A Multifaceted Exploration of Spatial Openness in Rental Housing: Big Data Analysis Across Tokyo's 23 Wards

賃貸住宅における空間開放性の多面的探究：東京23区のビッグデータ分析

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1 Introduction

Spatial openness represents one of the most critical factors influencing customer decision-making in property selection and serves as a fundamental consideration for designers creating effective residential spaces. This concept encompasses the perceived spaciousness, visual connectivity, and flow within living environments, directly impacting occupant satisfaction and quality of life. Understanding and quantifying spatial openness is therefore essential for both real estate professionals and architectural designers seeking to optimize residential design.

Traditional approaches to analyzing spatial openness have predominantly relied on structured data analysis, constrained by the availability and format of existing data sources. These conventional methods typically depend on standardized metrics such as floor area, room count, and basic dimensional measurements, which fail to capture the nuanced spatial qualities that truly define openness. Few studies have successfully leveraged rich, unstructured data sources such as interior design imagery and madori (floor plan) data to transform these abstract visual elements into quantifiable statistics that can yield innovative insights.

This research addresses these limitations by proposing a novel methodology that harnesses various innovative information sources through advanced computational techniques. Our approach integrates interior images combined with semantic segmentation, floor plan (madori) images processed through semantic segmentation, and optical image-based visibility graph analysis (VGA). This methodology breaks the traditional constraints of VGA studies, which have historically depended heavily on data inputs that require human intervention, such as AutoCAD vectorized maps and proprietary software like DepthMapX.

Our method incorporates several technical improvements utilizing purely open-source coding frameworks that significantly accelerate data processing capabilities. These advancements enable the extension of such analysis to substantially larger datasets, making it possible to extract meaningful insights from big data when working with unstructured, abstract image datasets. By largely reducing the need for manual processes typically required by traditional spatial analysis tools, our approach enables fully automated processing pipelines that can handle large-scale datasets without human intervention, opening new possibilities for comprehensive urban-scale studies of residential spatial quality.

2 Data Source and Preprocessing

The data source for this study is the rental category of data from the Lifull dataset. In this study, we focus on the rental property in Tokyo area, constructed date from 1960 to most recent years. Every decades we sampled roughly 1000 to 1500 properties to make the distribution more balanced. Since we need clear interior images for interior semseg analysis, clear madori images to extract the VGA distributions, and compare the properties visual elements from those images to their tabular specs data, we have to screen outs those poor quality images and very incomplete infos, after the filtering we have around 6000 properties left. As illustrated in Figure 1, our dataset demonstrates a comprehensive coverage across Tokyo's 23 wards spanning multiple construction decades.

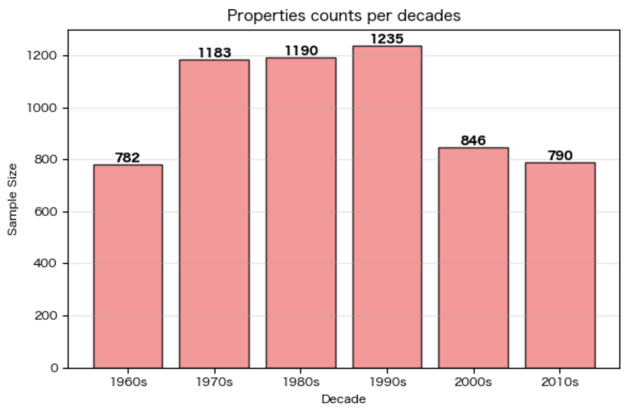

Figure 1: Dataset overview showing property construction date distribution across Tokyo's 23 wards.

The entire data processing pipeline remains stable and fast in this level, the whole processing time can be finished within a couple of hours, though depends on the actual specs of the machine. We will mention about the details in the thesis when it comes to the actual technical steps.

3 Quantifying the Openness of Residential Spaces

We focus on several key quantifiable statistics that might be related to the openness of properties, beyond the already existing tabular features such as room types and room area.

From interior data, we first filtered the main living room images, then applied semantic segmentation using the Mask2Former model which is pretrained on the ADE20K dataset to ensure that key components such as walls, ceilings, and windows can be correctly tagged. We then extract the ratio of their appearance in each image as features for later analysis, as shown in Figure 2.

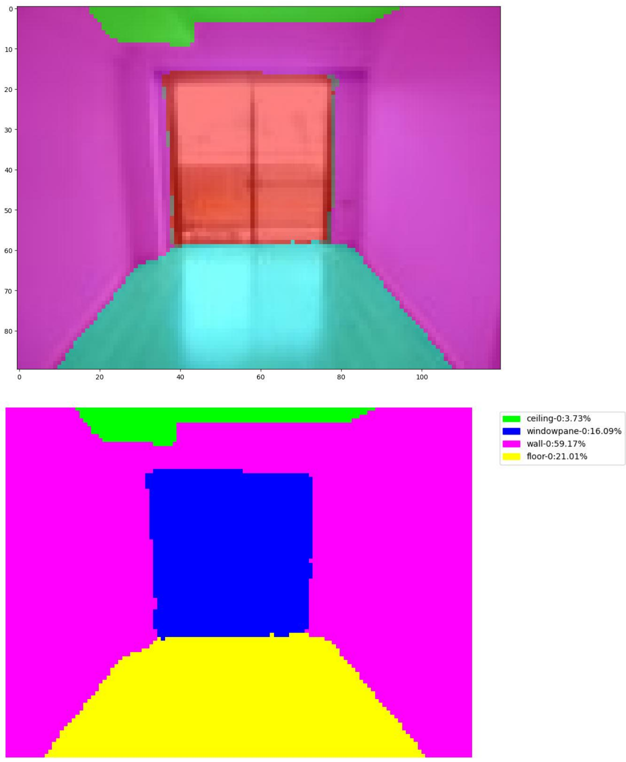

Figure 2: Example of interior semantic segmentation results.

From madori (floorplan) data, we first performed semantic segmentation using a model pretrained on non-floorplan data, then utilized a labeled dataset to perform fine-tuning to ensure it can classify floorplan components like walls, bedrooms, living rooms, etc.

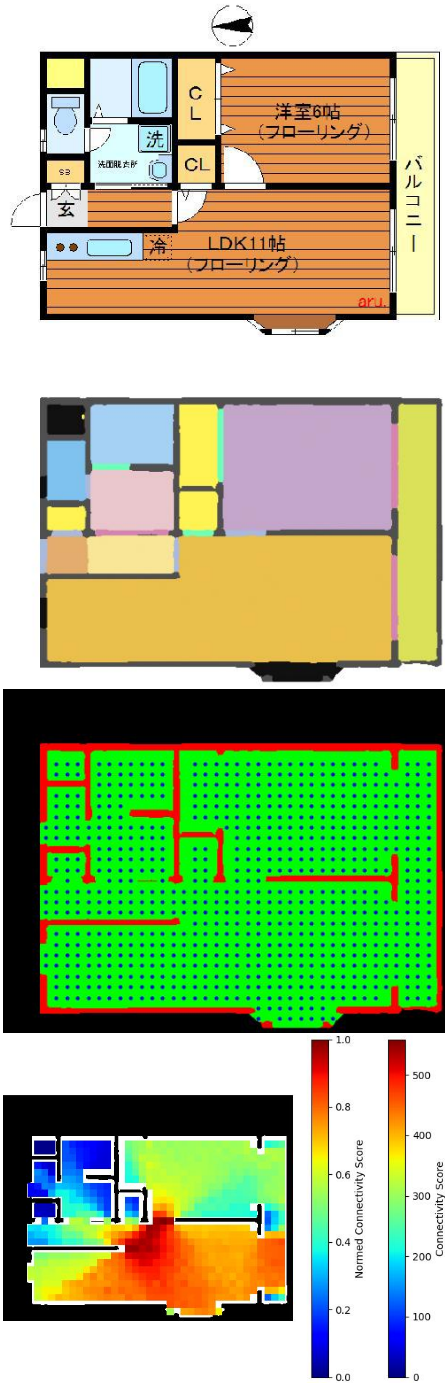

Figure 3: From top to bottom: raw floorplan, the semantic segmentation output, the physical gridding, and the heatmap of VGA.

To obtain VGA scores, we extract the open area by filtering out the background and walls. Then, by a given granularity, we create a grid over the area. Since every property has different physical dimensions, we normalize the density of gridding by physical size, with each grid cell ranging around 20 cm.

We define the VGA value at each grid node by the number of visible nodes from that node:

$$S(i) = \sum_{j=1}^{N} V_{ij} \tag{1}$$

where $S(i)$ is the visibility score at node i, N is the total number of nodes, and $V_{ij} = 1$ if node j is visible from node i, otherwise $V_{ij} = 0$. By this method, a VGA heatmap can be generated, and we extract VGA scores by taking the mean, standard deviation, minimum/maximum, etc., over the whole property or only living rooms to represent its VGA features. The output result with the raw floorplan input for the above processings are demonstrated in the following graph as shown in Figure 3.

4 Correlation Analysis Between Subjective Impressions and Openness

To validate our approach, we analyzed correlations between computed spatial metrics and subjective impressions using a pre-trained model by Shimomura et al. that outputs impression scores (q3) from interior images. We analyzed correlations between q3 impression scores and our extracted observables from both interior images and floorplan analysis. Since the model generate the q3 model was trained on the data that only reveal living room images to users, to reduce the bias, we only extract the vga stats from the floorplan overlayyed with living room masks. However, no significant correlation is found between them, as shown in Figure 4. The lack of significant correlation stems from a fundamental data source mismatch: the q3 model uses limited-view interior photographs while our VGA analysis processes complete floorplan layouts, capturing different aspects of spatial openness.

We also examined correlations between interior semantic segmentation component ratios and q3 scores. After filtering outliers using centered clustering with a 75th percentile cutoff, the results are shown in Figures 5 and 6.

The interior semantic segmentation analysis reveals that window pane and wall components show very weak correlation with impression scores, while floor exhibits mild negative correlation and ceiling shows moderate negative correlation with q3 scores. This could suggests that shooting angles capturing excessive floor area or ceiling visibility negatively impact user evaluations of living room quality from single images, emphasizing the importance of balanced camera perspective in interior photography.

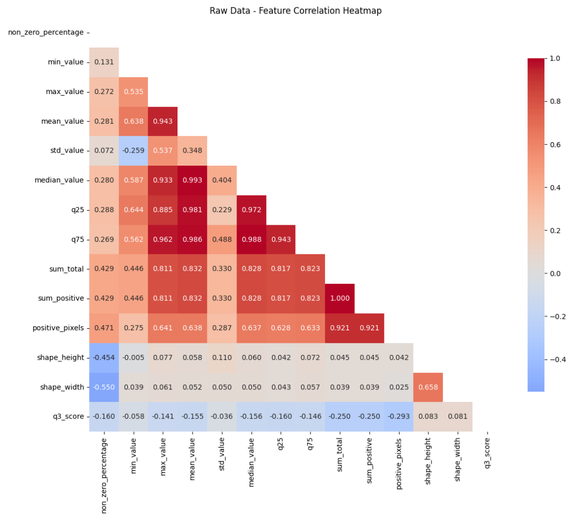

Figure 4: Correlation matrix between q3 impression scores, VGA metrics (mean, std, min, max)

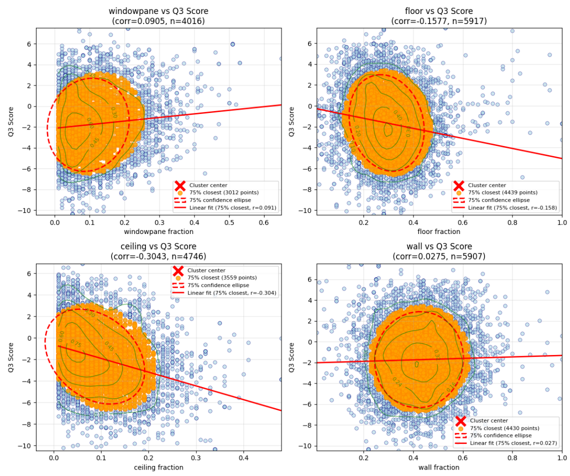

Figure 5: 2D distributions of q3 scores vs. interior semantic segmentation component ratios

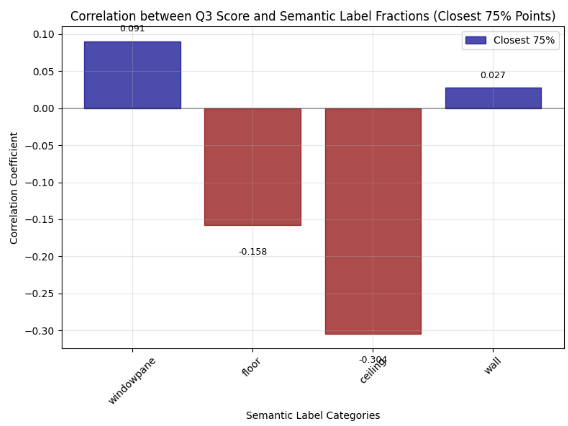

Figure 6: Correlation analysis between q3 scores and semantic segmentation ratios after outlier filtering

We also analyzed correlations between VGA statistics, interior segmentation results, and property data. Figure 7 shows q3 impression scores by construction decade, revealing trends in perceived spatial quality over time. This demonstrates how our framework can identify temporal patterns in housing design preferences.

Figure 8 presents VGA analysis results and q3 impression score distributions across Tokyo's 23 special wards, showing spatial distribution patterns of visibility graph metrics and subjective quality assessments. The visualization demonstrates regional variations in spatial openness characteristics, providing insights into urban housing design patterns at the metropolitan scale.

Detailed analysis will be presented in the full thesis.

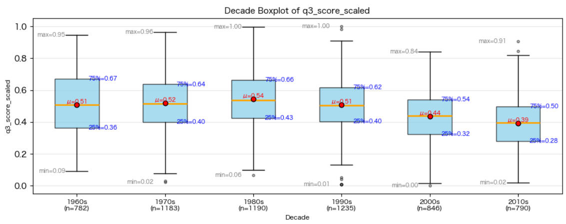

Figure 7: Distribution of q3 impression scores by property construction decade

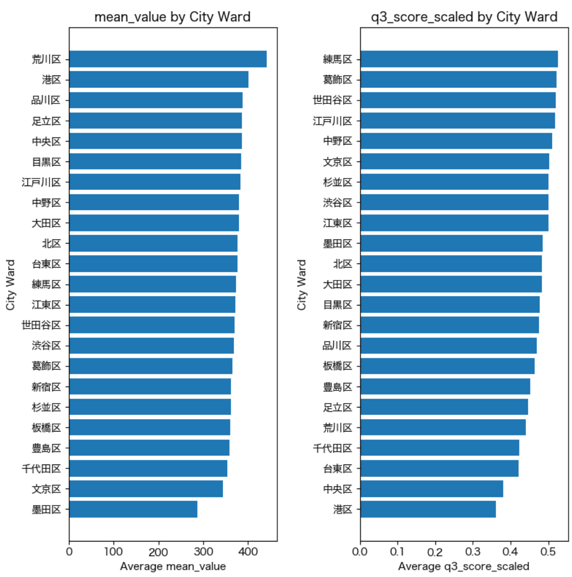

Figure 8: VGA analysis results and q3 impression score distributions across Tokyo's 23 special wards

5 Conclusion and Future Work

This research presents a comprehensive framework for analyzing spatial openness in rental housing through automated madori interpretation, image-based visibility graph analysis, and interior semantic segmentation. Our methodology leverages big data approaches to quantify subjective spatial qualities using unstructured visual data from rental platforms, demonstrating scalable processing techniques for large-scale urban analysis. Key findings reveal weak correlations between VGA metrics and user impression scores, with interior segmentation showing that excessive floor/ceiling visibility negatively impacts quality perceptions. However, several limitations affect our results: (1) q3 impression scores derive from comparative models with potential alignment bias and large variance, (2) VGA accuracy depends heavily on semantic segmentation quality, introducing systematic errors when segmentation fails, and (3) interior segmentation captures only visual element types rather than aesthetic qualities that significantly influence spatial perception. Future work should address these biases through improved scoring methodologies, robust segmentation validation, and integration of aesthetic analysis models. Despite limitations, this open-source framework provides practical tools for real estate professionals and urban planners seeking data-driven spatial quality assessment, with potential expansion beyond Tokyo and incorporation of 3D spatial information for enhanced analysis.

6 References

[References would be listed here.]