8.8% in the case of Barcelona.

These findings indicate that the bottom-up districts, across both cities, consistently supported more-intricate housing stock granularity, but slightly lower district-scale population densities.

What of housing stock diversity?

In order to calculate the diversity of dwelling unit sizes, categories based on dwelling unit area ranges were established. Starting with 0-10sq.m., and moving up in increments of 10sq.m., a total of 20 categories were established. Calculated based on these categories, the SDI values for both bottom-up districts were 0.90 (Bellas Vistas and Vila de Gracia), and for the top-down districts, the values were 0.91 (Palos de la Frontera) and 0.89 (Nova Esquerra). Regardless of bottom-up or top-down, all the districts fell approximately within the same diversity range, only deviating from one another by 1.1% in either direction.

Looking at the overarching picture, the question remains—Does the housing stock of the sampled bottom-up neighborhoods consistently differ from their top-down counterparts?

The answer is in the affirmative, however, in addition to the discrepancy between grain and diversity noted prior, density has now been added to the equation.

The bottom-up districts exhibited finer-grain housing stocks, no significant differences in housing stock diversity, and slightly lower district scale population densities when compared to the top-down.

Even if real-estate market behaviors were identical across bottom-up and top-down districts, the more intricate housing-stock granularity noted here would indicate bottom-up districts supporting more affordable residential footholds, when compared to their top-down counterparts. Naturally, smaller-scale units will cost less than larger-scale units, when priced at the same rent-per-area values. However, there is a compounding effect that emerges here.

In the prior section, it was demonstrated that the real-estate behaviors were not identical across the board. Rather, the bottom-up exhibited slightly lower rental costs in maximum, minimum, and median metrics. In this section, these same bottom-up districts were found to support a more intricate housing stock granularity (across all quintiles).

Smaller-scale units, priced at slightly cheaper rent-per-area values, will of course be more affordable than larger-scale units, priced at slightly higher cost/area values. This strengthens the capacity of the bottom-up neighborhoods to offer cheaper residential footholds than their top-down counterparts.

To put this in real terms, the upper delimiters of the first quintiles and the minimum rents of Madrid can be taken as an example—that is, a 47 sq.m. one-bedroom apartment valued at 9.8 euros / sq.m. / month in Bellas Vistas (bottom-up, Madrid) and a 51 sq.m. one-bedroom apartment valued at 10.0 euros / sq.m. / month in Palos de la Frontera (top-down, Madrid). The Bellas Vistas apartment would cost approximately 461 euros/month. The Palos de la Frontera Apartment would cost approximately 510 euros/month—10.9% higher than the Bellas Vistas unit.

3.4 Cross-scalar synthesis

Across sections 3.1-3.3, the following findings have emerged:

- The bottom-up districts consistently supported a more intricate urban morphological granularity (in terms of block sizes, plot sizes, and street widths) when compared to their top-down counterparts. This granularity however was not consistently accompanied by heightened diversity of urban-morphological elements.
- Based on minimum, maximum, and median values, bottom-up districts supported slightly lower rents / sq.m. However, the rental ranges supported by top-down and bottom-up districts had nearly identical levels of diversity.

- The bottom-up districts exhibited finer-grain housing stocks, no significant differences in housing stock diversity, and slightly lower district scale population densities when compared to the top-down. This more intricate housing stock granularity, combined with the slightly lower rents / sq.m. noted above, further supports the heightened affordability offered by bottom-up districts.

Table 1: Collation of the diversity and granularity assessments emerging from the datasets analyzed throughout Sections 3.1-3.3. Note the mixed results with regard to diversity metrics, but the consistent results with regard to granularity metrics—with the bottom-up districts consistently supporting a finer grain, but not necessarily higher diversity, of urban morphological and housing stock parameters.

Parameter	Neighborhood type	Relative Diversity (comparing top-down and bottom-up)	Relative Granularity (comparing top-down and bottom-up)
Block sizes	Top-down	mixed results	coarser
	Bottom-up	mixed results	finer
Plot sizes	Top-down	more diverse	coarser
	Bottom-up	less-diverse	finer
Street widths	Top-down	less diverse	coarser
	Bottom-up	more diverse	finer
Dwelling unit sizes	Top-down	equal	coarser
	Bottom-up	equal	finer

Based on these findings, a subsequent question that arises is whether the smaller-scale dwelling units in the bottom-up districts were situated in the smaller-scale plots of said districts. That is, whether there is a cross-scalar link between the plot stock and housing stock granularity in these neighborhoods.

To begin this calculation, the average of all four districts' median plot size (calculated to be 295sq.m.) and the average of all four districts' median dwelling unit size (calculated to be 80.m.) were used to differentiate smaller-scale plots and units (plots below 295sq.m. or units below 80sq.m.) from larger-scale plots and units (plots greater than 295sq.m. or units greater than 80sq.m.).

In Bellas Vistas (Madrid, bottom-up), it was found that smaller-scale plots made up 39.6% of the district stock of plots, but supported 45.2% of the smaller-scale unit stock. In Vila de Gracia (Barcelona, bottom-up) smaller-scale plots made up 59.1% of the district stock of plots but supported 65.7% of the smaller-scale unit stock. In Palos de la Frontera (Madrid, top-down) smaller-scale plots made up 16.2% of the district stock of plots but supported 22.6% of the smaller-scale unit stock. In Nova Esquerra (Barcelona, top-down), smaller-scale plots made up 21.5% of the district stock of plots but supported 37.3% of the smaller-scale unit stock.

Median areas of dwelling units situated on smaller- versus larger-scale plots also confirm this pattern (see Table 2). Across all four districts, these median values indicate that smaller-scale units consistently tended to be situated on smaller-scale plots, and larger-scale units on larger-scale plots.

Table 2: Median dwelling unit sizes for small- and large-scale plots (less than or greater than 295 sq.m. respectively), for the four districts studied.

	Median Dwelling Unit Size (sq.m.)	
Neighborhood	For Small-scale plots (less than 295 sq.m.)	For Large-scale plots (greater than 295 sq.m.)
Bellas Vistas	62	74
Vila de Gracia	76	95
Palos de la Frontera	63	80
Nova Esquerra	63	80

These analyses confirm that smaller-scale plots exhibited a higher likelihood of supporting smaller-scale housing units. A critical point to underscore is that this took place regardless of a district's bottom-up versus top-down qualities. This indicates a significant relationship between the grain of urban plots and the grain of urban housing stock. A comparable cross-scalar relationship between smaller-scale blocks supporting the formation of smaller-scale plots however could not be verified.

The inherent limitations to the design of urban buildings, and the tendency of urban multi-family buildings to aim for both front (street-facing) and rear (courtyard-facing) units, even within smaller-footprint buildings (Kayatekin 2021, 891+902), support this relationship between small-scale plots and small-scale units. Small plots, when setbacks and maximum plot coverage are taken into account, will produce even smaller building footprints. Building plans, when communal/egress areas, wall widths, areas for building systems, etc., are taken into account, will produce even smaller total rentable areas. And when the aforementioned tendency of urban multi-family buildings trying to produce both front- and rear units is taken into account, this even smaller total rentable area would be divided in two. If these steps are followed for plot areas of 295 sq.m. or less, the remaining rentable units would seem to naturally fall within the smaller-scale ranges being discussed.

This echoes the work of (Pont et al 2019, 1239), "that fine-grain, compact plots are more often found in association with [compact mid-rise] building types" (1239).

The reason for Bellas Vistas and Vila de Gracia outperforming their top-down counterparts in supporting a finer-grained housing stock, therefore, seems to rest upon a basic issue of plot numbers. The two bottom-up districts simply had higher numbers of smaller-scale plots, which gave them a stronger urban morphological foundation for supporting higher numbers of smaller-scale units.

The differences in the density of smaller-scale plots across districts are quite noteworthy. Bellas Vistas had a density of 167 smaller-scale plots (under 295 sq.m.) per hectare, compared to 33 plots per hectare for Palos de la Frontera; and Vila de Gracia had a density of 196 smaller-scale plots per hectare, compared to 56 plots per hectare for Nova Esquerra.

These findings underscore the critical (and largely hidden) role played by intricate urban-morphological granularity in the context of urban housing stock diversity, as well as the critical need to understand granularity metrics in tandem with diversity metrics, to have a more precise picture of what is taking place within such complex built-environmental relationships.

4. Conclusions and Implications

Three critical findings emerge from this research.

First—granularity is not synonymous with diversity. More specifically, possessing an intricate urban morphological (or housing stock) granularity does not come hand-in-hand with having high urban morphological (or housing stock) diversity. Within this work, the two bottom-up districts analyzed consistently exhibited a finer-grained urban morphology when compared to their top-down counterparts. However, these bottom-up districts were also often outperformed by their top-down counterparts in terms of the diversity of specific urban morphological elements.

Second—despite not possessing a higher diversity of urban morphological elements, the bottom-up districts still behaved as slightly divergent real estate bubbles when compared to the top-down neighborhoods. With regard to some variables (i.e., mode values), the real estate market of the four districts exhibited nearly identical behaviors. However, with regard to minimum, maximum, and median rent values, the two bottom-up districts consistently exhibited slightly cheaper, but not more diverse, rental rates than their top-down counterparts.

Third—across all the districts examined, smaller-scale plots consistently supported more than their expected share of smaller-scale dwelling units. This indicates the presence of a relationship between the intricacy of plot-scale urban-morphological granularity, and the intricacy of a district's housing stock. A comparable cross-scalar relationship between smaller-scale blocks supporting the formation of smaller-scale plots however could not be verified.

To be clear, there do not appear to be any significant differences in how such small-scale plots operate whether they are situated in morphologically heterogeneous or -homogeneous districts. This indicates that regardless of morphological conditions, should a district's plot stock be artificially incentivized or directly shaped to have greater numbers of smaller-scale plots, over time these plots should be able to comparably support the formation and maintenance of disproportionately elevated numbers of smaller-scale housing units.

This is a finding of significance for urban design, urban planning, and urban policy. The affordability and variety of housing options are critical factors espoused by a range of contemporary urban initiatives, most notably within the fifteen-minute city framework being adopted by a range of municipalities worldwide (Pozoukidou and Chatziyiannaki 2001, 9). The findings within this paper of course do not offer full-fledged solutions for achieving the full range of housing stock variety and affordability required. However, the observed beneficial behavior of smaller-scale plots in supporting a heightened intricacy and affordability of smaller-scale housing options does offer a tool for helping the smaller-scale end of the housing stock spectrum.

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Ethics approval:

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Conflict of interest:

The authors declare that there is no competing interest.

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