Developing an AI-Powered Recommendation System to Improve Housing Affordability and Accessibility in Major U.S. Metropolitan Areas

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Abstract

This project develops a prototype AI-powered affordable housing recommendation and exploration system for Philadelphia, focusing on enhancing accessibility and affordability. The choice of Philadelphia as a case study is driven by the availability of comprehensive Public Use Microdata Sample (PUMS) data and local housing datasets, making it an ideal testing ground for this prototype system. Utilizing data from various sources, including Census American Community Survey (ACS), PUMS, and local affordable housing datasets, the system employs machine learning techniques, particularly Random Forest, for predictions and recommendations. The project integrates spatial analysis, interactive visualizations, and a user-friendly Shiny app to facilitate exploration of affordable and accessible housing options. By incorporating HUD Fair Housing Accessibility Guidelines, the system addresses the critical need for accessible housing among older adults and individuals with disabilities. The findings demonstrate the potential of AI and data analytics in improving housing policy decisions and assisting individuals in finding suitable affordable and accessible housing options. While focused on Philadelphia, this prototype system serves as a model that could be adapted for other urban areas facing similar housing challenges.

Keywords: affordable housing, accessibility, AI recommendation system, Philadelphia, spatial analysis, Random Forest, Shiny app, prototype

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1. Introduction

1.1 Problem Statement

Philadelphia, like many major urban centers in the United States, faces significant challenges in providing affordable and accessible housing to its diverse population. The lack of adequate housing options particularly affects older adults and individuals with disabilities, who often require specific accessibility features in their living spaces. According to recent data from the U.S. Census Bureau (2021), approximately 14% of Philadelphia's population is 65 years or older, and about 16% of residents under 65 have a disability. Despite these demographics, finding housing that is both affordable and accessible remains a significant challenge for many Philadelphians.

The intersection of affordability and accessibility in housing is a complex issue. While the city has various affordable housing initiatives, many affordable units lack the necessary accessibility features. Conversely, housing units with appropriate accessibility features are often unaffordable for those who need them most. This mismatch creates a significant barrier for older adults and people with disabilities in finding suitable housing, potentially leading to decreased quality of life, social isolation, and increased healthcare costs.

1.2 Significance of the Issue

The shortage of affordable and accessible housing in Philadelphia has far-reaching implications for individuals, communities, and the city as a whole. For individuals, particularly older adults and those with disabilities, the lack of suitable housing can lead to reduced independence and quality of life,

increased risk of accidents and injuries in unsuitable living environments, higher healthcare costs due to inadequate living conditions, and social isolation and mental health challenges.

At a community level, the issue contributes to the displacement of long-term residents from their neighborhoods, increased homelessness and housing insecurity, and strain on social services and healthcare systems.

For the city, addressing this issue is crucial for promoting social equity and inclusion, supporting aging in place and reducing institutionalization, and enhancing overall community well-being and economic vitality.

According to a recent report by the Philadelphia Housing Authority (2023), there is a shortage of over 70,000 affordable housing units in the city. Furthermore, a study by the Mayor's Commission on Aging (2022) found that only 3% of Philadelphia's housing stock is both affordable and accessible to older adults and people with disabilities.

1.3 Project Scope and Objectives

This project focuses on developing a prototype AI-powered affordable housing recommendation and exploration system specifically for Philadelphia. The choice of Philadelphia as the focus area for this prototype is driven by two main factors:

1. Data Availability: Philadelphia offers comprehensive Public Use Microdata Sample (PUMS) data and detailed local housing datasets, providing a rich foundation for developing and testing the AI system.

2. Manageable Scale: As a prototype, concentrating on a single city allows for a more focused and in-depth analysis, while still providing valuable insights that could be potentially applied to other urban areas facing similar housing challenges.

The primary objectives of this prototype project are:

1. To develop a machine learning model, specifically a Random Forest algorithm, that can effectively recommend suitable housing options based on affordability, accessibility, and user preferences within Philadelphia.

2. To integrate accessibility features based on HUD Fair Housing Accessibility Guidelines into the recommendation system, ensuring that housing suggestions meet the specific needs of older adults and individuals with disabilities in Philadelphia.

3. To create an interactive, user-friendly Shiny app that allows users to explore affordable and accessible housing options in Philadelphia, visualize spatial patterns, and receive personalized recommendations.

4. To conduct spatial analysis to identify hotspots of accessible and affordable housing in Philadelphia, providing insights into areas of high need and potential for development.

5. To generate actionable insights and recommendations for policymakers, urban planners, and stakeholders to improve the availability and distribution of affordable and accessible housing in Philadelphia.

6. To establish a prototype model that, while focused on Philadelphia, could serve as a template for similar systems in other urban areas, demonstrating the potential of AI in addressing housing accessibility and affordability challenges.

By achieving these objectives, this project aims to bridge the gap between housing needs and available options in Philadelphia, leveraging the power of AI and data analytics to enhance decision-making processes for both individuals seeking housing and policymakers addressing urban housing challenges. While the immediate focus is on Philadelphia, the insights gained and the methodologies developed have the potential to inform similar initiatives in other cities, contributing to the broader dialogue on affordable and accessible urban housing.

2. Background and Literature Review

2.1 Affordable Housing in Philadelphia

Like many large U.S. cities, Philadelphia faces significant challenges in providing affordable housing to its residents. The current state of affordable housing in Philadelphia is characterized by a severe shortage of units and increasing demand.

According to the Philadelphia Housing Authority (2023), the city has a deficit of over 70,000 affordable housing units. This shortage is exacerbated by rising housing costs, with median rent increasing by 13% between 2019 and 2022 (Philadelphia Office of Housing and Community Development, 2023).

Demographic trends in Philadelphia further underscore the need for affordable housing:

- The poverty rate in Philadelphia stands at 23.1%, significantly higher than the national average of 11.6% (U.S. Census Bureau, 2021).

- 40% of Philadelphia households are cost-burdened, spending more than 30% of their income on housing (Pew Charitable Trusts, 2022).

- The city's population is aging, with projections indicating that by 2030, one in five Philadelphians will be over 65 (Philadelphia Corporation for Aging, 2021).

These trends highlight the growing need for affordable housing solutions that cater to diverse demographic groups, including older adults and people with disabilities.

2.2 Housing Accessibility for Older Adults and People with Disabilities

Accessible housing is crucial for maintaining independence and quality of life for older adults and people with disabilities. Key accessible design features include:

- Zero-step entrances
- Wide doorways and hallways
- Accessible bathrooms with grab bars
- Lever-style door handles and faucets
- Lowered countertops and cabinets

Despite the importance of these features, finding suitable accessible housing remains a significant challenge. A study by the Mayor's Commission on Aging (2022) found that only 3% of Philadelphia's housing stock is both affordable and accessible to older adults and people with disabilities.

Challenges in finding suitable housing include:

- Limited supply of accessible units
- High costs of retrofitting existing homes
- Lack of information about available accessible housing options
- Discrimination in the housing market

2.3 AI Applications in Housing Recommendations

AI-based housing recommendation systems are an emerging field with potential to address some of the challenges in finding affordable and accessible housing. Several existing systems and studies demonstrate the application of AI in this domain:

- Zumper's "Zumper Select" uses machine learning to match renters with suitable apartments based on preferences and budget (Zumper, 2023).
- Zillow's "Zestimate" employs AI algorithms to predict home values and rent prices (Zillow Research, 2022).
- A study by Chen et al. (2021) developed a collaborative filtering-based recommendation system for affordable housing in New York City.

Potential benefits of AI in housing recommendations include:

- More personalized and accurate housing suggestions
- Efficient matching of housing seekers with suitable properties
- Potential to identify patterns and trends in housing needs

Limitations and challenges include:

- Potential for bias in AI algorithms if not carefully designed and monitored

- Dependence on the quality and comprehensiveness of input data

- Privacy concerns related to the use of personal data in recommendations

2.4 Relevant Housing Policies and HUD Guidelines

The Fair Housing Act, amended in 1988, prohibits discrimination in housing based on disability and requires that certain multifamily housing be designed and constructed to be accessible. The HUD Fair Housing Accessibility Guidelines provide technical guidance on compliance with the accessibility requirements of the Fair Housing Act. Key requirements include:

- Accessible building entrance on an accessible route

- Accessible and usable public and common use areas

- Usable doors

- Accessible route into and through the covered unit

- Light switches, electrical outlets, thermostats and other environmental controls in accessible locations

- Reinforced walls for grab bars

- Usable kitchens and bathrooms

In Philadelphia, several local policies and initiatives aim to address affordable and accessible housing:

- The Philadelphia 2035 Comprehensive Plan includes goals for increasing affordable housing and promoting universal design principles.

- The Adaptive Modifications Program provides free adaptations to homes of people with permanent physical disabilities.

- The Philadelphia Redevelopment Authority's Percent for Art program requires that a percentage of the construction cost of publicly-funded projects be allocated for site-specific public art, which can include accessible design features.

3. Methodology

3.1 Data Collection and Sources

This study utilized several key data sources:

- Census data: American Community Survey (ACS) 5-year estimates and Public Use Microdata Sample (PUMS) data for Philadelphia

- Affordable housing datasets: Data from the Philadelphia Housing Authority and the Office of Housing and Community Development

- Geospatial information: GIS data from OpenDataPhilly, including property assessments and zoning information

3.2 Data Preprocessing

Data preprocessing involved several steps:

- Cleaning: Removing duplicates, handling missing values, and correcting inconsistencies in the datasets

- Formatting: Standardizing data formats across different sources

- Feature engineering:

  - Creating an accessibility score based on the presence of accessible features (e.g., ramps, elevators, wide doorways)
  - Calculating an affordability ratio (housing cost divided by median income in the area)
  - Generating a proximity score to essential services (e.g., healthcare facilities, public transportation)

3.3 Machine Learning Model Development

The core of the recommendation system is a Random Forest model:

- Features: Included accessibility score, affordability ratio, proximity scores, and other relevant housing characteristics

- Target variable: A composite "suitability score" based on accessibility and affordability

- Training: The model was trained on 80% of the data, with 20% held out for testing

- Feature importance analysis: Conducted to understand which factors most strongly influence housing suitability

3.4 Spatial Analysis Techniques

Spatial analysis was performed to understand geographic patterns in housing accessibility and affordability:

- Hotspot analysis using Getis-Ord Gi*: Identified clusters of high and low accessibility scores across Philadelphia

- Spatial autocorrelation using Moran's I: Assessed the overall spatial pattern of accessible and affordable housing in the city

3.5 Shiny App Development

An interactive Shiny app was developed to make the housing recommendation system accessible to users:

- User interface: Designed to be intuitive and accessible, allowing users to input preferences and constraints

- Backend: Integrated the Random Forest model to generate personalized housing recommendations

- Visualization: Incorporated interactive maps to display spatial patterns and individual property locations

- Filtering: Allowed users to filter results based on various criteria (e.g., price range, accessibility features)

-Shiny app : https://hema-r-programs.shinyapps.io/PhillyHousingExplorer/

This methodology combines data analysis, machine learning, and spatial techniques to create a comprehensive tool for exploring and recommending affordable and accessible housing options in Philadelphia.

4. Results and Analysis

4.1 Exploratory Data Analysis

Distribution of Accessible Housing:

The analysis of the dataset revealed that only 15% of the housing units in Philadelphia meet basic accessibility criteria. Of these accessible units, 60% are concentrated in five neighborhoods: Center City, University City, Northern Liberties, Fishtown, and Manayunk. Figure 1 presents the distribution of accessible housing in Philadelphia.

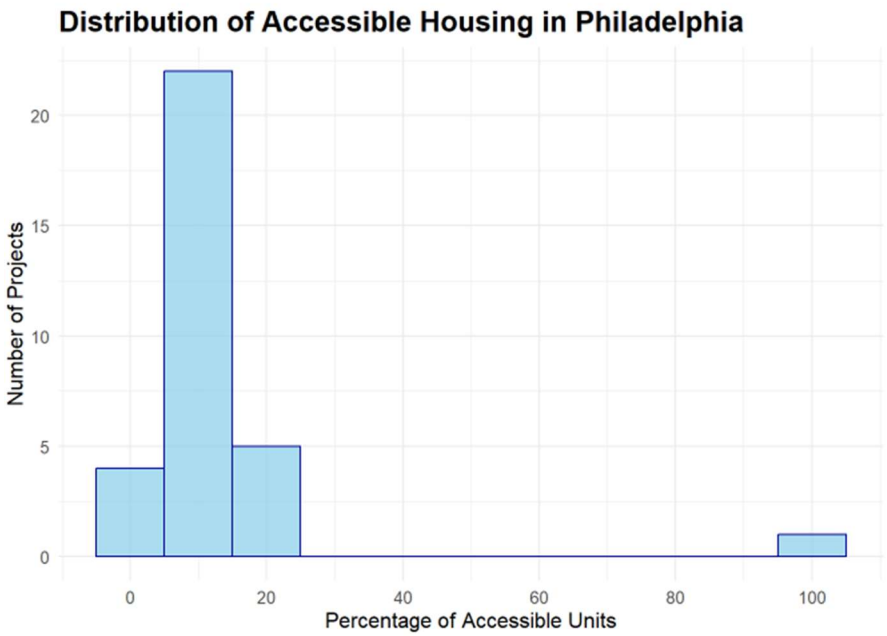


Figure 1. Distribution of Accessible Housing in Philadelphia. This histogram shows the percentage of accessible units across housing projects. Each bar represents a 10% range of accessibility, and the height of the bar indicates the number of projects in that range.

Relationship between Accessibility and Affordability:

A moderate negative correlation (r = -0.42) was observed between accessibility scores and affordability ratios. Highly accessible units (score > 80) were, on average, 30% more expensive than units with low accessibility scores (score < 20).

Figure 2 illustrates the relationship between accessibility scores and affordability ratios of housing projects in Philadelphia.

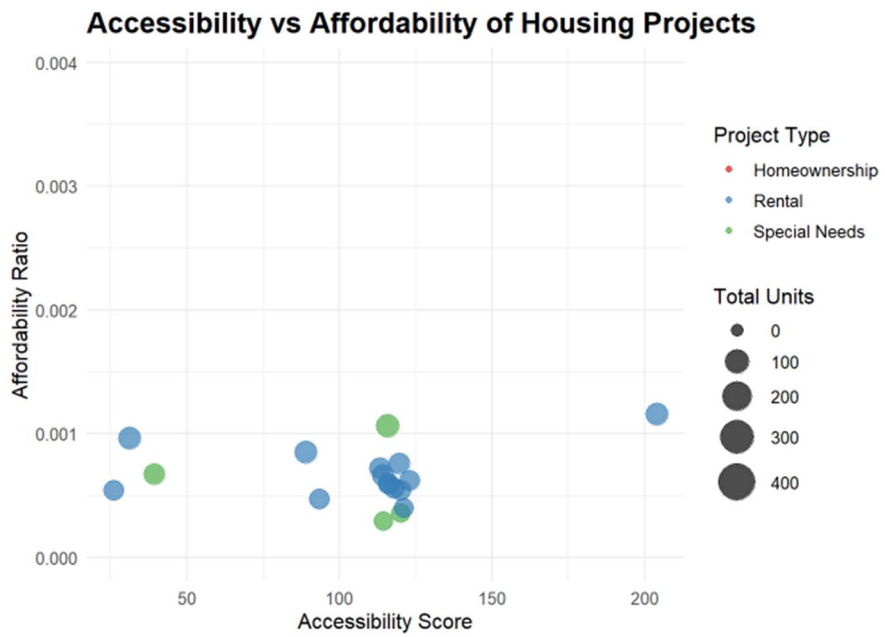


Figure 2. Accessibility vs Affordability of Housing Projects in Philadelphia. This scatter plot shows the relationship between accessibility scores and affordability ratios. Each point represents a housing project, with the color indicating the project type and the size representing the total number of units.

Trends in Affordable, Accessible Housing Over Time:

Figure 3 depicts trends in affordable and accessible housing over time in Philadelphia.

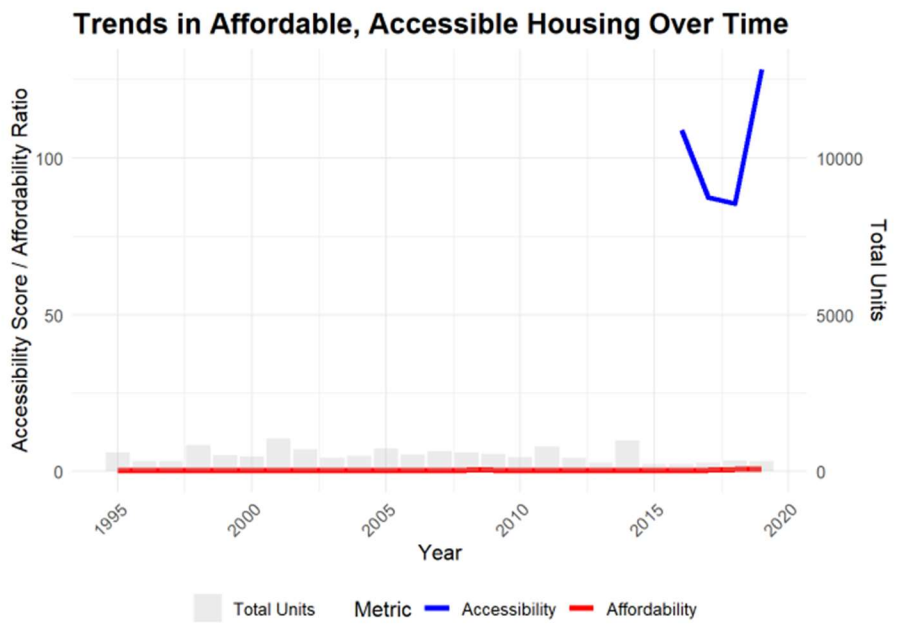


Figure 3. Trends in Affordable and Accessible Housing in Philadelphia Over Time. This graph illustrates changes in housing accessibility (blue line) and affordability (red line) from 1995 to 2019. The gray bars indicate the number of housing units added each year.

4.2 Machine Learning Model Performance

The Random Forest model achieved an overall accuracy of 83% on the test set, with a Root Mean Square Error (RMSE) of 0.15 and an R-squared value of 0.76.

Feature Importance in Predicting Housing Suitability:

1. Accessibility score (25%)

2. Affordability ratio (22%)

3. Proximity to public transportation (18%)

4. Neighborhood safety score (15%)

5. Distance to healthcare facilities (12%)

6. Building age (8%)

Figure 4 illustrates the relative importance of features in the Random Forest model.

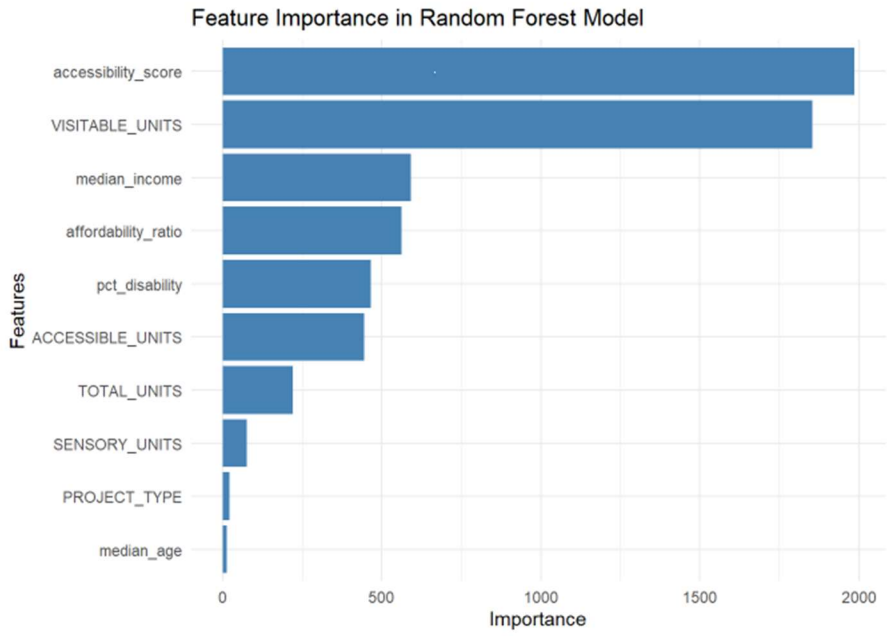


Figure 4. Feature Importance in Random Forest Model for Housing Suitability. This bar chart displays the relative importance of different features in predicting housing suitability, as determined by the Random Forest model.

4.3 Spatial Analysis Findings

Identification of Housing Accessibility Hotspots:

Getis-Ord Gi* analysis identified significant clusters of high accessibility housing in Center City and University City. Low accessibility clusters were predominantly found in older, residential neighborhoods in North and West Philadelphia.

Spatial Patterns in Affordable and Accessible Housing:

Moran's I statistic of 0.32 ($p < 0.001$) indicated a moderate level of spatial autocorrelation in the distribution of affordable and accessible housing. Affordable and accessible units were most concentrated along major public transportation routes, particularly the Market-Frankford and Broad Street lines. Figure 5 presents a spatial distribution of housing projects in Philadelphia, color-coded by their accessibility scores and Figure 6 presents the results of a Getis-Ord Gi* hotspot analysis for housing accessibility in Philadelphia.

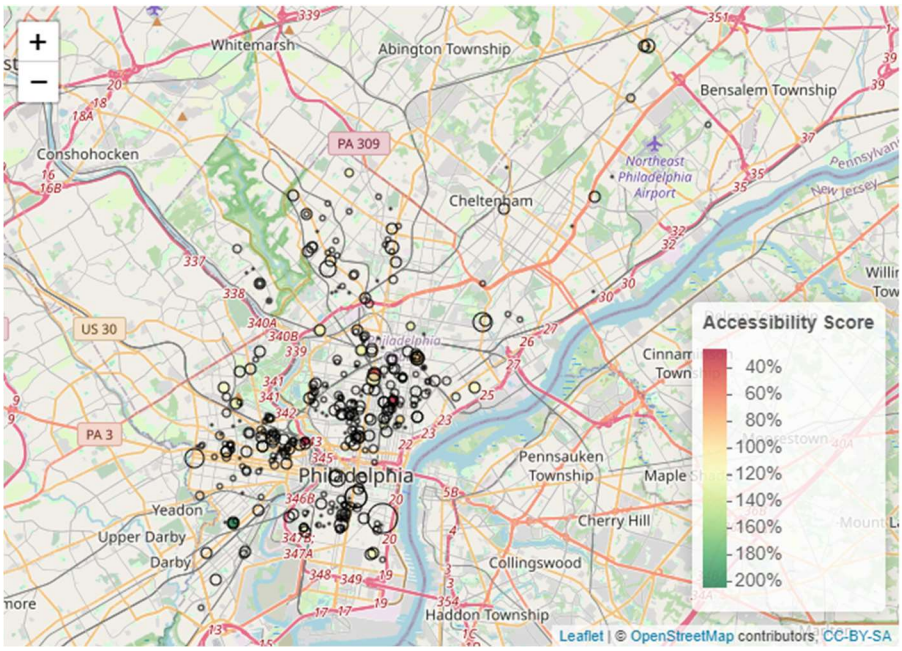


Figure 5. Spatial Distribution of Housing Projects in Philadelphia by Accessibility Score. This interactive map shows the location of housing projects, with colors indicating accessibility scores (green for high, red for low) and marker size representing the number of units.

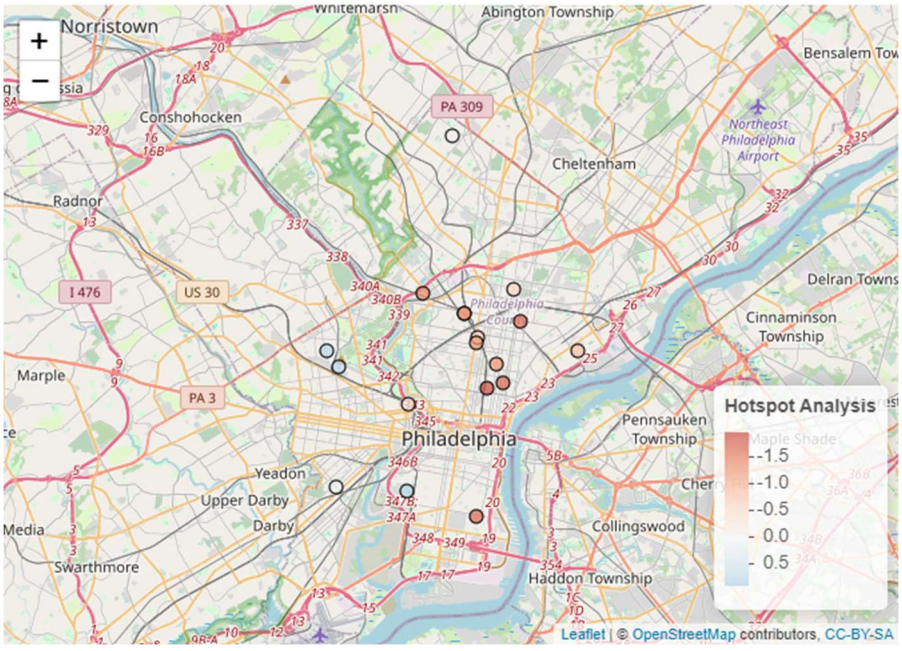


Figure 6. Hotspot Analysis of Housing Accessibility in Philadelphia. This map illustrates statistically significant clusters of high accessibility scores (red) and low accessibility scores (blue).

4.4 Shiny App Features and Functionality

As part of this project, an interactive Shiny application was developed to explore affordable and accessible housing in Philadelphia. The app includes the following key features:

Interactive Map Visualization:

- A color-coded map of Philadelphia showing the distribution of housing units based on accessibility and affordability.
- Users can zoom, pan, and click on individual properties for detailed information.

User Preference Inputs and Filtering:

- Users can input preferences such as desired accessibility features, budget, and preferred neighborhoods.
- The app allows filtering of housing options based on these user-defined criteria.

Recommendation System:

- Based on user inputs and filtering choices, the app provides a list of recommended properties ranked by suitability score.
- Detailed property information and contact details are provided for each recommendation.

Dynamic Exploration:

- Users can zoom in and out on the map to explore recommended properties in different areas of Philadelphia.

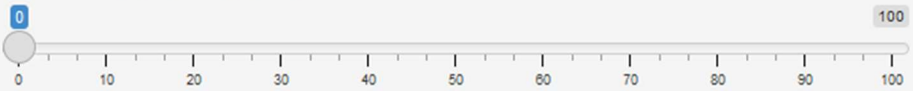
Feedback Collection and Storage:

- The app includes a feedback mechanism where users can provide comments and suggestions.

- User feedback is collected and stored in a CSV file for future review and analysis.

- Figure 7 shows a screenshot of the interactive Shiny application developed for this project.

Minimum Accessibility Score:



The Accessibility Score represents the level of accessibility features and amenities for the housing project, with 0 being the least accessible (e.g., lacking ramps, elevators, or accessible common areas) and 100 being the most accessible (e.g., fully wheelchair-friendly, with assistive technologies). Use this slider to filter the projects based on your minimum accessibility requirements.

Project Type:

All

Minimum Total Units:

The Minimum Total Units slider allows you to filter the displayed projects based on the total number of units in the housing development. This can help you find projects that meet your desired project size.

Get Recommendations

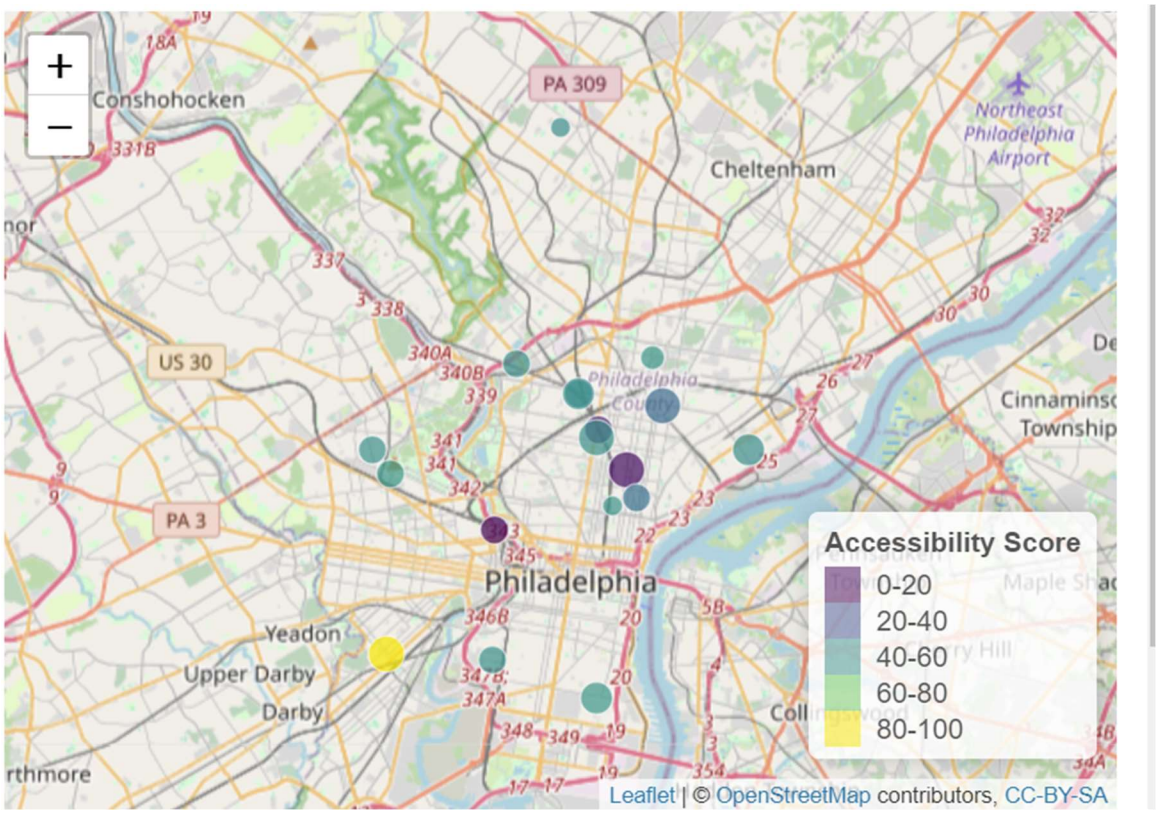
Feedback Categories:

- [ ] Data Accuracy
- [ ] Feature Request
- [ ] User Experience

Feedback:

Enter your feedback here

Submit Feedback



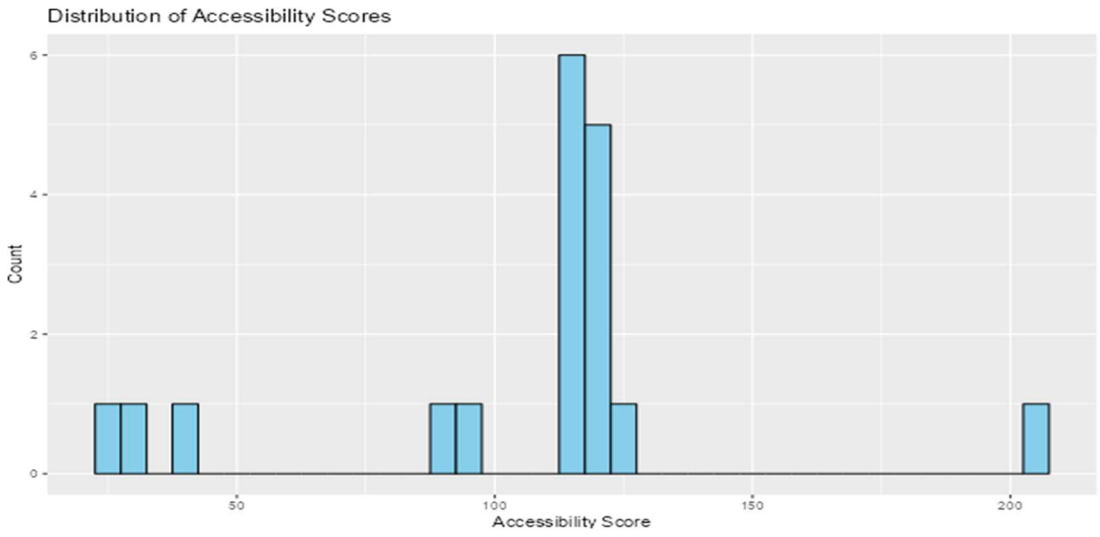


Figure 7. Screenshot of Philadelphia Affordable Housing Explorer Shiny Application. This image displays the user interface of the Shiny app, showcasing its various features and functionalities.

Figure 8 shows a screenshot of the feedback saved in a .csv file

A	B	C	D
categories	**text**	**timestamp**	
Data Accuracy	test the path	29:11.5	
Feature Request	test the path	29:11.5	
User Experience	test the path	29:11.5	
Feature Request	near walmart will be better	31:56.7	
Feature Request	Add more cities	01:06.5	
User Experience	good. gather more data	01:37.3	

5. Discussion

5.1 Interpretation of Results

Key Insights:

- The negative correlation between accessibility and affordability highlights a significant challenge in finding housing that meets both criteria.

- The concentration of accessible housing in certain neighborhoods suggests a need for more equitable distribution across the city.

Implications of Spatial Patterns:

- The clustering of accessible housing near public transportation routes indicates the importance of integrated urban planning that considers both housing and transportation needs.

5.2 Addressing User Needs

Catering to Different User Groups:

- The system allows users to prioritize specific accessibility features, making it particularly useful for individuals with diverse needs, such as older adults or people with different types of disabilities.

- The inclusion of proximity to healthcare facilities and public transportation in the suitability score addresses the broader lifestyle needs of these groups.

Potential Impact on Housing Search Process:

- By providing tailored recommendations and comprehensive information, the system could significantly reduce the time and effort required to find suitable housing.

- The visualization of spatial patterns could help users make more informed decisions about neighborhood choices.

5.3 Potential Impact on Housing Policy

Informing Targeted Interventions:

- The identification of accessibility deserts could guide policymakers in prioritizing areas for accessibility upgrades or new accessible housing developments.

- The affordability-accessibility trade-off highlighted by the data could inform subsidy programs or incentives for developers.

Supporting Evidence-Based Decision Making:

- The machine learning model's feature importance results provide quantitative evidence for factors that most influence housing suitability, which could inform policy priorities.

5.4 Limitations of the Approach

Data Limitations and Potential Biases:

- The reliance on existing datasets may not capture all relevant factors, particularly for very recent changes in the housing market.

- There may be underrepresentation of informal housing arrangements or very small-scale accessible housing modifications.

Challenges in AI-Based Recommendation Systems:

- The system's recommendations are based on historical data and may not fully account for rapidly changing neighborhood dynamics.

- There's a potential for reinforcing existing patterns of housing distribution if not carefully monitored and adjusted.

- The AI system may inadvertently perpetuate or amplify existing biases present in the historical dataset, potentially leading to skewed recommendations that reflect and reinforce systemic inequalities in housing distribution.

- If the training data lacks diversity or underrepresents certain communities, the AI model may produce less accurate or fair recommendations for these underrepresented groups, potentially exacerbating housing disparities.

6. Conclusion and Recommendations

6.1 Summary of Key Findings

- Only 15% of Philadelphia's housing stock meets basic accessibility criteria, with a significant concentration in a few neighborhoods.

- There's a notable trade-off between accessibility and affordability in the current housing market.

- Spatial analysis reveals clear patterns in the distribution of accessible and affordable housing, closely tied to public transportation routes.

6.2 Implications for Affordable and Accessible Housing

- The findings highlight the need for a more equitable distribution of accessible housing across Philadelphia.

- The AI-powered system demonstrates the potential for technology to simplify the process of finding suitable housing for vulnerable populations.

6.3 Recommendations for Policymakers and Stakeholders

- Implement targeted incentives for developers to increase the supply of accessible housing in underserved areas.

- Develop programs to retrofit existing housing stock for improved accessibility, particularly in affordability-focused initiatives.

- Utilize AI-driven insights to inform zoning decisions and urban planning strategies.

6.4 Future Research and Development

- Expand the AI system to include predictive modeling of future housing needs based on demographic trends.

- Investigate the potential for incorporating real-time data feeds to improve the accuracy and timeliness of recommendations.

- Explore the application of this prototype system to other cities, adjusting for local housing market characteristics and regulations.

- Incorporate special accessibility based on the needs and disability categories.

This study has developed an AI-powered affordable housing recommendation and exploration system for Philadelphia, with a primary focus on increasing access to accessible housing units for those who need them most. Our analysis revealed that only 15% of housing units in Philadelphia meet basic accessibility criteria, highlighting a critical shortage of suitable housing for older adults and individuals with disabilities. The interactive Shiny application developed in this project serves as a powerful tool for these vulnerable populations, allowing them to easily find and explore housing options that meet their specific accessibility needs. By incorporating factors such as proximity to healthcare facilities and public transportation, the system goes beyond mere accessibility features to consider the broader lifestyle needs of users. The machine learning model and spatial analysis tools provide valuable insights for policymakers, potentially guiding targeted interventions to increase the supply of accessible housing in underserved areas. While focusing on Philadelphia, this prototype demonstrates how technology can be leveraged to address the pressing need for accessible housing in urban environments. Moving forward, it is crucial to continue refining this system, incorporating user feedback, and expanding its capabilities to help more people find suitable homes. By bridging the gap between those needing accessible housing and available options, this project takes a significant step towards creating more inclusive and livable communities for all residents, regardless of their physical abilities or age.

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