Advancing Urban Environment Studies in Murcia, Spain through an Automated Facade Image Classification Model

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1. Overview

Background & Motivation

Urban sustainability is strongly influenced by land use and city structure. Traditional remote sensing methods often miss street-level details essential for understanding urban transformation.

Why Façade Images?

Façades offer rich visual indicators of:

- Construction quality
- Maintenance levels
- Socio-economic context

They reveal micro-scale urban dynamics often hidden in satellite imagery.

Method Overview

We propose a novel GeoAI-based methodology combining:

- Convolutional Neural Networks (CNNs) for automatic image classification
- Cadastral data for urban context
- GIS tools for spatial integration and visualization

Case Study: Murcia, Spain

A Mediterranean city experiencing fast-paced urban growth, offering a diverse urban fabric for analysis.

Objective

To create a scalable and replicable framework for:

- ☑ Classifying façade images
- ☑ Identifying urban patterns
- ☑ Supporting territorial planning with high-resolution insights

Impact

This integrated approach enhances urban analysis by bridging the gap between visual data, spatial intelligence, and AI-driven insights.

2. Introduction

- Urban sustainability is shaped by land use and urban form; rapid growth often affects vulnerable areas (Gómez, 1994).
- GeoAI, which combines GIS and AI, enhances urban analysis by applying machine learning to spatial data (Li et al., 2022).
- Deep learning models like CNNs are increasingly used to analyze façade imagery, offering insights into construction quality and socio-economic context (Belinga & El Haziti, 2023).

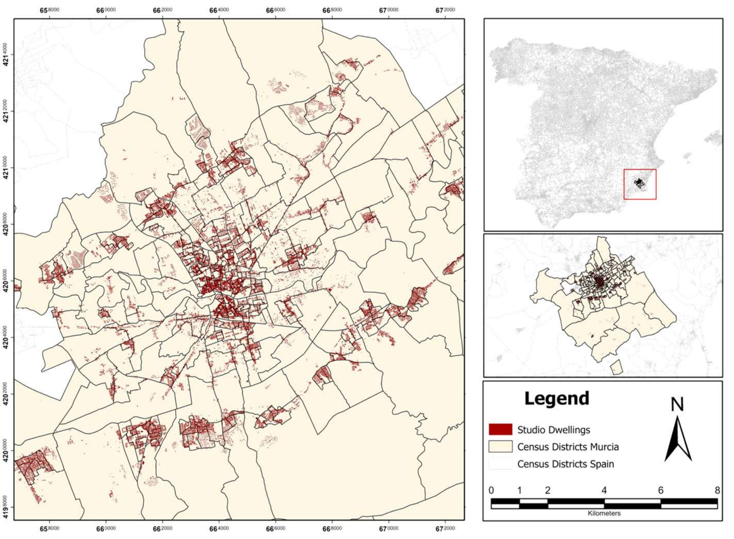


Fig. 1.- Study area: Region of Murcia, Spain

- Murcia, located in an agricultural valley along Spain's Mediterranean coast, has experienced rapid urban expansion, leading to the loss of farmland and smaller settlements.
- Initially focused on the historic city center, Murcia's growth has expanded northward through new developments (Martí & Moreno, 2014).
- Since 1980, Murcia has become one of Spain's fastest-growing cities, with a 55% population increase and a 110% rise in real estate development (Statistical Atlas of Urban Areas in Spain, 2024).

3. Methods

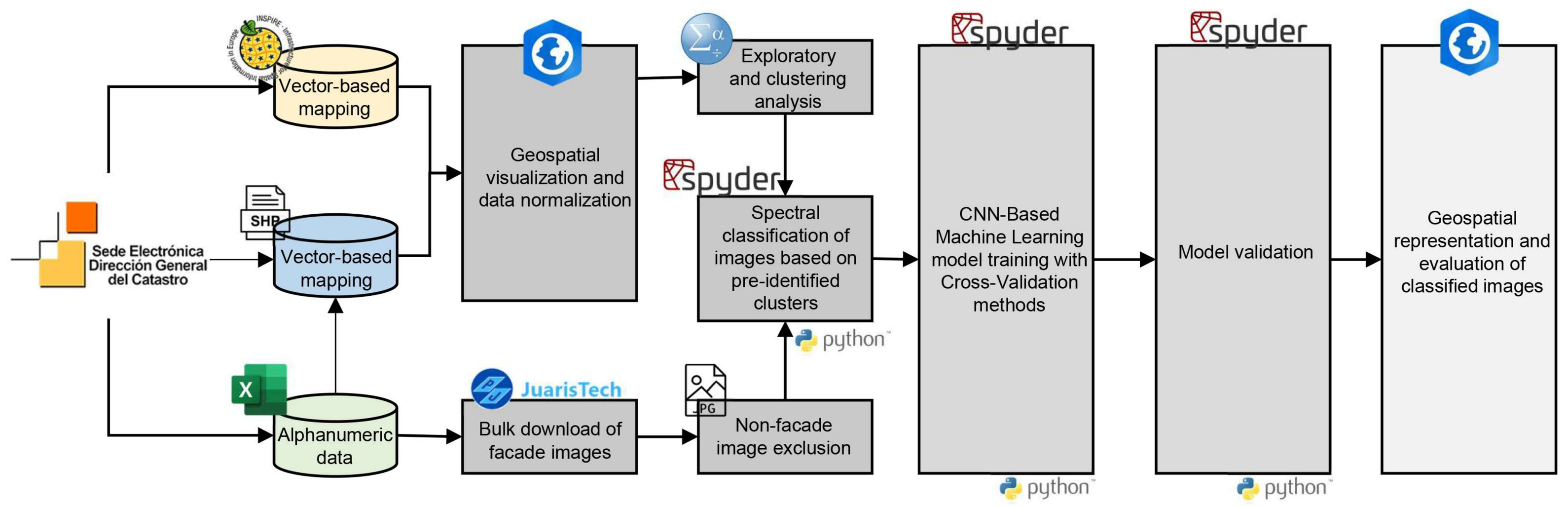


Fig. 2.- Research Workflow

4. Cluster Analysis

An initial cluster analysis using two variables showed excellent results, with a silhouette index close to 1. To further examine variable relationships, a Principal Component Analysis (PCA) was also performed.

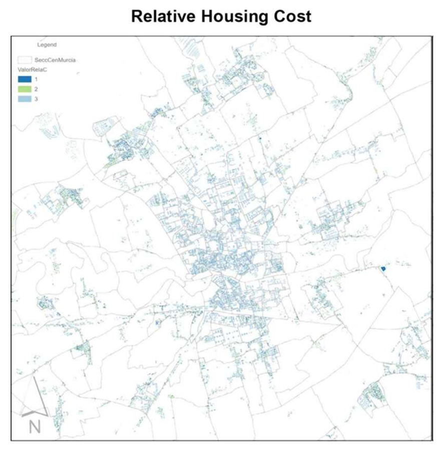


Fig. 3 Relative Housing Cost Spatial Analysis

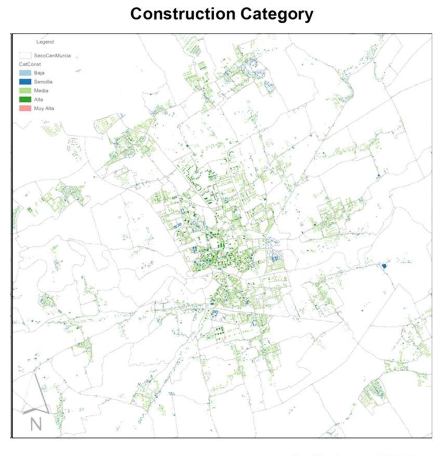


Fig. 4 Construction Category Spatial Analysis

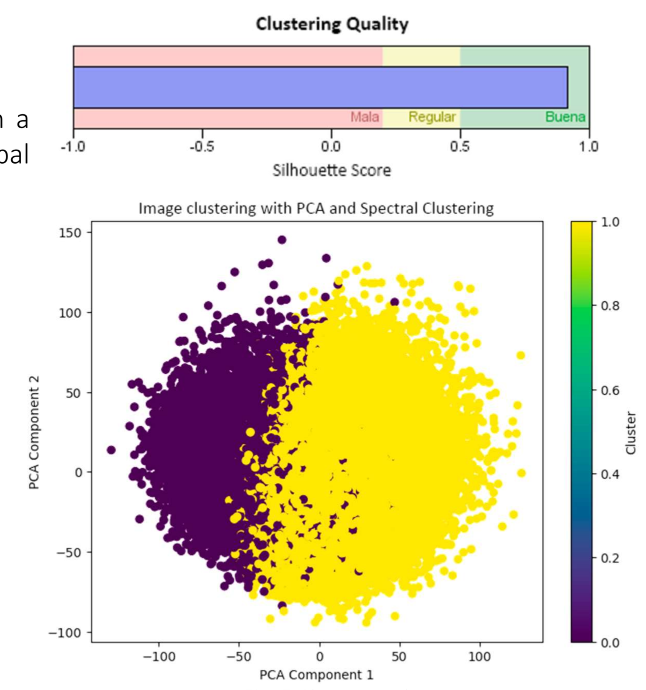


Fig. 5 Cluster analysis

5. Classification Model

- The EfficientNetB0 model was trained in Python using 19,000 façade images, split into two clusters.
- A 5-fold cross-validation and an 80/20 train-validation split ensured balanced performance.
- TensorFlow, Keras, and SCIKIT-learn handled the model workflow, with ImageDataGenerator for preprocessing and the Adam optimizer for efficient training..

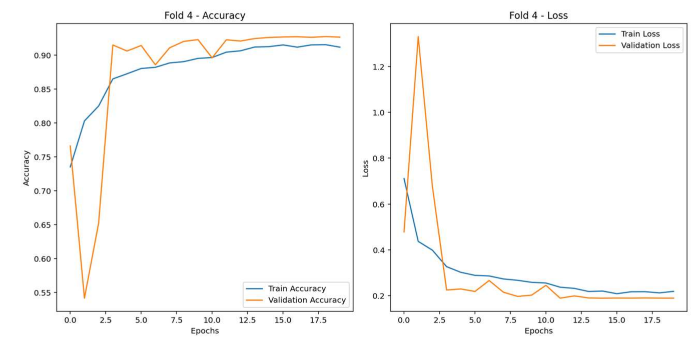
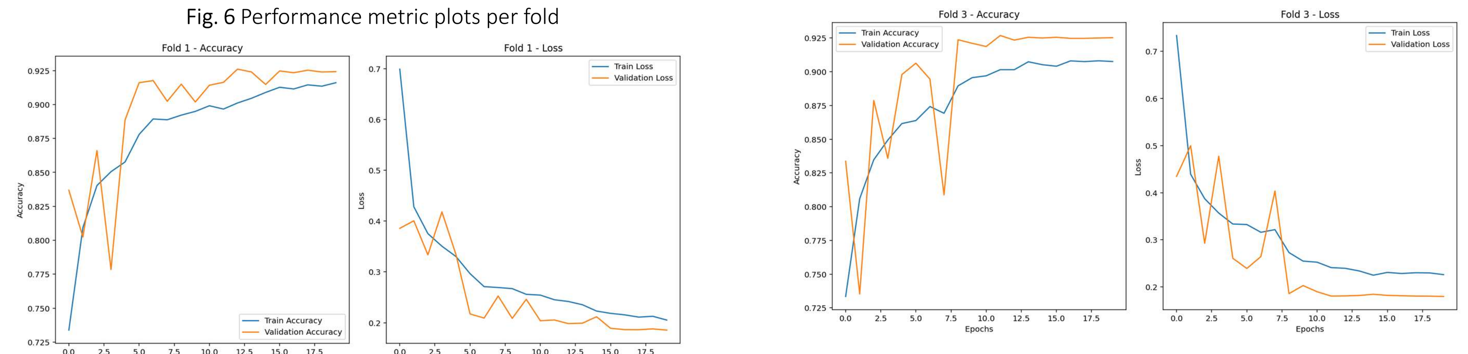
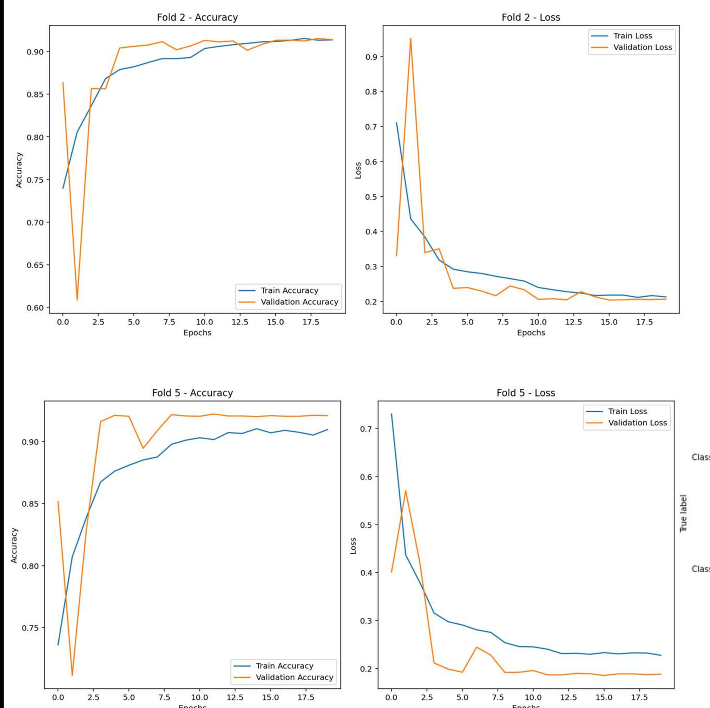


Fig. 6 Performance metric plots per fold





Key metrics results for each fold

Fold	Loss	Accuracy (%)	Precision	Recall
1	0.1849	92.42	0.93	0.92
2	0.2084	91.00	0.93	0.9
3	0.1822	92.84	0.94	0.93
4	0.1855	92.58	0.94	0.92
5	0.2000	91.16	0.94	0.88
Average result	0.19	92		

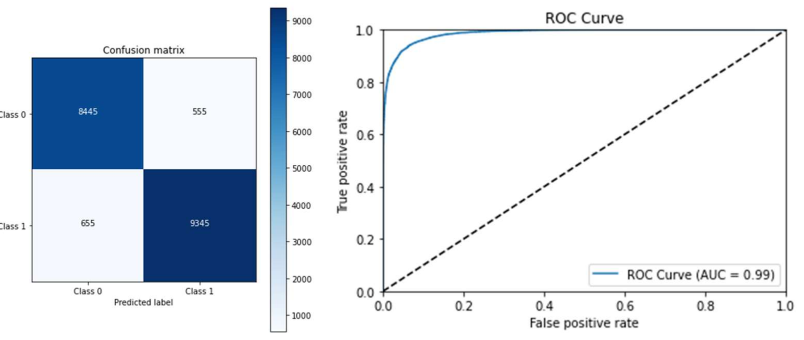
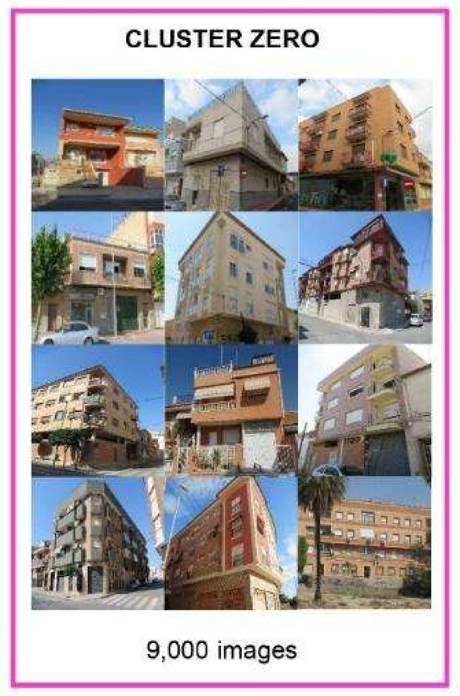


Fig. 7 Model evaluation plots

6. Results

Fig. 8 Grad-CAM Heatmaps on Classified Façade Images



CLUSTER ZERO

- They predominantly appear in central districts
- Heights of two or more levels
- Collective dwellings type predominates
- Average relative value between 2 and 3
- The central district is the most expensive (average relative value of 2.9)
- The cheapest area is Rural Murcia (Average relative value of 1.89)
- 27% remain in their original state
- 36% have a life condition of 1
- 36% have a life condition of 2

CLUSTER ONE

- Predominantly located in peripheral district
- Maximum height of two levels
- Single-Family dwellings predominate
- Average relative value below 2
- The northern district is the most expensive (average relative value of 1.89)
- The cheapest area is Rural Murcia (Average relative value of 1.46)
- 20% remain in their original state.
- 30% have a life condition of 1
- 50% have a life condition of 2

Fig. 9 Architectural and Physical Features of Classified Façades

- Cluster One is primarily located in suburban areas, marked by dispersed urban settlements situated farther from the central core and exhibiting closer ties to Rural Murcia.
- Cluster Zero represents a compact, dense urban fabric that characterizes the central part of the city.

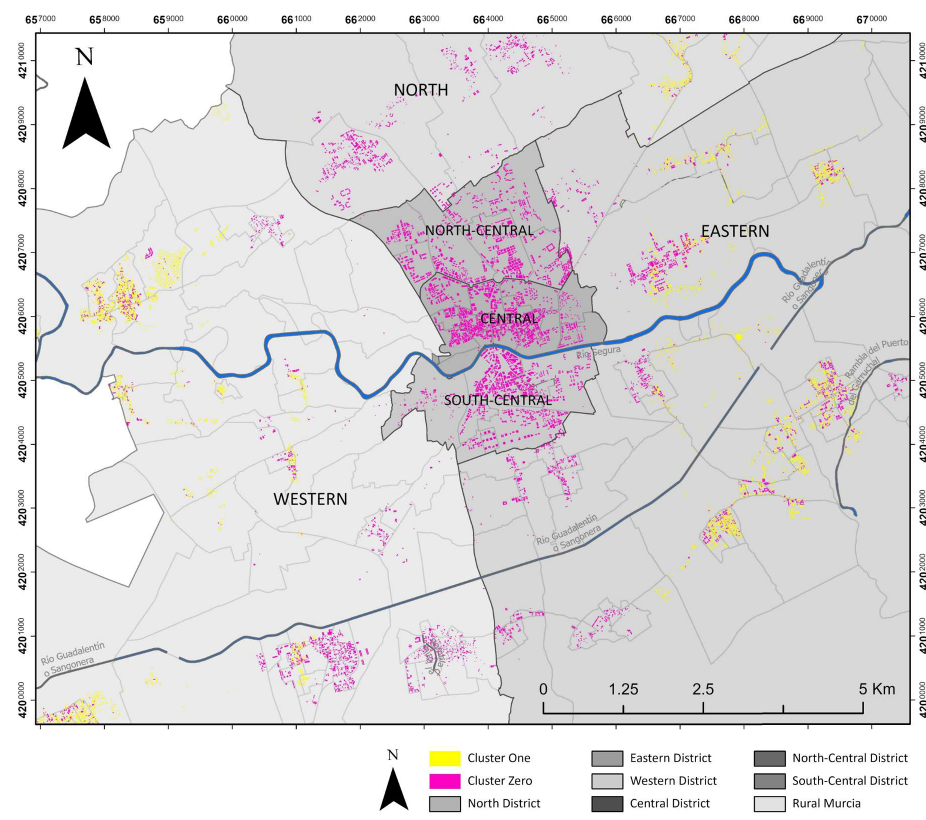


Fig. 10 Spatial Analysis of Clusters derived from the Classification Model

- The map displays the geographic layout of the identified clusters, enabling a clear visualization of territorial segmentation based on construction and urban attributes across districts.
- This cartographic analysis supports the interpretation of urban development trends and enhances the understanding of spatial differentiation across the territory.

7. Conclusion

I. Despite limited variability in façade images, the model achieved successful autonomous classification using cluster analysis.

II. The classification model accurately grouped façades into two categories, which correspond to spatial patterns in Construction Category and Relative Housing Cost.

III. Urban differences were clearly identified: taller, collective buildings dominate central areas, while shorter, single-family dwellings are more common in the periphery.

IV. The model offers a fast and scalable alternative to manual building surveys, significantly reducing time and resource demands.

V. It enables a preliminary assessment of the urban housing stock, supporting municipal planning and simplifying fieldwork.

VI. The approach lays the foundation for identifying priority areas for climate adaptation, with potential long-term benefits exceeding initial investments.

VII. Overall, the model serves as a valuable tool for urban analysis and planning, with potential applications across Spanish cities.

VIII. This GeoAI-based model offers a fast, scalable approach to urban façade classification, supporting data-driven planning in rapidly evolving cities.

8. References

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Acknowledgments

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