# Satellite Imagery-Based Property Valuation

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**1. Overview**

This project focuses on predicting residential property prices using a **multimodal regression approach** that combines:

- **Structured tabular data** (e.g., location, size, temporal features)
- **Unstructured satellite imagery** capturing neighborhood and environmental context

Traditional valuation models rely heavily on tabular features and often fail to capture visual indicators such as greenery, road density, or surrounding infrastructure. To address this, a **CNN-based feature extractor** was used to encode satellite images into numerical embeddings, which were then fused with tabular features and modeled using **LightGBM**.

**Modeling Strategys**

- Extract visual embeddings from satellite images using a pretrained CNN
- Concatenate image embeddings with engineered tabular features
- Train a gradient boosting regression model
- Compare performance against a tabular-only baseline

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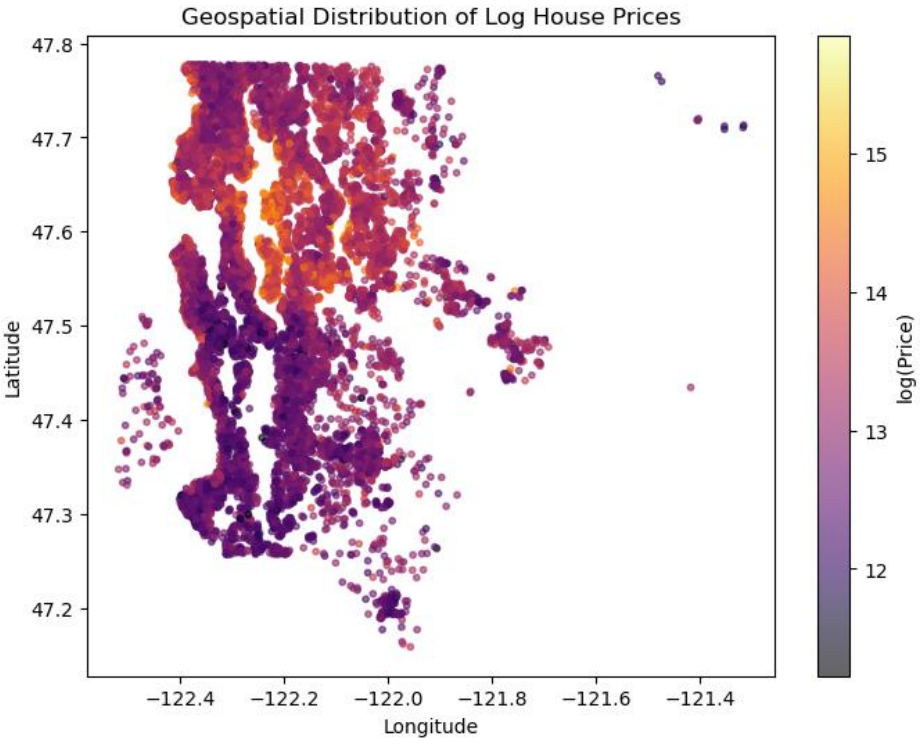
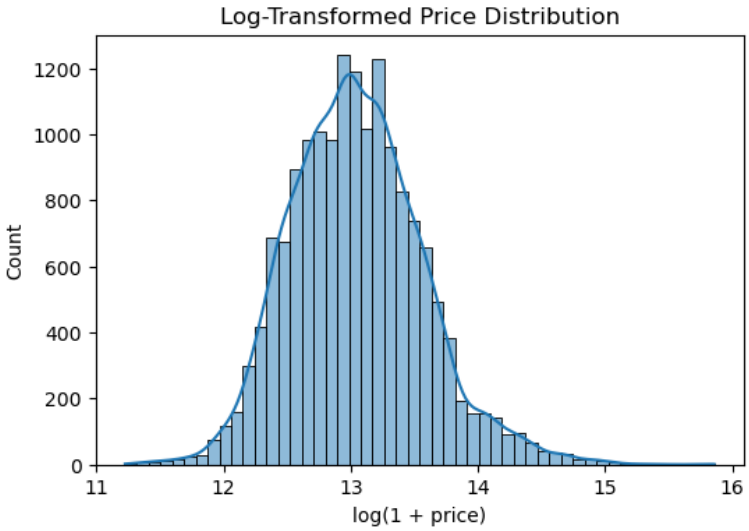
**2. Exploratory Data Analysis (EDA)**



### 2.1 Price Distribution




**Price is right-skewed; log transformation stabilizes variance and improves regression behavior.**

- The target variable (property price) shows a **right-skewed distribution**
- A small number of high-value properties significantly influence the mean
- This motivated the use of robust, non-linear models

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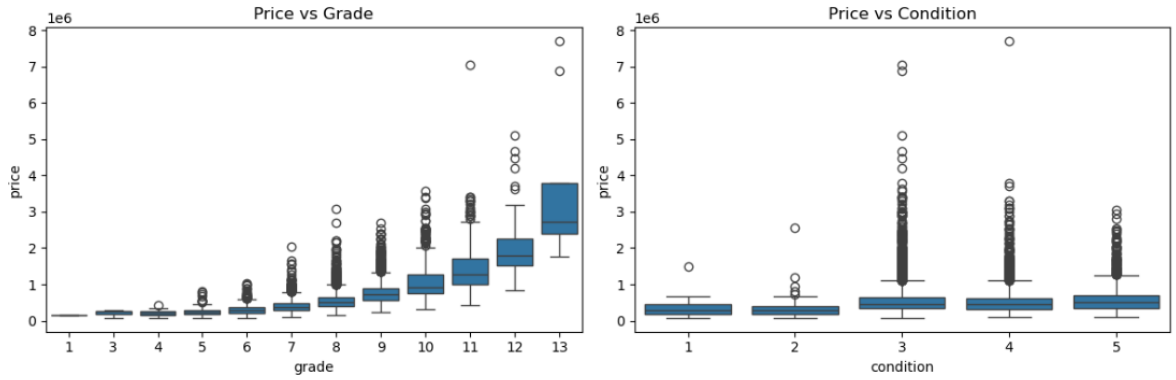
### 2.3 Grade and condition




**grade shows a strong monotonic increase with price**

**condition has a weaker but still positive influence**

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### 2.3 Satellite Image Samples

Satellite images reveal substantial variation in:

- Green cover
- Road connectivity

- Density of surrounding structures

These visual differences motivate the inclusion of imagery in the valuation pipeline.


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**3. Financial & Visual Insights**

Satellite imagery enables the model to capture **neighborhood quality**, which is difficult to encode numerically.


Key observed visual drivers of value:

- **Higher prices** associated with:
    - Dense green cover (trees, parks)
    - Organized road layouts
    - Proximity to open spaces
- **Lower prices** associated with:
    - Concrete-dominated regions
    - Congested or irregular road patterns
    - Sparse infrastructure

These insights suggest that satellite images act as a proxy for **socio-environmental quality**, complementing traditional financial features.

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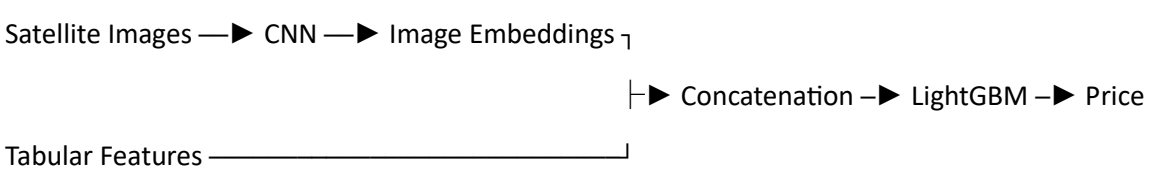
**4. Multimodal Architecture**

The project follows a **late-fusion multimodal architecture**, where visual and tabular features are processed separately and combined before prediction.

**Architecture Description**

1. Satellite images are passed through a **pretrained CNN**
2. The CNN outputs fixed-length image embeddings
3. Tabular features are cleaned and engineered independently
4. Both feature sets are concatenated
5. A **LightGBM regressor** predicts the final property price

Example (conceptual):

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**5. Results**

**5.1 Model Performance Comparison**

| Model Type | RMSE ↓ | $R^2$ ↑ |
|---|---|---|
| Tabular Only | 187340 | 0.720321 |
| Tabular + Satellite Images | 137550 | 0.805810 |

(*Lower RMSE and higher $R^2$ indicate better performance*)

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**5.2 Observations**

- The **multimodal model consistently outperforms** the tabular-only baseline
- Visual features significantly improve predictive accuracy
- Image embeddings help capture latent neighborhood attributes unavailable in structured data

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**6. Conclusion**

This project demonstrates that incorporating satellite imagery into property valuation models leads to **measurable performance gains**. The multimodal approach enhances traditional regression pipelines by embedding real-world visual context, making predictions more robust and realistic.

**Key Takeaways:**

- Multimodal learning improves valuation accuracy
- CNN embeddings effectively encode environmental context
- LightGBM handles fused high-dimensional features efficiently

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**7. Future Work**

- Fine-tuning CNNs on real-estate-specific imagery
- Using attention-based multimodal fusion
- Incorporating additional geospatial data (POIs, traffic, amenities)