Balancing Growth and Livability Using Performance Metrics: A Solution to Housing Crisis in San Francisco

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Cities all over the world are experiencing exponential growth in population. To address these growing needs which are as basic as an affordable home, public spaces, work environments near their homes, mix of daily amenities within walking distances, all of this is becoming more and more challenging to achieve, particularly in major cities. Traditional zoning of segregating uses along complemented by encouraging automobile centric infrastructure are the current drivers of American urban development. Traditional zoning and design planned around promoting vehicular connections and single-family residential growth. It can be argued in most of the cases that outdated and traditional zoning regulations, coupled with a lack of technological advancements in planning context-specific and adaptable urban scenarios, are the primary reasons why cities are failing to meet the growing needs of their populations. Rising densities with low supplies of housing specifically affordable, lack of jobs opportunities and amenities within walkable distance has resulted in skyrocketing land and household prices within city cores. This has seen displacement of the middle and lower-income groups raising concerns of gentrification in cities. People looking for single-family homes, so called deemed as the ideal American living standard are bound to travel farther from the downtowns in search of them thus contributing to one of the biggest problem of cities, urban sprawl.

San Francisco is one of the many cities in the United States facing a housing crisis. The research aims to offer innovative strategies that can potentially address housing crisis in San Francisco. The research started with evaluating the existing urban framework and zoning policies and identifying the limitations that have resulted in shortage in affordable housing supplies, segregation, urban sprawl and in turn failing to accommodate the growing population in cities, followed by implementing performance-based zoning typologies as an alternative to bringing in more affordable housing and diverse communities. The research integrated the inputs of building height & parcel coverage with specific performance objectives, including the number of dwelling units, number of household members, accessible open space, and economic viability of the planned development.

DECODING ZONING: FOUNDATIONS & CONTEMPORARY URBAN CHALLENGES

To deconstruct and implement a performance-based zoning design approach for this research, it is crucial to comprehend the foundational role of zoning in urban planning. Traditional zoning, also known as Euclidean zoning, first emerged in 1926 when the City Council of Euclid, Ohio, passed an ordinance to segregate all other uses of land away from single-family residential areas. The other land uses included multifamily apartments, institutional, public, semi-public uses, and industrial zones, with the aim of prohibiting these practices in single-family residential areas. Despite facing challenges from developers, the zoning ordinance successfully passed, resonating with the idea that the common interest and welfare of the people outweigh any private interest (VILLAGE OF EUCLID, OHIO, et al. v. AMBLER REALTY CO. 1926). Apartments were even deemed as parasites by the Supreme Court that might cause a nuisance and degrade the quality of life in a single-family residential area by cutting off light and air, and by increasing noise and traffic (Power 1997).This aspect had a particular impact on zoning, establishing a precedent that zoning was a legitimate exercise of power by the municipality, but only if it contributed to the overall improvement of urban health in the area.

ZONING TODAY

Zoning, initially designed to regulate density and land use for organized urban development, has evolved into a complex system. Prior to the implementation of zoning, many cities allowed mixed-use growth, enabling people of different incomes and races to harmoniously coexist. Despite modifications and rule adjustments, zoning has contributed to, rather than resolved, the housing crisis in many cities globally. The segregation of land uses today has increased distances between homes, workplaces, and recreational activities, thereby amplifying travel time and reinforcing the reliance on automobiles and the development of expansive highways. Zoning has solidified the concept of single-family homes as the American urban ideal, prompting more individuals to move away from downtown areas in search of single-family homes with private yards. Residential zoning

districts located away from downtown areas have resulted in social isolation, extended travel times, and significant disinvestment in city centers. Regulations, such as minimum lot sizes, stringent building codes, and parking requirements per dwelling unit, have limited affordable and diverse housing typologies beyond single-family homes, which are often only affordable to above-middle-class income families (M. N. Gray, Cancel Zoning 2022). Undoubtedly, zoning is a significant contributor to the housing crisis in cities.

Zoning is not a good institution gone bad, and its purpose is not to address traditional externalities to co-ordinate growth with infrastructure, as suggested by zoning defenders. But zoning is a mechanism of exclusion designed to inflate property values, slow the pace of new developments, segregate cities by race and class and enshrine the detached single family residential as the exclusive urban ideal (M. N. Gray, Arbitrary Lines: How Zoning Broke the American City and How to Fix It 2022).

ZONING FOR THE FUTURE - PERFORMANCE BASED APPROACH

There is no need to entirely override the concept of zoning; however, it should exhibit greater flexibility in addressing issues and accommodating the growing needs of both micro and macro-level populations. Currently, minimum lot sizes, setbacks, parking requirements, height allowances, and green area ratios remain uniform across many American cities and neighborhoods, regardless of contextual variations in the area's demands. A data-driven and analytical approach is essential to comprehend the core problems faced by neighborhoods or cities, allowing zoning policies to adapt using quantifiable performance metrics.

A performance-based design approach facilitates understanding the area's carrying capacity or potential, accommodating a broader range of land uses and residential options, reducing conflicts of interest, providing governments and developers with increased design flexibility, and enhancing overall efficiency. This approach acknowledges that the performance-based metrics for one city may not be suitable for another context, fostering distinct urban identities and neighborhood characters based on current and future growth requirements. Leveraging parametric methods and performance metrics aids in evaluating the performance of design iterations and urban developments in residential districts. Performance-based zoning allows for the pre-implementation analysis of urban developments to determine their effectiveness in addressing contextual problems.

WHY SAN FRANCISCO?

The city implemented housing segregation from all other uses, relocating them away from the city center. This practice originated in Berkeley, California, between 1915-1920 (M. N. Gray, Arbitrary Lines: How Zoning Broke the American City and How to Fix It 2022). Zoning regulations in Berkeley prohibited apartments and other affordable housing options, allowing only single-family residential units, which were the most expensive residential types (M. N. Gray, Arbitrary Lines: How Zoning Broke the American City and How to Fix It 2022). This situation mirrors the legal battle between South Burlington County and the Township of Mt. Laurel. While zoning regulations that restrict diverse housing in predominantly residential areas may or may not be intentional, the outcome has led to the segregation of people, excluding certain race and income groups from these areas, and primarily controlling density (Southern Burlington County NAACP v. Township of Mount Laurel 1975). All of this has resulted in a significant shortage of available housing.

Currently, in the city of San Francisco, there is a high demand for housing, but the supply falls short (Morris and Dineen 2023). One reason for this shortage is the lack of diverse housing options in residential districts. A single parcel that could accommodate multiple families and allow for increased dwelling units is restricted to single-family homes. While there are valid reasons, such as preserving the historic and architectural value of residential single-family districts, the question remains: at what cost? As of the most recent zoning code that was published in 2022, 38% of San Francisco's zoning is designated for single-family residences, which accounts for almost 2/3rd of the land zoned for residential purposes (Devulapalli 2023). The San Francisco zoning department has pending plans to add around 82,000 units between 2023 and 2031 (Morris and Dineen 2023). The addition of units, as per the comprehensive plan, is essential for accommodating the growing population, securing future funds for development, and sustaining the city's growing infrastructural needs. More than half of these 82,000 units must be affordable, specifically targeting middle- and lower-income residents. To meet these demands, the city's zoning department plans to rezone low-density areas, such as the Sunset district and Richmond district (Dineen 2022). These areas are predominantly single-family dominated and located on either side of Golden Gate Park to the west of the city. The increased density is planned along the main MUNI transit corridors in these districts and other parts of the city (SF Planning Department 2023).

The concept plan by SF zoning and planning program includes relaxed restrictions on the heights of new developments, space for accessory dwelling units (ADUs), and allowing multifamily homes along these transit lines (SF Planning Department 2023). Zoning dictates the size and type of structures permitted on a specific parcel. For example, enforcing the minimum lot sizes policy creates challenges for developers aiming to construct multifamily homes, rendering the project unprofitable and leading to its abandonment (M. N. Gray, Arbitrary Lines: How Zoning Broke the American City and How to Fix It 2022). To understand how minimum lot size works and impacts affordable development consider the application of the regulation in the following example. In a sprawling 120,000 sqft piece of land, the potential for 5,000 sqft per lot exists, allowing for 24 lots and a higher number of units such as apartments, studios, and single-room occupancies (SROs). However, if zoning regulations stipulate a minimum lot size of 10,000 sqft, the number

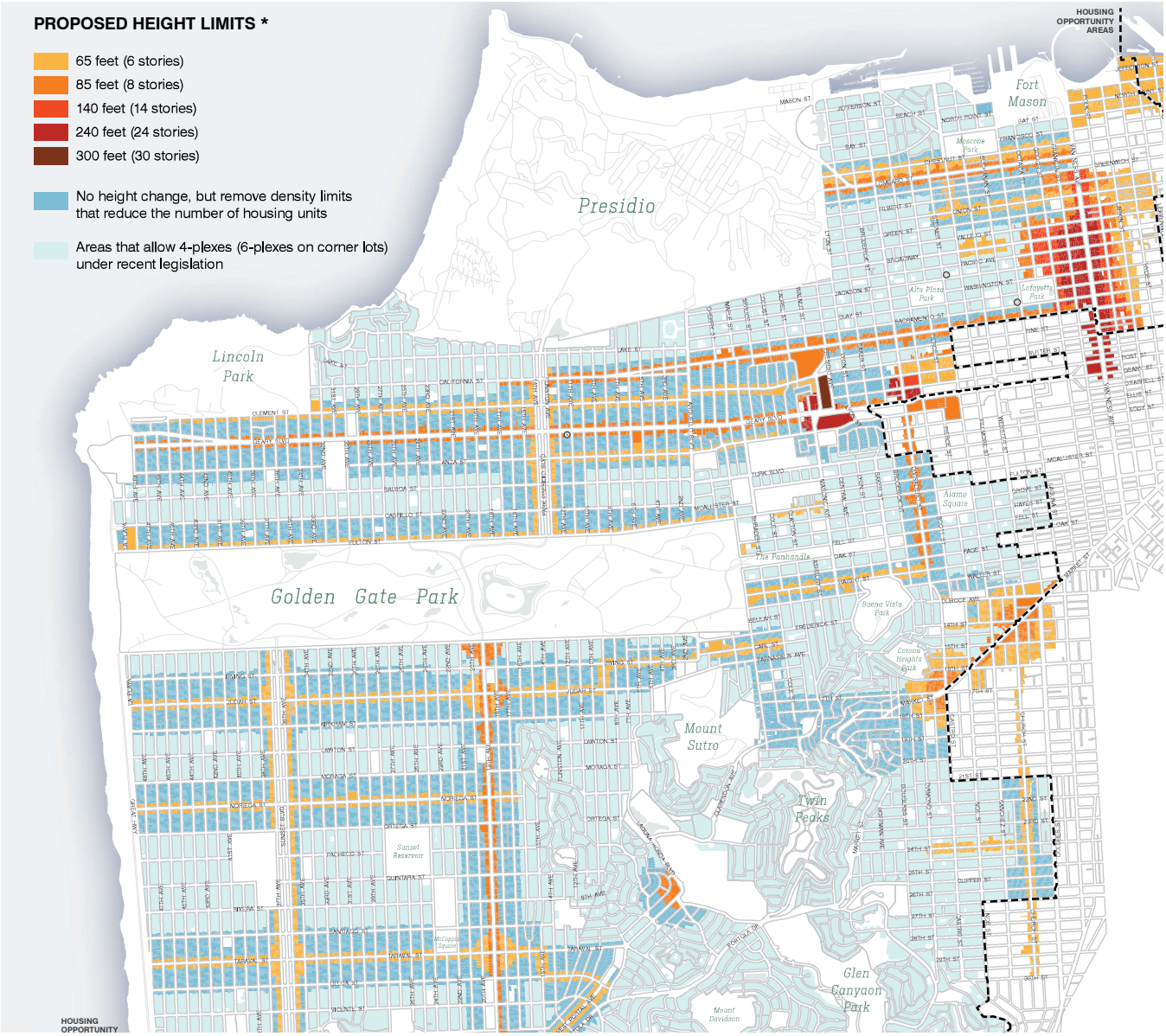

Figure 1. Zoning Concept 1: Major Streets and Surrounding Areas. Image credit to SF Planning Department.

of lots is reduced by 50%, diminishing the potential for housing. Additionally, stringent parking requirements per unit can make development financially unfeasible for builders, contributing to increased housing unit costs (M. N. Gray, Arbitrary Lines: How Zoning Broke the American City and How to Fix It 2022). In many cities, single-family housing is idealized and constitutes over 70% of residential districts (BADGER and BUI 2019). Restrictions in these areas often limit the construction of affordable housing options like apartments, studios, single resident occupancy (SRO) housing, and Accessory Dwelling Units (ADUs) (M. N. Gray, Cancel Zoning 2022). These restrictions, influenced by the preferences of higher-income residential homeowners, perpetuate segregation between social classes. The intention is to drive up costs of single-family lots and homes, reducing space for denser development in residential zones throughout the city, thereby impacting housing supply citywide (Gyourko and Molloy 2015). This scenario forces individuals to allocate a substantial portion of their median income toward living in single-family homes in affluent neighborhoods, often situated far from city centers and workplaces. Consequently, many individuals find themselves spending most of their income on rent, leading to homelessness for those unable to sustain such financial strains. Therefore, San Francisco is considering several strategies to address this issue, including relaxing restrictions on building heights and dwelling units along major transit corridors in residential zones (SF Planning Department 2023).

San Francisco, having adhered to traditional zoning, grapples with a housing crisis—a consequence, perhaps, of its stringent zoning policies. The significance of choosing San Francisco as

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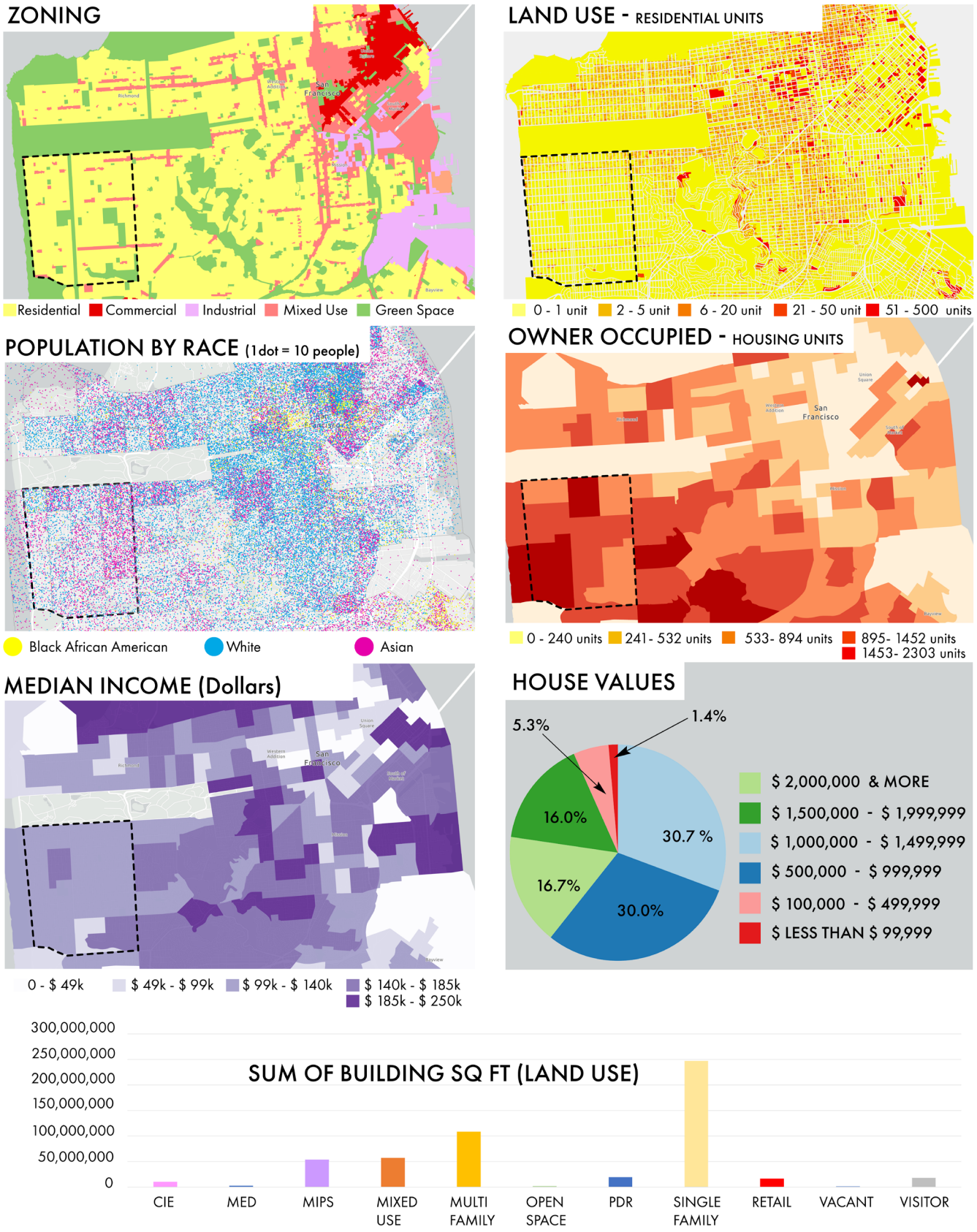

Figure 2. Urban Analysis & Demographic Study. Image credit to Author.

the research context lies in the state's historical role as the birthplace of zoning, its continued dominance in urban growth, and the city's current commitment to comprehensive plans for rezoning and relaxation. This unique combination presents an opportune context, where the awareness of tremendous problems and the prospect of reforms make San Francisco an ideal context for the research.

URBAN ANALYSIS & DEMOGRAPHIC STUDY

To study zoning and how it has affected the housing market, following is an urban analysis of the city of San Francisco created in ArcGIS pro. The following analysis and maps generated in ArcGIS pro are prepared using the numerical data of the 2020 census, retrieved from census.gov. The maps and charts highlight the urban fabric and demographics of the sunset district (I.e. the study area within the black dashed boundary) and the city of San Francisco. It is critical to understand why the SF planning department has conceptual plans in works to up-zone Sunset (study area) & Richmond districts to the west of the city.

The initial segment of the research delineates the prevalence of single-family housing in both the broader city and the specific study area, as illustrated in Zoning (Figure 1, Map: Zoning). This observation is further substantiated by the sum of building sqft (land use) bar chart (Fig 1, Sum of Bldg. Sqft (Land Use)), which delineates building square footage in support of the identified case.

The study aims to elucidate the multifaceted impacts of single-family zoning on various aspects within the city, especially housing. An exploration into the effects of single-family zoning encompasses an examination of population density concerning race, as depicted in population by race map (Figure 1, Population by Race). The analysis extends to the availability of number residential units at parcel level which shows the percentage of single family and other housing options in the city in the map (Fig 1, Land Use : Residential units), the ownership of housing units at census tract level is shown in the owner occupied units map (Fig 1, Total Owner Occupied) and median family income in dollars (Fig 1, Median Income dollars. Additionally, the research investigates the dearth of affordable housing options, as discerned from the pie chart showing the values of homes in the city (Fig 1, House Values). The population by race map (Fig 1, Population by Race) reveals a pronounced concentration of white and Asian populations in residential areas, with Black African Americans predominantly confined to specific sections of the city. Correlations with ownership of housing, Land use based of residential units and median income of families in the city, show economically disadvantaged areas, underscore disparities. The Sunset district, notably, exhibits a high percentage of single-family residences or structures comprising a single unit, distinguishing it from the broader landscape of San Francisco. The exorbitant home values across the city underscore a lack of affordable and diverse housing options.

PERFORMANCE-BASED DESIGN USING METRICS

The performance-based design approach is implemented at the parcel level in the Sunset district. In the scope of this research, the performance metrics are specific to housing on a massing level or macro scale rather than an individual unit or human scale. Performance-based zoning aims to analyze urban developments and their potential to address the housing crisis. Based on the initial study so far, the factors governing the design include Parcel coverage and Height of development.

Parcel Size and Types: The parcel size in each block is of two types, determined using the 3D context model of the city developed in Rhino 3D modeling software: Parcel type A: 7.6m x 26.5m and Parcel type B: 7.6m x 30.9m. For this paper, the development is planned along the transit corridors of the Sunset district, and the selected parcel size is type A - 7.6 meters x 26.5 meters. A set of 8 parcels (type A) has been selected along the MUNI transit corridor. Building upon the preliminary study, understanding design constraints and conceptual approaches outlined in the Housing Element Zoning Program (SF Planning Department 2023) we have determined four key performance metrics for this study:

Housing/Dwelling Units– Based on the summary of planning codes in residential districts for San Francisco, which includes RM1: 1 unit per 800 square feet; RH3: 1 unit per 1000 square feet; RH2: 1 unit per 1500 square feet (San Francisco Planning 2008) the dwelling unit area is defined to range from 800 square feet up to 1500 square feet. A metric to quantify the number of housing/dwelling units in the design.

Open Space Access – The goal is to maximize the open space area and create more shared open space than the current private backyards on each parcel. Therefore, an amalgamated shared semi-public space is calculated by the sum of the area (square meters) of green spaces on the ground level.

Economic Feasibility/Affordability - Dwelling units are generated based on areas specified in the traditional SF planning codes, determining the average cost of the dwelling units. The more affordable the generated housing units are, the lower the average cost.

The median listing home price in the Sunset District is $885/square feet (News Corp subsidiary Move n.d.). A simple formula was created to calculate the average cost of dwelling units in the development. Average cost per dwelling unit in development = (Area of parcel x Number of Parcels for development x Median home price cost per square foot) / Sum of Dwelling units

Floor Area Ratio – Using the floor area ratio to understand the building area developed with respect to parcel size, later to be analyzed against the permissible FAR in the area for that specific zoning code.

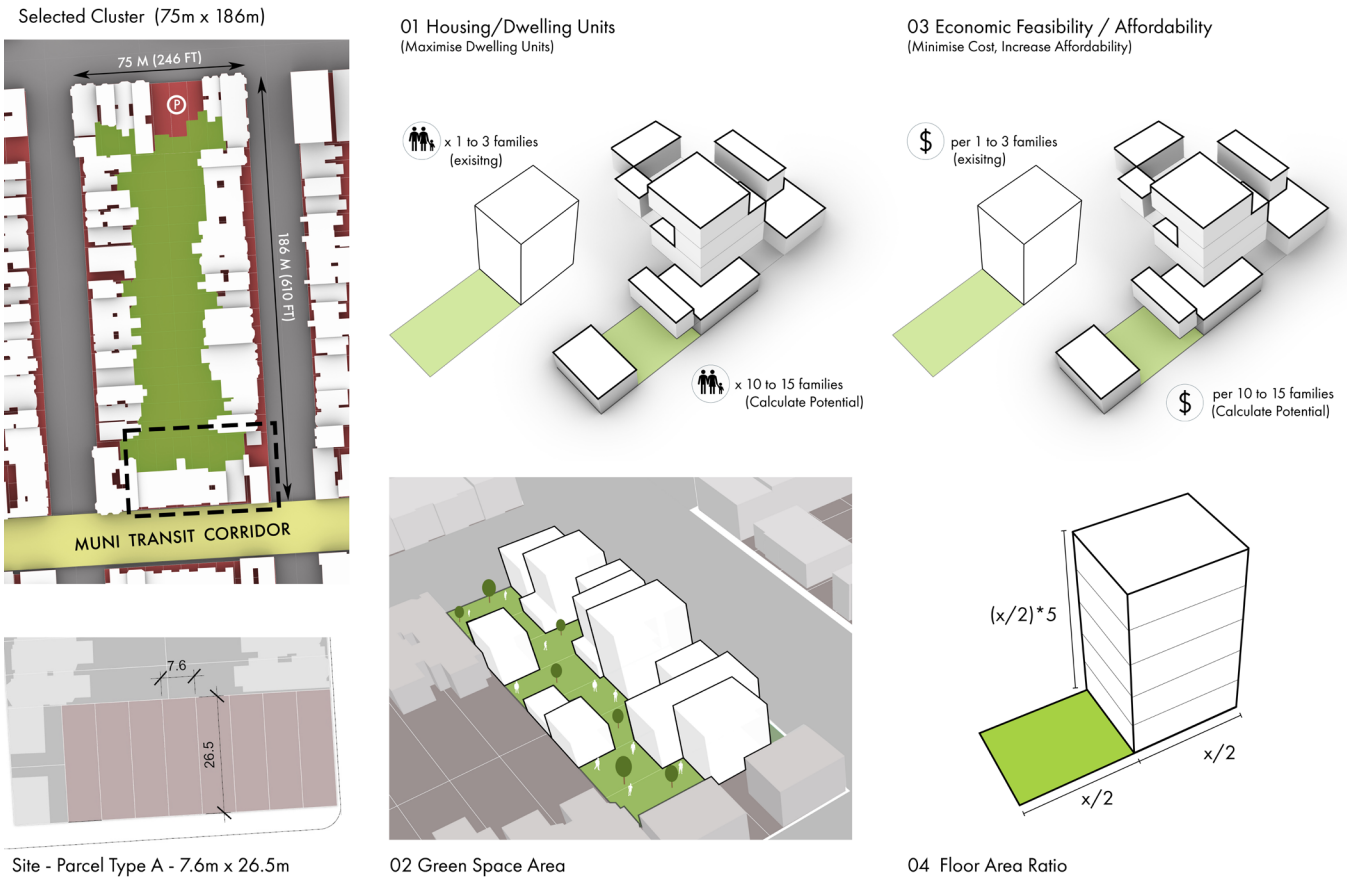

Figure 3. Selected cluster along public transit corridor and selected parcels for development facing the corridor. Performance metrics for this research. Selected Cluster (Top left) ; Site -Parcel (Bottom left) ; Metric : Housing Unit (Top centre) ; Metric : Green Space Area (Bottom centre) ; Metric : Economic feasibility / Affordability (Top right) ; Metric : Floor area ratio (Bottom Right) Image credit to Author.

RESULTS AND ANALYSIS

Utilizing various Grasshopper plugins in the development of a script, we aim to employ parcel coverage and height as parameters for generating 3D massing on selected parcels. Additionally, the script is designed to derive numeric values for four key design metrics: 1) Housing/Dwelling Unit Size; 2) Open Space Access; 3) Economic Feasibility/Affordability; and 4) Floor Area Ratio. The 5000 iterations are composed of 100 generations (Generation Count), each comprising 50 iterations (Generation Size). The integration of the Wallacei X Grasshopper 3D plugin facilitates the analysis, cross-referencing, and parsing through 5000 iterations to identify optimal design solutions based on designer priorities and performance metrics.

For the generated iterations, we conducted a comprehensive analysis employing the following charts and graphs from Wallecei X shown in Figure 4.

Parallel Coordinate Plot - The Parallel Coordinate Plot (PCP) systematically analyzed all 5000 solutions by comparing the fitness values for each simulation across the four fitness objectives. This analysis provided insights into the generative process's behavior. Each thread in the graph corresponds to one of the 5000 iterations, with the point of contact at each metric (vertical line) indicating the value for that specific iteration.

Standard Deviation Chart - The SD chart represents distribution of a set of values from the mean. A low standard deviation factor indicates that most values are clustered around mean (less variation within population). The chart helped analyze levels of variation/convergence for each generation as well as if the generations are getting fitter throughout the simulation.

Mean Value Trendline - The Mean fitness trendline graphs highlight mean fitness value, for each of the four-fitness metrics independently, for each of the generations.

Diamond Fitness Chart – The chart analyzes the values of the four-performance metrics for every single solution to understand how the single solution performs by comparing the metrics and ranking its performance values.

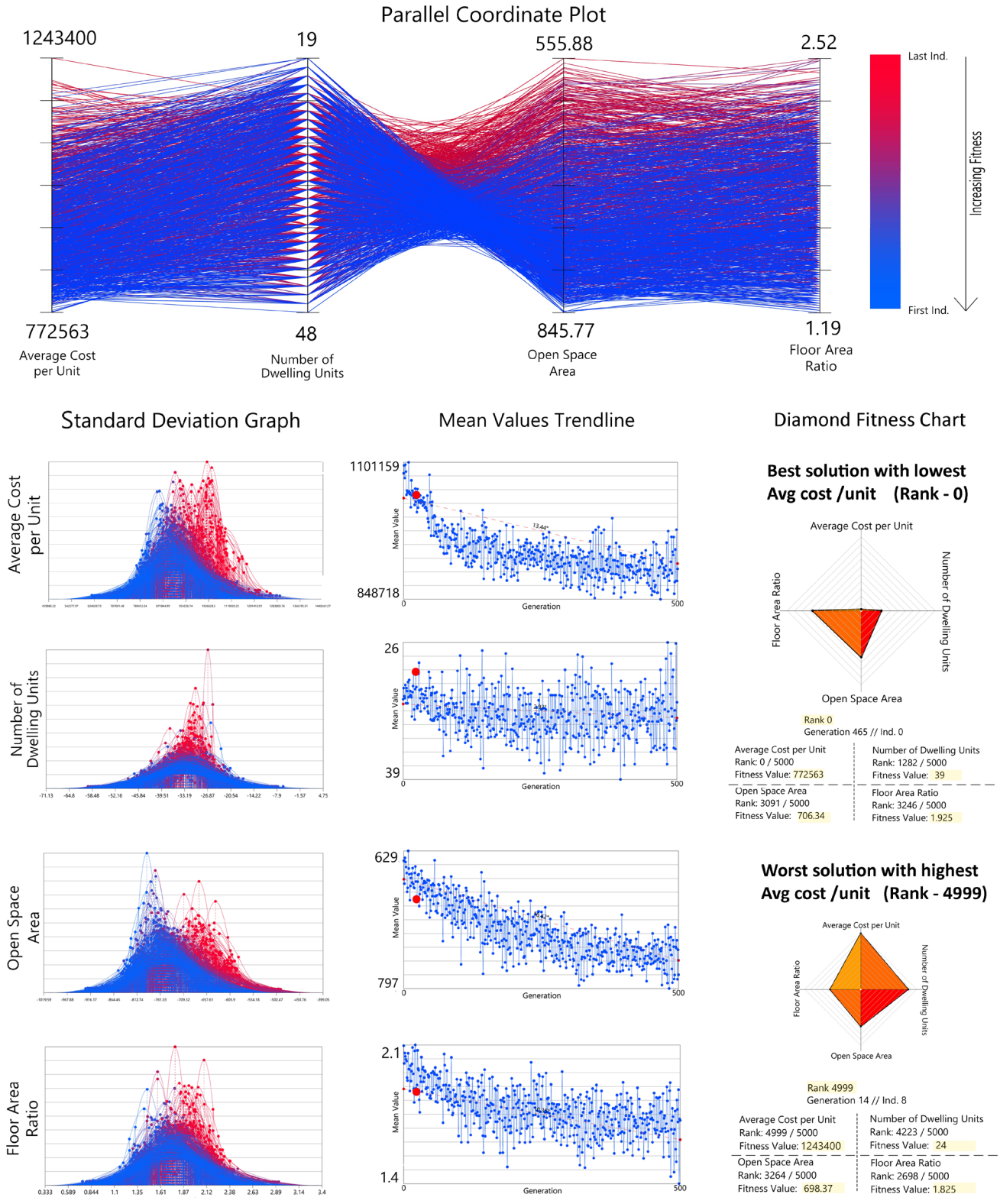

Fig 4: Wallecei X analytics & charts to analyze the performance of the 5000 design iterations generated. Image credit to Author.

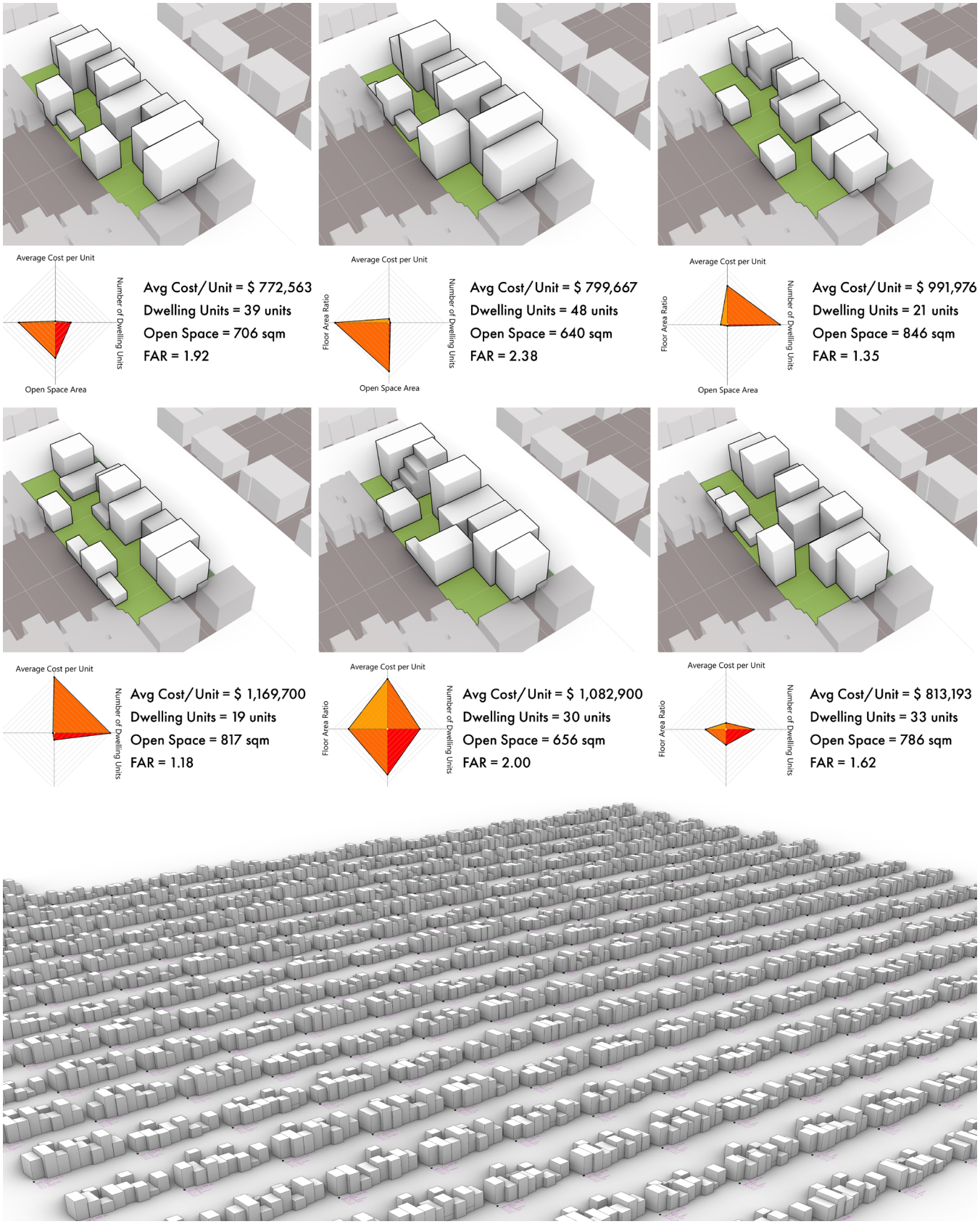

Figure 5. Six selected iterations with four best performing solutions for each metric and two balanced solutions all with their diamond charts (Top) Aerial view of 276 of the possible 5000 random massing iterations exported (Bottom). Image credit to Author.

SELECTION PROCESS AND EVALUATION

The selection process is rigorous, involving a critical review of the 5000 iterations generated for the four performance indicators. In this current research, the selected iterations excel in individual goals. Figure 5 displays the best-performing solutions for each performance metric, independent of the other three indicators, accompanied by their respective diamond charts to support the analysis. For instance, iterations with the lowest average cost per unit are chosen for affordability, those with the highest number of dwelling units are prioritized, iterations maximizing open space are selected, and iterations with the lowest Floor Area Ratio (FAR) consumption are considered. Given that selecting the best for each objective may not necessarily optimize performance across all criteria, the tool provides an option for average performing solutions. These iterations represent the best outcomes for a minimum of two out of the four specified objectives.

The selection process can also be tailored to adhere to permissible FAR in the Sunset district. Simultaneously, the criteria ensure that the design solutions fall within an affordable price range in the context of San Francisco. By leveraging these performance metrics, the selection of designs aligns with quantifiable goals and objectives, ultimately benefiting the neighborhood.

CONCLUSION

Traditional zoning regulations have profoundly impacted the growth and supply of affordable housing solutions in the residential areas of San Francisco. While zoning provides a structure and framework for city growth, certain parameters such as minimum lot coverage, parking requirements, and a lack of diverse housing typology in prime residential zones adversely affect the housing market's performance. The urban analysis makes a case for having more diverse options in the Sunset District, suggesting that it could be an ideal place to increase density to meet San Francisco's housing goals. The proposed performance-based design and zoning have facilitated an understanding of the development potential in the single-family residential areas of the Sunset District in San Francisco. The approach not only specifically looked at adding dwelling units on a parcel but also considered the economic feasibility by calculating the average cost per unit in the development. It also helped study the floor area consumed by each development to determine whether the floor area ratio is high or low, allowing for potential design improvements. The approach moves away from the focus on the private backyards of single-family homes and takes into consideration the open space metric in correlation with other performance metrics. This is crucial to improving the qualitative aspect and understanding whether there is a proper balance between the proposed density and the designed or generated open space.

The proposed approach not only addresses the imperative of increasing density but also ensures a balanced consideration of key metrics, including economic feasibility, floor area utilization, open space, and qualitative enhancements. By focusing on these four interconnected aspects, the strategy provides a solution that facilitates the understanding and calculation of the development's potential.

RESEARCH LIMITATIONS AND FUTURE WORK

Limitations of Research

Conducting this research within a limited timeframe during the winter period did not permit a more in-depth analysis that would have contributed to a better understanding of additional significant factors influencing housing at a more user-centric level. The research relied on models and simulations from Grasshopper and various plug-ins. Given additional time, there could have been further analysis of vacant lots and parcels in the specific context of the area, providing a robust rationale for their selection as development sites in this research. Moreover, with an extended timeline, there would have been an opportunity for on-site exploration of the study area and selected parcels. This on-site experience would have allowed for a firsthand understanding of the housing character, socio-cultural values of the neighborhood, pedestrian and vehicular connectivity, and interviews with Sunset District residents to gather insights on potential solutions for the city's housing crisis. A more extended timeframe would have facilitated the refinement of these massing iterations into more realistic developments. This approach emphasizes portraying increased density as an addition of life and vibrancy, thereby enhancing the overall urban health of the area. It goes beyond merely stacking units and people, considering how such developments can harmoniously complement the unique character of the district.

Future Work

Despite ample development opportunities with the performance-based methodology, limitations identified in this study are crucial considerations for the next stage of research. A primary aspect is the development of parametric incremental unit floor plans, including studios, one-bedroom, two-bedroom, etc. These plans aim to enhance credibility and understanding of the functionality of dwelling units on a human scale. They play a crucial role in presenting a compelling case for how families will experience space, moving beyond simple massing design iterations. Additionally, the inclusion of more quantifiable metrics such as energy consumption, carbon footprint, mobility, land use, daylight, and solar gain into the workflow is suggested. This addition aims to broaden the selection criteria, assisting in achieving even more comprehensive decision-making when selecting solutions best suited for both the residents and the urban fabric.

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