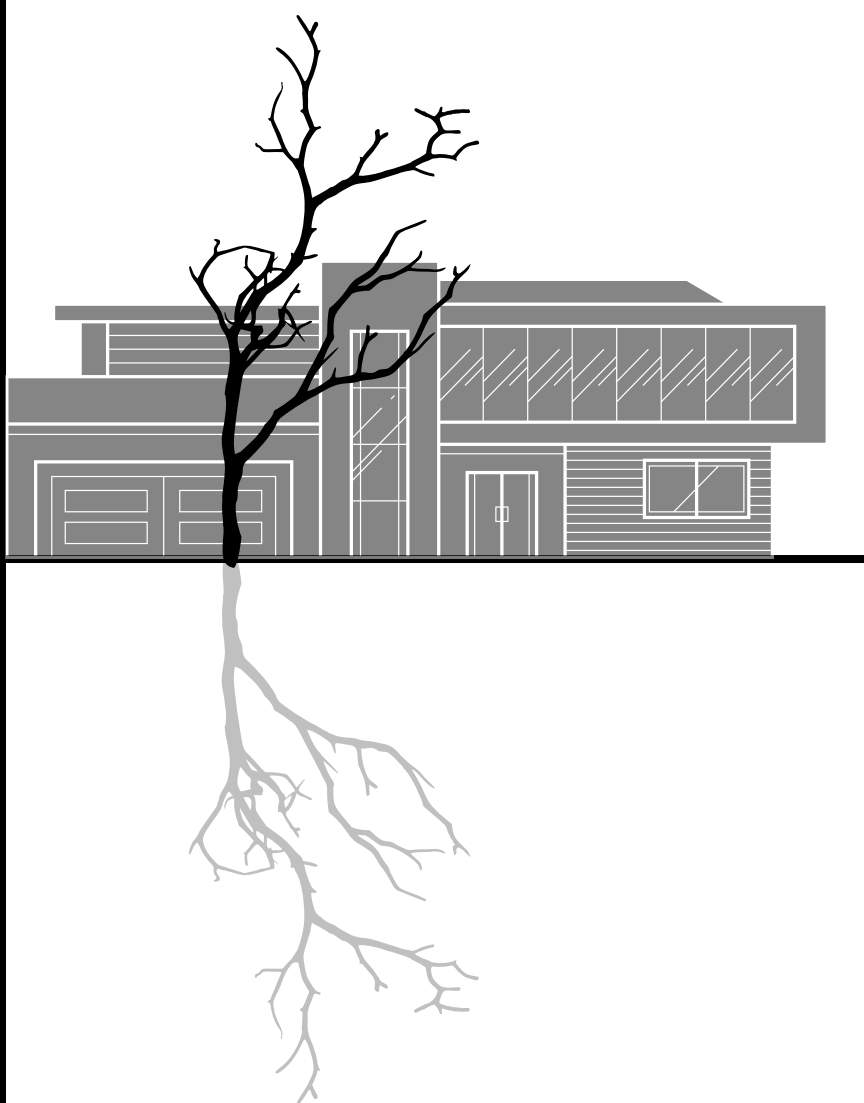


Satellite Imagery-Based Property Valuation

PROJECT REPORT



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1. Overview: Approach & Modeling Strategy

This project aims to predict residential property prices by combining structured housing attributes with satellite imagery, enabling the model to capture both numerical and environmental signals.

Approach Overview

- Traditional property valuation relies heavily on tabular features such as size, location, and room count.
- However, neighborhood characteristics (green cover, road density, urban layout) are not fully captured by structured data.
- To address this, a multimodal regression framework was designed that integrates:
 - * Tabular features for structural and locational information
 - * Satellite images for visual neighborhood context

Modeling Strategy

- Three models were implemented for comparison:
 1. **Mean Baseline** – predicts average price (lower bound)
 2. **Tabular-Only Model** – linear regression using structured features
 3. **Multimodal Model** – CNN + MLP with late fusion
- The multimodal model uses:
 - * A ResNet-18 CNN to extract high-level visual embeddings from satellite images
 - * A fully connected network for tabular features
 - * A fusion layer to combine both modalities before final price prediction

Why Multimodal?

- Tabular features explain *what* the property is.
- Satellite imagery explains *where* the property is situated.
- The combination improves interpretability and captures contextual value drivers.

2. Exploratory Data Analysis (EDA)

EDA was conducted to understand price behavior, spatial patterns, and visual characteristics of neighborhoods.

Price Distribution

- Property prices show a right-skewed distribution, with a small number of very high-value homes.
- A log transformation ($\log_{10}(\text{price})$) was applied to stabilize variance and improve model training.



Geospatial Analysis

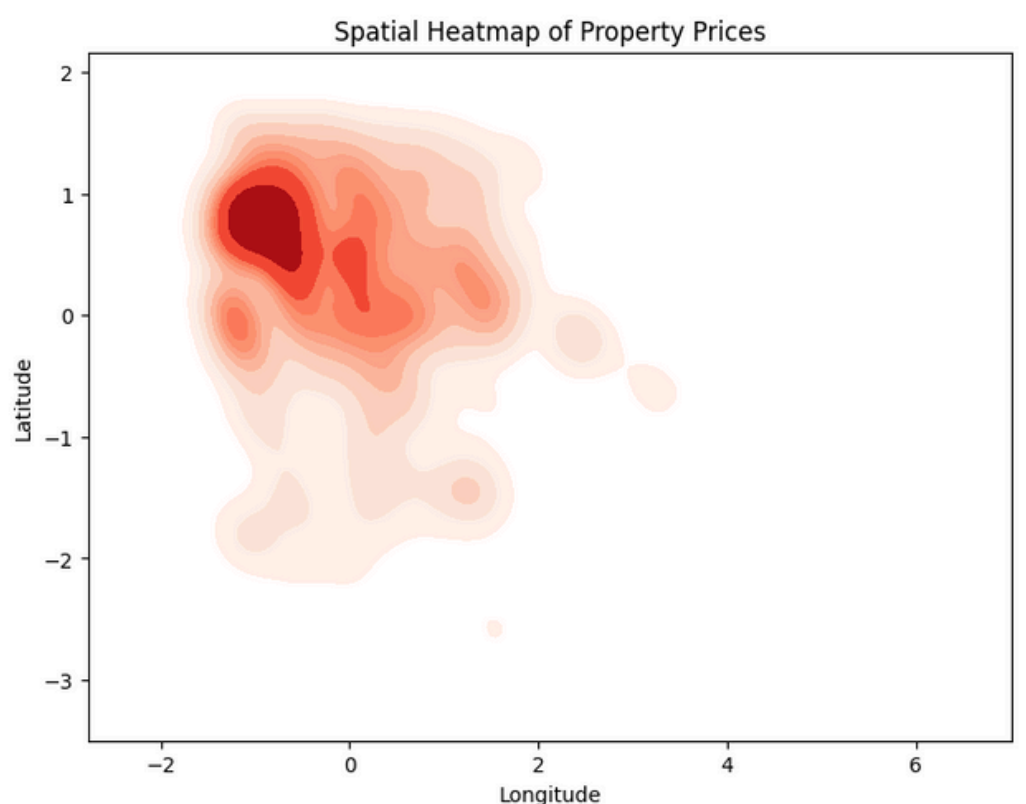
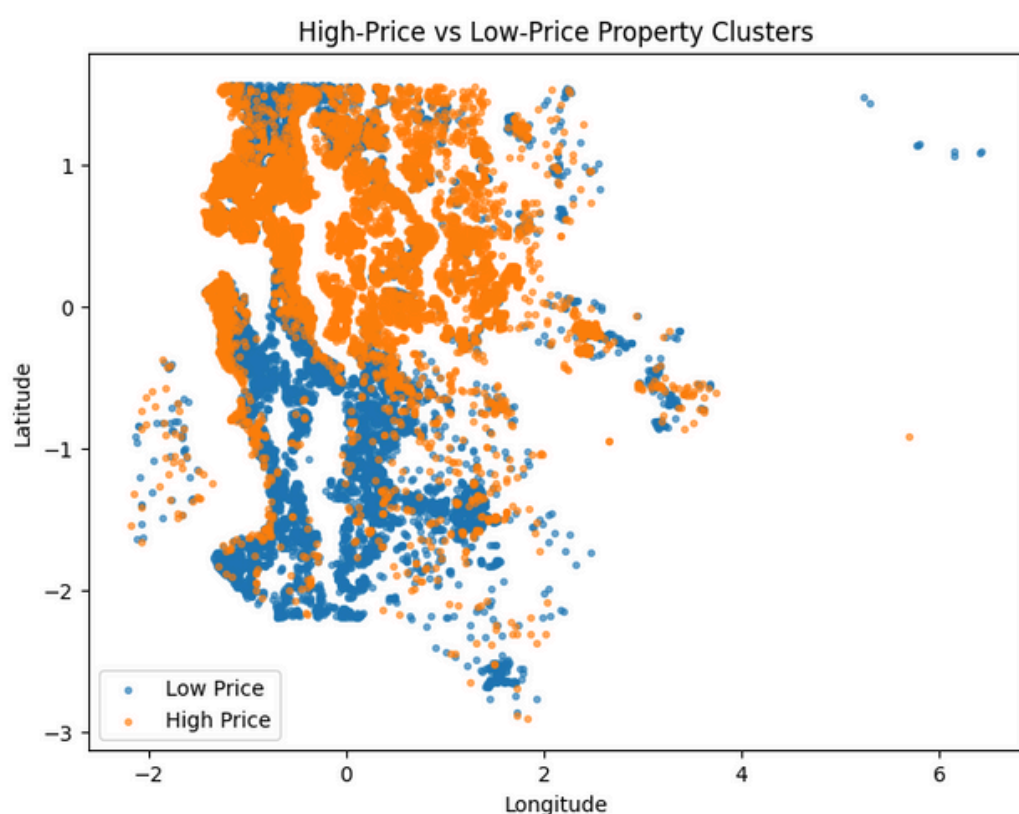
- Price vs Latitude/Longitude scatter plots reveal clear geographic clustering.
- High-priced properties tend to be concentrated in specific latitude-longitude bands, indicating strong location dependence.

- Price heatmaps highlight regions with consistently higher property values.



Satellite Image Exploration

- Sample satellite images show clear variation in:
 - Road density
 - Green cover
 - Urban compactness
 - Proximity to open or water-adjacent areas
- These visual differences motivate the use of CNNs to extract neighborhood-level features not present in tabular data.



3. Financial & Visual Insights

Understanding What Drives Property Value from Visual and Spatial Signals

By combining exploratory spatial analysis with Grad-CAM-based visual explainability, we identify how environmental context and neighborhood structure influence property prices beyond traditional tabular features.

Built Environment vs. Natural Features

- **Low-priced properties** show attention concentrated along:
 - Linear road networks
 - Dense, uniform housing blocks
 - Large continuous concrete surfaces
- **High-priced properties** show strong activation around:
 - Individual building footprints
 - Open spaces within plots
 - Surrounding greenery and tree cover

Financial Interpretation:

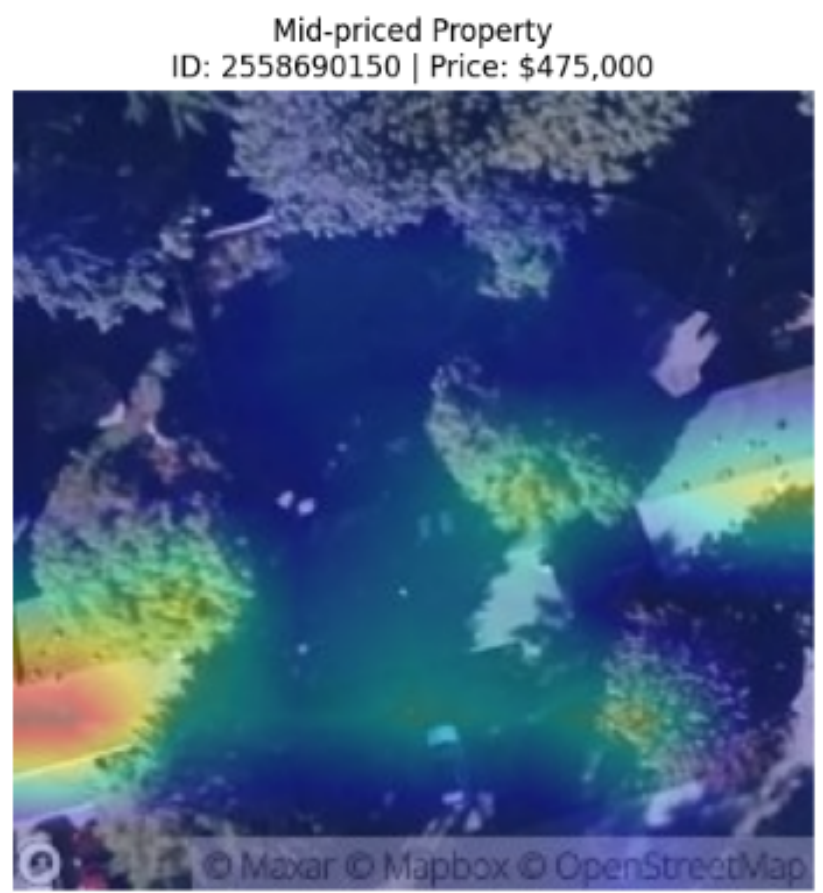
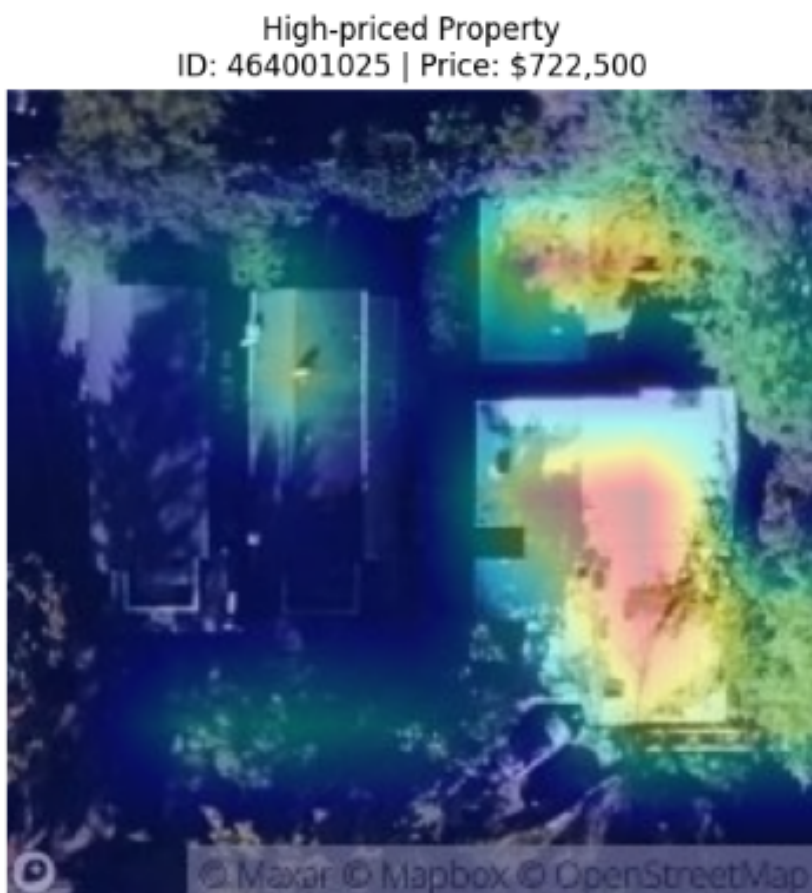
- Dense concrete infrastructure and tightly packed housing are associated with **lower land value** per unit area.
- Properties with visible **green cover, spatial separation, and open surroundings** command a price premium.
- The model implicitly captures “**quality of living space**”, not just building size.

Neighborhood Density as a Price Signal

- **Low-priced homes:**
 - Diffuse activation across many rooftops
 - Limited focus on any single property
- **High-priced homes:**
 - Sharp, localized activation centered on the target house

Financial Interpretation:

- High-density neighborhoods **dilute** individual property value.
- Low-density layouts **increase exclusivity**, a key driver of higher prices.
- This aligns with real estate economics:
scarcity of space → higher valuation.



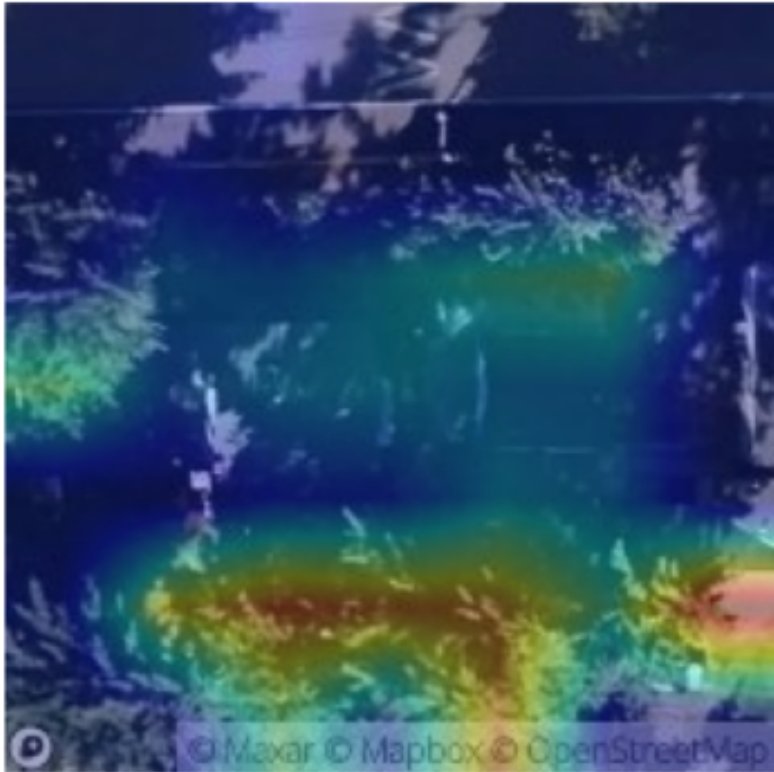
Green Cover and Visual Amenity

- **High-priced properties** show consistent activation in:
 - Tree canopies
 - Garden-like textures
 - Natural, irregular patterns

Financial Interpretation:

- **Greenery** acts as a visual proxy for environmental quality:
 - Better air
 - Aesthetic appeal
 - Higher socio-economic neighborhoods

Low-priced Property
ID: 9117000170 | Price: \$268,643



Key Insight

Visual features do not replace tabular predictors, but they provide contextual signals that explain why certain locations command higher prices.

Correlation: lat, long, price

	lat	long	price
lat	1.000000	-0.140838	0.310008
long	-0.140838	1.000000	0.024279
price	0.310008	0.024279	1.000000

- Location matters, but not in a simple straight-line way
- Price is influenced by:
 - Micro-neighborhoods
 - Amenities
 - Density patterns
- This justifies:
 - Geospatial heatmaps
 - Cluster plots
 - Satellite imagery (non-linear spatial context)

Correlation: sqft_living15 vs price

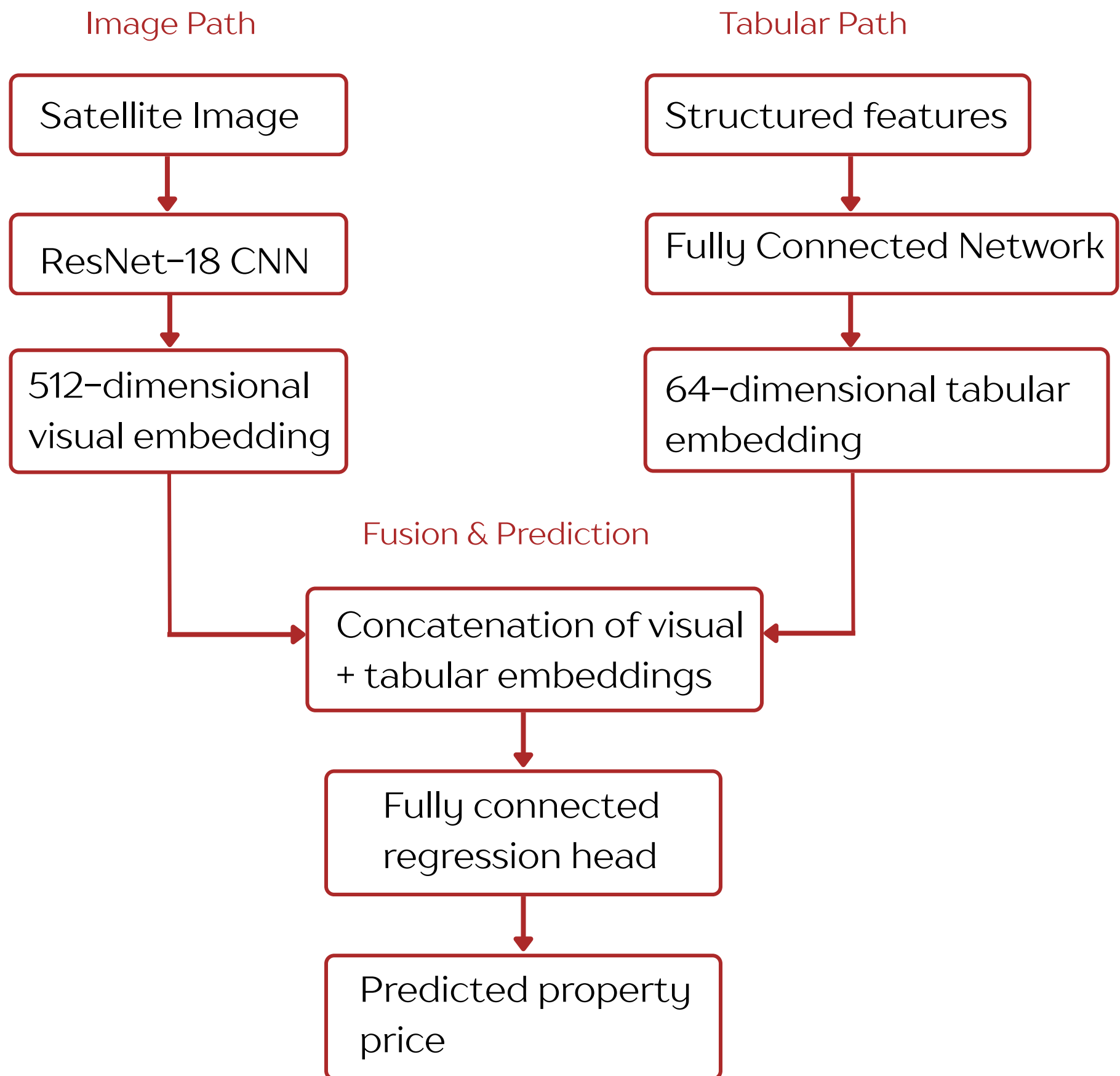
	sqft_living15	price
sqft_living15	1.000000	0.581781
price	0.581781	1.000000

- Location matters, but not in a simple straight-line way
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EDA Summary

- Property prices are highly skewed, requiring log transformation.
- Location **dominates** pricing, with strong spatial clustering.
- **High-value** homes cluster geographically and visually.
- Neighborhood-level features (density, greenery, openness) matter as much as house-level features.
- Grad-CAM confirms that the **multimodal model** captures environmental and urban structure cues, not just roofs.

4. Architecture Diagram



Why Late Fusion?

- Allows each modality to learn independently
- Prevents tabular features from dominating early CNN layers
- Simplifies interpretation and debugging

5. Results: Model Comparison

The performance of different models was evaluated using RMSE and R^2 .

Model	RMSE	R^2
Mean Baseline	~354k	0
Tabular(Neural MLP)	~231k	~0.57
Improved Tabular (XGBoost)	~112k	~0.89
Multimodal (CNN+MLP)	~243k	~0.53
Improved Multimodal(CNN+XGBoost)	~161k	~0.79

Baseline Performance

The mean baseline model serves as a naïve benchmark, achieving an R^2 of 0.0. This confirms that property prices exhibit substantial variance and cannot be captured by simplistic averaging strategies.

Tabular Models

- Tabular Neural MLP achieved $RMSE \approx 231K$, $R^2 \approx 0.57$
- Demonstrates that structured housing attributes provide strong predictive signal

- **Improved Tabular (XGBoost)** achieved:
 - Lowest RMSE: $\approx 112K$
 - Highest R^2 : ≈ 0.90
- Indicates that gradient-boosted trees effectively capture non-linear interactions in tabular real estate data

Multimodal Models

- Naïve multimodal model (CNN + MLP) underperformed tabular baseline
- Suggests that simple feature concatenation introduces noise without careful fusion
- **Improved Multimodal (CNN embeddings + XGBoost)** achieved:
 - RMSE $\approx 161K$
 - $R^2 \approx 0.79$
- Confirms that satellite imagery adds meaningful value when integrated using a strong non-linear learner

Key Insights

- **Tree-based models** outperform neural networks on structured housing data
- Visual features alone do not guarantee better performance
- Fusion strategy is **critical** for multimodal success
- Satellite imagery improves **context awareness and interpretability**, even when accuracy gains are moderate

Final Takeaway

- **Structured features** remain the dominant predictors of price
- Multimodal learning enhances spatial understanding and explainability
- The improved multimodal model offers a strong balance between **accuracy and interpretability**