RECONNECTING THE CITY.

Using Ai To Help Solve Social Isolation In Gothenburg: A Data-Driven, Evidence-Based Approach To Urban Design
Chalmers School of Architecture + Department of Architecture & Civil Engineering

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Examiner & Supervisor:
Ioanna Stavroulaki, Joaquim Tarraso

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ABSTRACT.

How can we connect with one another?

Social isolation has become a pressing public and urban design issue, especially in rapidly developing and increasingly fragmented cities. In the current era of rapid development in artificial intelligence, the use of interdisciplinary computational methods to support urban design offers a promising research direction. This master's thesis investigates how AI-supported spatial analysis can inform urban design strategies to address structural social isolation in Gothenburg.

The research focuses on Bergsjön, Gothenburg. The methodology combines QGIS-based spatial analysis and Python-based data processing with three statistical modelling techniques: linear regression, logistic regression, and K-means clustering. First, a continuous proxy for structural isolation was constructed based on POI accessibility, combining distance to the nearest facility and the number of facilities within walking distance. Linear regression was then used to examine how angular integration, GFA density relate to isolation patterns. Logistic regression was applied to estimate the probability of each spatial unit belonging to a high isolation-risk condition, producing both a continuous risk map and a categorized design priority map. Finally, K-means clustering was used to classify high-risk areas into different spatial types.

The results show that structural isolation in Bergsjön is spatially uneven and strongly related to low integration, weak functional access, and fragmented urban conditions. High-risk areas are often located near green edges, infrastructure boundaries, and spaces with poor spatial continuity. The analysis also shows that different high-risk areas operate through different spatial mechanisms and therefore require different design responses.

To translate these findings into site-scale design, City2Graph and Python-based network analysis were used to examine the relationships between paths, buildings, POIs, and network centrality. These analyses helped identify where a community spine should be strengthened and where social nodes should be placed. Based on this evidence, a detailed design proposal is developed for one selected site, focusing on external connectivity, public space as daily infrastructure, and targeted block retrofit.

The thesis concludes that AI-supported and graph-based spatial analysis can strengthen urban design by revealing hidden spatial risk patterns, supporting site selection, and linking design decisions more clearly to spatial evidence.

Project authors: Ziyue Wang

CONTENTS.

1. INTRODUCTION

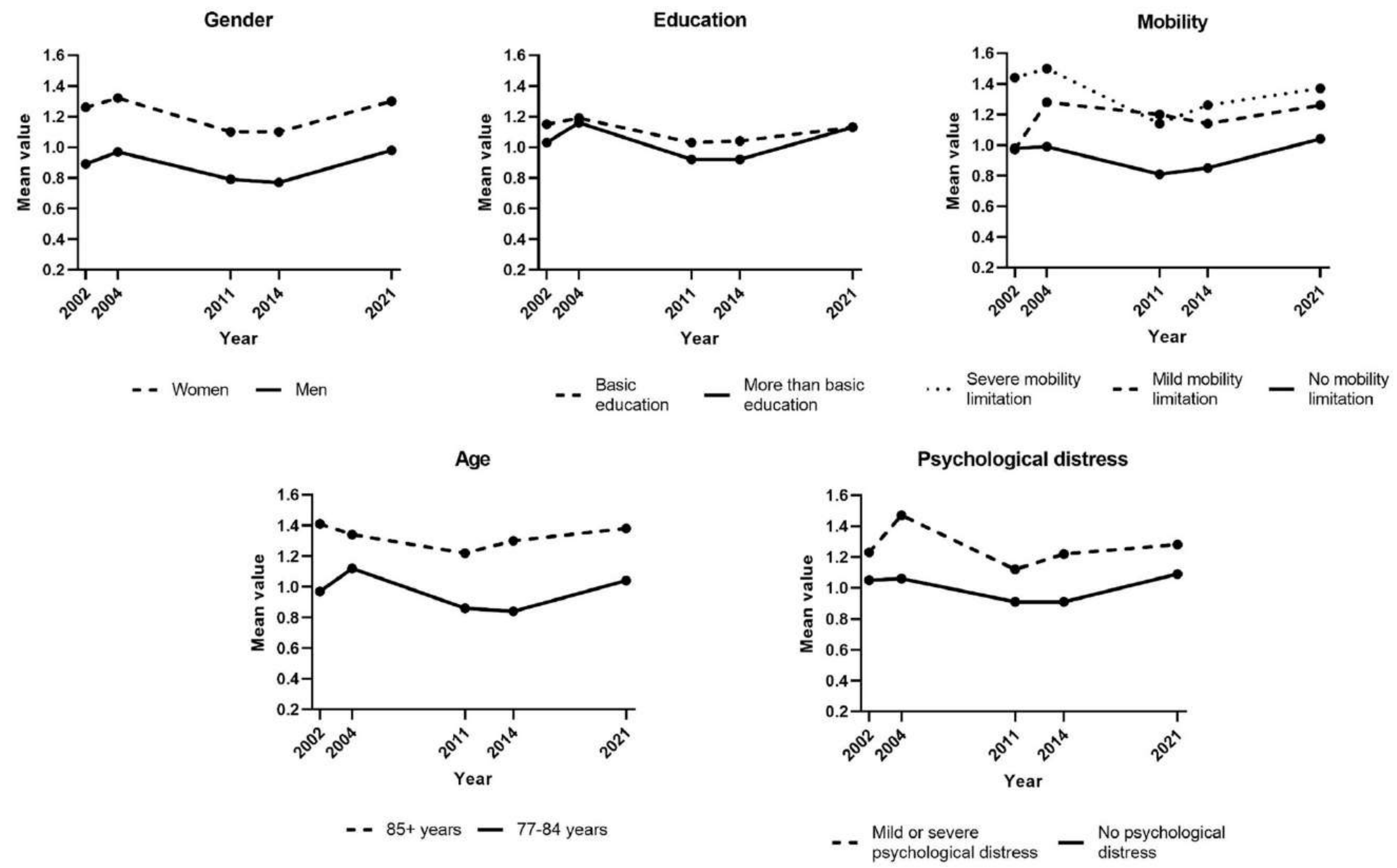


Figure 1: Adapted from Dahlberg (2024, Figure 5)

"Overall prevalence of loneliness among people aged 65 and over in high-income countries is 28.5%, with the prevalence reaching 31.3% among those aged 75 and over."

- Chawla et al., 2021

1.1 Background.

Social isolation has become a growing urban problem in many European cities, exacerbated by segregated planning patterns, economic disparities, and unequal access to public spaces. In Gothenburg, the spatial separation between the affluent city center and marginalized neighborhoods reflects deeper social stratification. Limited connectivity, inconvenient public transport, and inadequate social infrastructure in these areas contribute to residents' feelings of isolation. From a professional perspective, this thesis contributes to the field of urban design and planning by developing a data-driven, design-driven approach that combines AI modeling with evidence-based design. The project aims to bridge the knowledge gap between urban data analysis and design translation—how to effectively interpret complex datasets and use them to guide design interventions aimed at improving social connectivity. From a personal perspective, this topic is significant because it aligns with my interest in AI-assisted urban design and spatial justice. I believe that future urban designers must link technological literacy with social responsibility, and computational tools such as linear regression and logistic regression can provide new insights into the humanistic dimension of urban form.

1.2 Research Aim and Question.

Research Aim

This thesis investigates how AI-supported spatial analysis can contribute to evidence-based urban design by identifying patterns of structural social isolation in Bergsjön, Gothenburg. The study focuses on the relationship between urban form, accessibility, built density, and everyday destinations, and examines how these spatial conditions can be interpreted as structural isolation risk. The aim is not only to analyse these patterns, but also to translate them into urban design strategies that can support social connection at the community scale.

Main Research Question:

How can AI-supported spatial analysis be used to identify structural social isolation in Bergsjön and inform evidence-based urban design strategies?

Sub - Research Question:

1. Spatial Identification

· How can structural social isolation be identified and represented through spatial variables such as accessibility, density, and network integration?

2. Spatial classification

· How can high-risk areas be classified into different spatial types, and what different structural mechanisms of isolation do these types reveal?

3. Design translation

· How can the identified spatial patterns of structural isolation be translated into community-scale urban design strategies and a focused site intervention?

Delimitations.

This thesis focuses on Bergsjön in Gothenburg as a case study for exploring structural social isolation through spatial analysis. The research is limited to spatially observable and quantifiable conditions, including accessibility, network integration, built density, and the distribution of everyday destinations.

The study does not attempt to explain all social, psychological, or cultural dimensions of isolation. It does not measure loneliness as lived personal experience, nor does it claim to directly represent individual well-being. Instead, the thesis addresses structural isolation risk as a spatial condition that may affect opportunities for encounter, participation, and access to everyday urban life.

The analytical framework is therefore limited to spatial proxies and model-based interpretation. The results should be understood as relative and evidence-based indications of risk within the study area, rather than as an absolute diagnosis of social isolation. In addition, the design proposal developed in the thesis is not a full urban masterplan, but a focused design exemplification based on the spatial mechanisms identified through the analysis.

Expected Results.

Analytical Outcomes:

· A clear AI-supported spatial workflow for identifying structural isolation risk.

· A probability-based risk map and classification of high-risk spatial types in Bergsjön.

· An interpretation of how spacial factors, and urban discontinuities relate to structural isolation risk.

Design outcomes:

· A set of cluster-based urban design strategies derived from the analytical results.

· A focused Site 4 intervention as an exemplification of Cluster 4 strategy.

· A clearer link between data-supported spatial analysis and evidence-based design decision-making.

1.3 Thesis Structure.

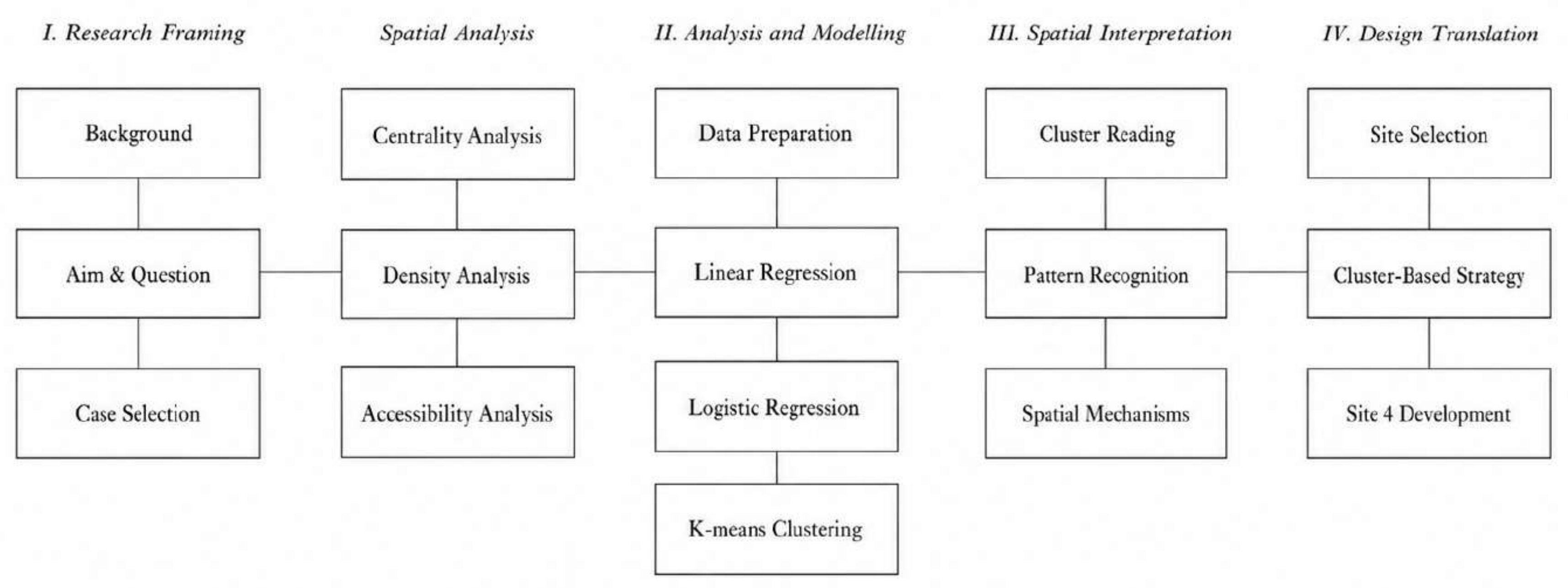


Figure 2. Thesis structure diagram. Author's own work.

This thesis is structured as a gradual process from research framing to design translation. The first part establishes the background of social isolation as a spatial and urban design issue, defines the research aim and question, and explains why Bergsjön is selected as the case study.

The second part develops the analytical framework. Spatial data are prepared through QGIS and Python, and three modelling tools are introduced: linear regression, logistic regression, and K-means clustering. These tools are used to examine spatial factors related to isolation, estimate high-risk areas, and classify different spatial conditions.

The third part interprets the analytical results as spatial patterns rather than only statistical outputs. Cluster reading, pattern recognition, and spatial mechanism analysis are used to understand how isolation is produced through weak accessibility, fragmented connections, and uneven urban resources.

The final part translates the findings into urban design decisions. The risk map and cluster interpretation support site selection and cluster-based strategies. The design development for Site 4 then tests how evidence-based spatial analysis can inform a community spine, social nodes, and targeted interventions.

1.4 Glossary.

Social isolation
A condition in which individuals or groups have limited social contact, weak access to social infrastructure, or reduced opportunities for everyday interaction. In this thesis, social isolation is approached as a spatial and structural issue rather than only an individual condition.

Linear regression
A statistical method used to examine relationships between a dependent variable and one or more explanatory variables. In this thesis, linear regression is used to explore how spatial variables such as accessibility, integration, and density relate to the isolation proxy.

Preliminary proxy
In this thesis, the preliminary proxy for structural isolation is based on POI accessibility, combining distance to the nearest facility and the number of facilities within walking distance.

Logistic regression
In this thesis, logistic regression is used to estimate the probability of each spatial unit belonging to a high isolation-risk condition.

Piso / P_iso
The estimated probability of spatial isolation generated by the logistic regression model. It is used to create a continuous risk map and to classify areas into different design priority levels.

K-means clustering
An unsupervised machine learning method that groups data into a fixed number of clusters based on similarity. In this thesis, K-means clustering is applied to high-risk areas in order to identify different spatial types and support cluster-based design strategies.

Risk map
A spatial map showing the estimated level of isolation risk across the study area. In this thesis, the risk map is generated from the logistic regression output and used to support site selection and design prioritisation.

Community spine
A main spatial route proposed in the design strategy. In this thesis, the community spine is developed as a design response to weak spatial continuity and fragmented access.

Integration
A spatial network measure that describes how well a street or path segment is connected within the wider urban system.

GFA Density
Gross Floor Area density. It describes the amount of built floor area within a given spatial unit. In this thesis, it is used as an indicator of built intensity and potential activity capacity.

POI
Point of Interest. POIs refer to everyday facilities and destinations. In this thesis, POI accessibility is used to describe how easily each spatial unit can reach everyday resources.

2. THEORETICAL AND METHODOLOGICAL FRAMEWORK

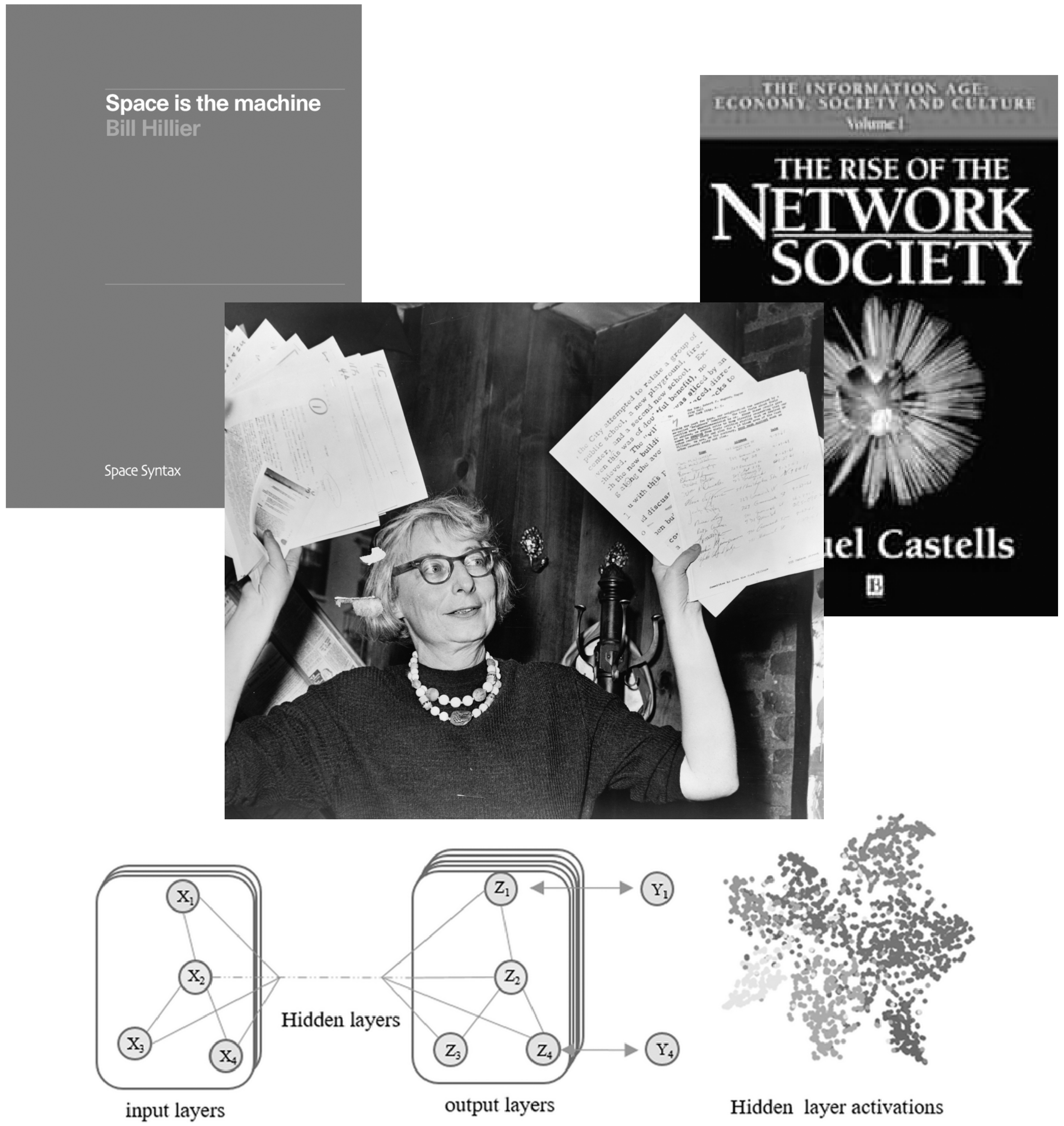


Figure 3. Theoretical references used in this thesis. Collage by the author, based on Hillier (1996), Jacobs (1961), Castells (1996), and AI / neural-network diagram adapted from [https://city2graph.net/latest/]

This thesis adopts an interdisciplinary theoretical framework that combines social-spatial theory, network thinking, and computational urban analysis. Together, these three perspectives provide the conceptual foundation for understanding structural social isolation as a spatial condition that can be interpreted through urban form, relational connectivity, and data-supported analysis.

2.1 Social-Spatial Theories and Urban Isolation.

The first theoretical layer understands urban space as closely related to everyday social life. Drawing on Henri Lefebvre's The Production of Space (1991 [1974]) and Jane Jacobs' The Death and Life of Great American Cities (1961), this thesis assumes that social isolation is not only an individual or emotional issue, but can also be partially shaped by the spatial organisation of the built environment. Lefebvre frames space as socially produced, while Jacobs emphasises everyday street life, visibility, and informal encounter. Therefore, this research focuses on spatial conditions that may weaken encounter, visibility, and participation in daily urban life.

2.2 Network and Relational Urban Theories.

The second layer views the city as a system of spatial relationships rather than a collection of isolated objects. Drawing on Manuel Castells' The Rise of the Network Society (1996) and Bill Hillier's Space is the Machine (1996), this thesis understands urban space through networks, flows, accessibility, and spatial configuration. Hillier's theory is especially relevant for this thesis, as it explains how spatial layout can influence movement, integration, and the potential for social encounter. This supports the idea that structural isolation may emerge not only from a lack of local facilities, but also from weak integration within the wider urban network.

2.3 Computational and Data-Driven Urban Theory.

The third layer situates the thesis within a computational and data-driven approach to urban analysis. Here, AI-supported spatial analysis is used to identify patterns, compare variables, and reveal risk structures that are difficult to see through observation alone. In this thesis, computational methods do not replace design judgment, but support a more explicit and evidence-based connection between analysis and urban design intervention.

Figure 4. Diverse Urban Spaces And A Constant Flow Of People. Photograph by author, 2024.

Spatial Scope of Social Isolation.

Within this thesis, social isolation is approached as a spatially mediated condition rather than a purely individual or psychological state. While social isolation is shaped by a broad range of social, economic, cultural, demographic, and health-related factors, the study deliberately limits its scope to those aspects that can be interpreted through urban space. The focus is therefore placed on spatial conditions that may restrict everyday encounter and participation, including weak accessibility, poor connectivity, fragmented public space, limited visibility, and uneven access to local facilities.

This spatial limitation is important for the methodological framework of the thesis. The study does not attempt to measure loneliness, personal social networks, or subjective experiences of isolation directly. Instead, it examines structural spatial conditions that may increase the likelihood of isolation by reducing access to people, services, and shared urban life. In this sense, social isolation is used as a lens through which the relationship between urban form and social opportunity can be investigated. The aim is not to claim that urban design alone can solve social isolation, but to explore how spatial analysis and design intervention can contribute to more connected everyday environments.

Urban Space as a Network.

This thesis views urban space as a network of spatial relationships. Streets, paths, buildings, public spaces, green edges, and facilities are understood not as isolated elements, but as connected parts of everyday urban life. Their social value depends on how they support movement, access, visibility, and encounter.

From this perspective, structural social isolation may emerge when connections are weak, routes are fragmented, facilities are difficult to reach, or public spaces are poorly integrated into daily movement patterns. The thesis therefore uses concepts such as accessibility, connectivity, proximity, and centrality to examine how urban form can either reinforce or reduce isolation. This network-based understanding provides the theoretical basis for the later use of graph-based analysis and City2Graph in the design development.

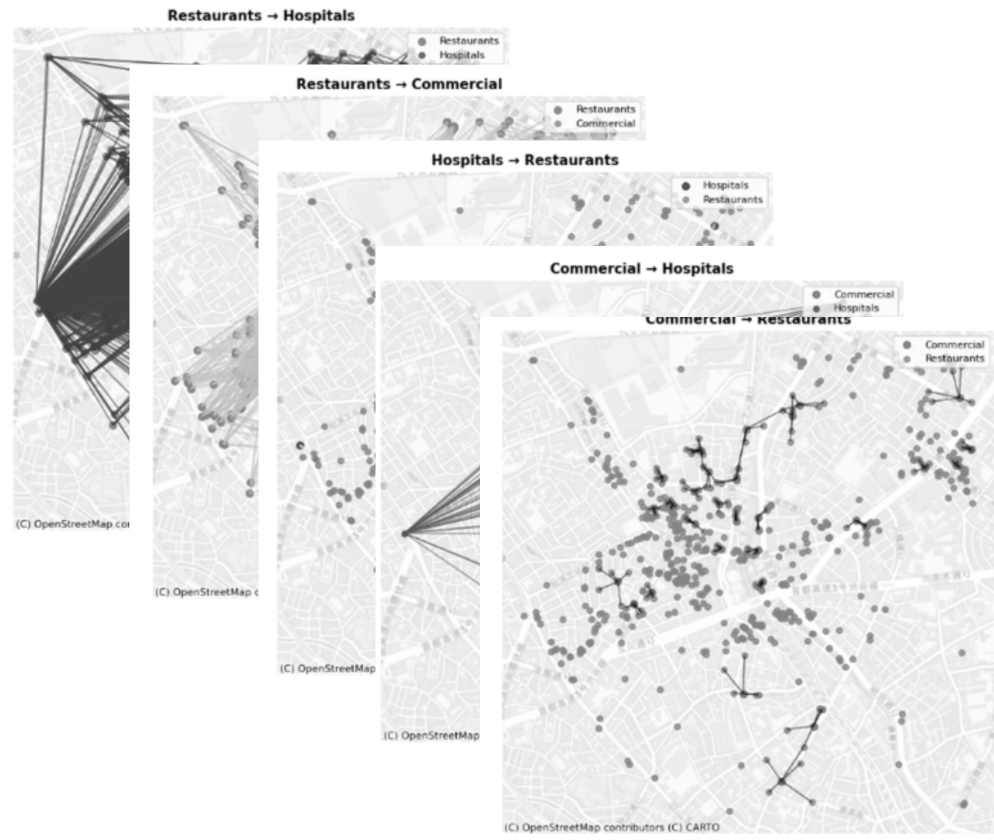


Figure 5. City2Graph framework. Modified by author from City2Graph (Sato, 2025).

Why AI Assistance Is Used in This Thesis

This thesis uses AI-supported spatial analysis not as a replacement for urban design judgement, but as an additional analytical layer that can help reveal patterns that are difficult to identify through visual observation alone. Social isolation is a complex and uneven spatial condition. It is often produced through multiple overlapping factors, such as weak accessibility, low network integration, limited functional diversity, and fragmented public space. These relationships are not always visible at the scale of conventional site analysis.

Computational and data-driven methods allow the thesis to examine these relationships more systematically. By combining GIS data, spatial indicators, regression models, clustering, and graph-based analysis, the study can move from individual observations toward a more structured understanding of risk patterns. AI assistance is therefore used to support three main tasks: identifying areas with higher potential isolation risk, classifying different spatial types, and translating analytical results into design priorities.

At the same time, the thesis does not treat AI as an objective or autonomous decision-maker. The results of the models require interpretation, contextual reading, and design judgement. In this sense, AI functions as a tool for expanding urban analysis rather than determining design outcomes. Its value lies in making hidden spatial relationships more visible and in strengthening the connection between evidence, interpretation, and design strategy.

3. STUDY AREA AND SCOPE

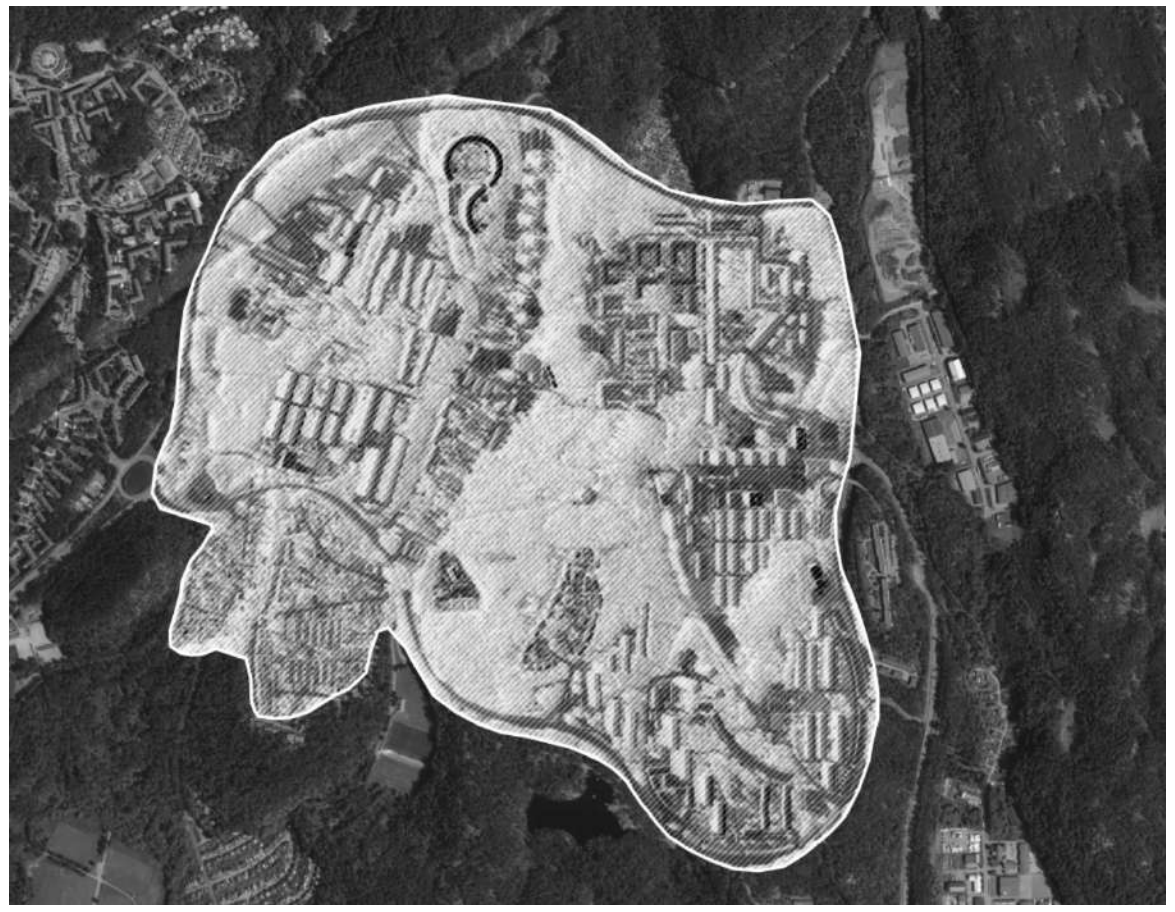


Figure 6. Aerial view of Bergsjön. Modified by author from Google Maps, 2026.

3.1 Bergsjön as Case Study.

Bergsjön is selected as the case study for this thesis because it represents a complex urban condition where questions of accessibility, connectivity, landscape, and social infrastructure overlap. Located in the north-eastern part of Gothenburg, Bergsjön is characterised by a strong relationship between residential areas, green landscapes, infrastructure corridors, and local centres. While the district contains significant natural and spatial qualities, these resources are not always equally accessible or well connected within everyday urban life.

From the perspective of this thesis, Bergsjön is not understood simply as a socially vulnerable area, but as a spatially complex urban environment. Its fragmented connections, topographical conditions, separated residential enclaves, and uneven distribution of everyday facilities create a relevant context for examining structural social isolation. These conditions make Bergsjön suitable for testing how AI-supported spatial analysis can identify hidden risk patterns and support more evidence-based urban design decisions.

The case study allows the research to move between different scales. At the district scale, spatial data and modelling are used to identify patterns of isolation risk and classify different high-risk spatial types. At the site scale, the analysis is translated into design strategies that address connectivity, public space, community nodes, and targeted block-level transformation. In this way, Bergsjön provides both an analytical field and a design testing ground for exploring how urban design can respond to spatially produced isolation.

Figure 7. "Refurbished Million Programme homes in Rinkeby " Adapted by author from Ellgaard, licensed under CC BY-SA 4.0, via Wikimedia Commons.

“By the 1970s, critics were describing these areas as "concrete suburbs," using terms such as "monotonous," "unattractive," "boring," and even "dangerous.".”

- Ristilammi, Citation, 1994

Million Programme.

Bergsjön was largely developed during the Swedish Million Programme, a national housing initiative from 1965 to 1974. Its planning logic was based on large-scale housing production, traffic separation, green open spaces, and functional zoning. These principles improved housing provision at the time, but they also produced spatial conditions that remain relevant today, such as separated residential areas, fragmented pedestrian connections, and weak links between housing, services, and public spaces. For this thesis, the Million Programme context helps explain why Bergsjön is studied as a spatially structured case of potential social isolation.

3.2 Urban Context and Spatial Timeline.

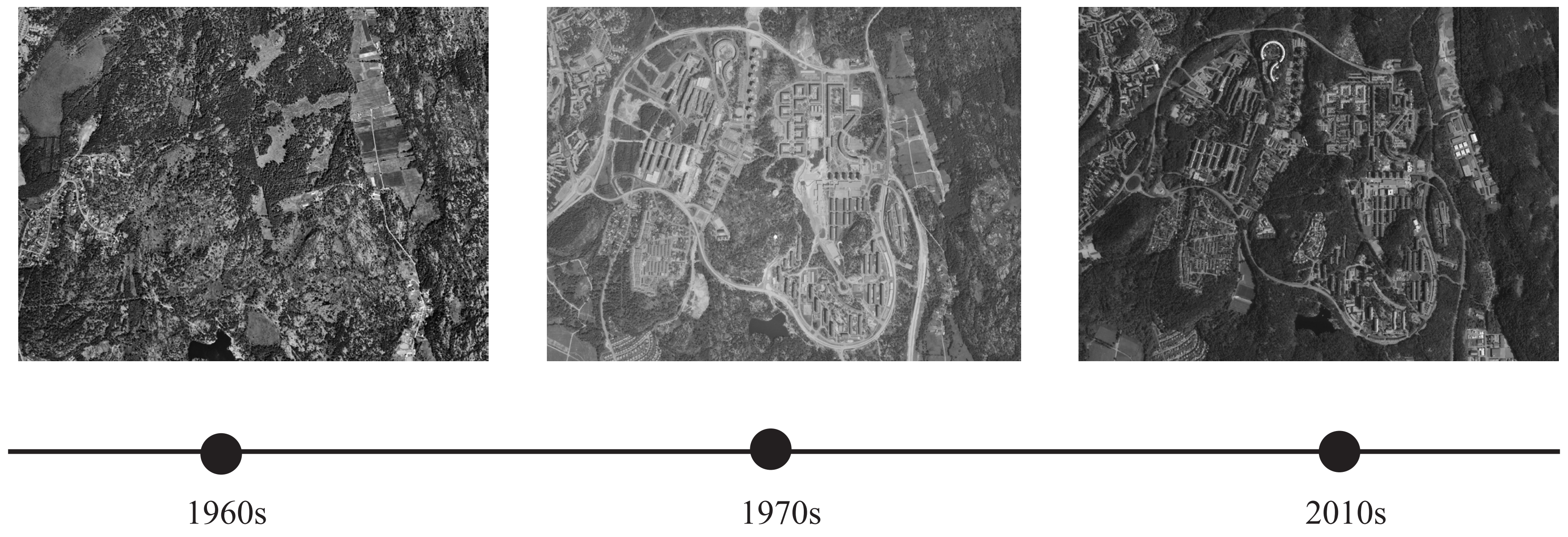


Figure 8. Timeline of Bergsjön's spatial development from the 1960s to the present. Produced by author based on Google Maps / Google Earth imagery, 2026.

Timeline of Bergsjön's spatial development.

Bergsjön's current spatial condition is closely related to its historical development. From the 1960s onwards, the area was transformed from a peripheral landscape into a planned residential district. The timeline images show how the urban fabric gradually expanded, while the surrounding forest and topography continued to shape the district's boundaries. This historical process produced a spatial structure in which housing areas, green landscapes, infrastructure corridors, and local centres are strongly present, but not always well connected.

Based on this urban context, the spatial delimitation of the study focuses on Bergsjön and its immediate surrounding conditions. The boundary is defined not only by administrative or visual limits, but also by spatial relationships: residential areas, pedestrian routes, green edges, infrastructure barriers, and access to everyday facilities. This delimitation allows the thesis to examine structural isolation at a district scale, while later zooming into a selected site where the relationship between risk patterns and design intervention can be tested in more detail

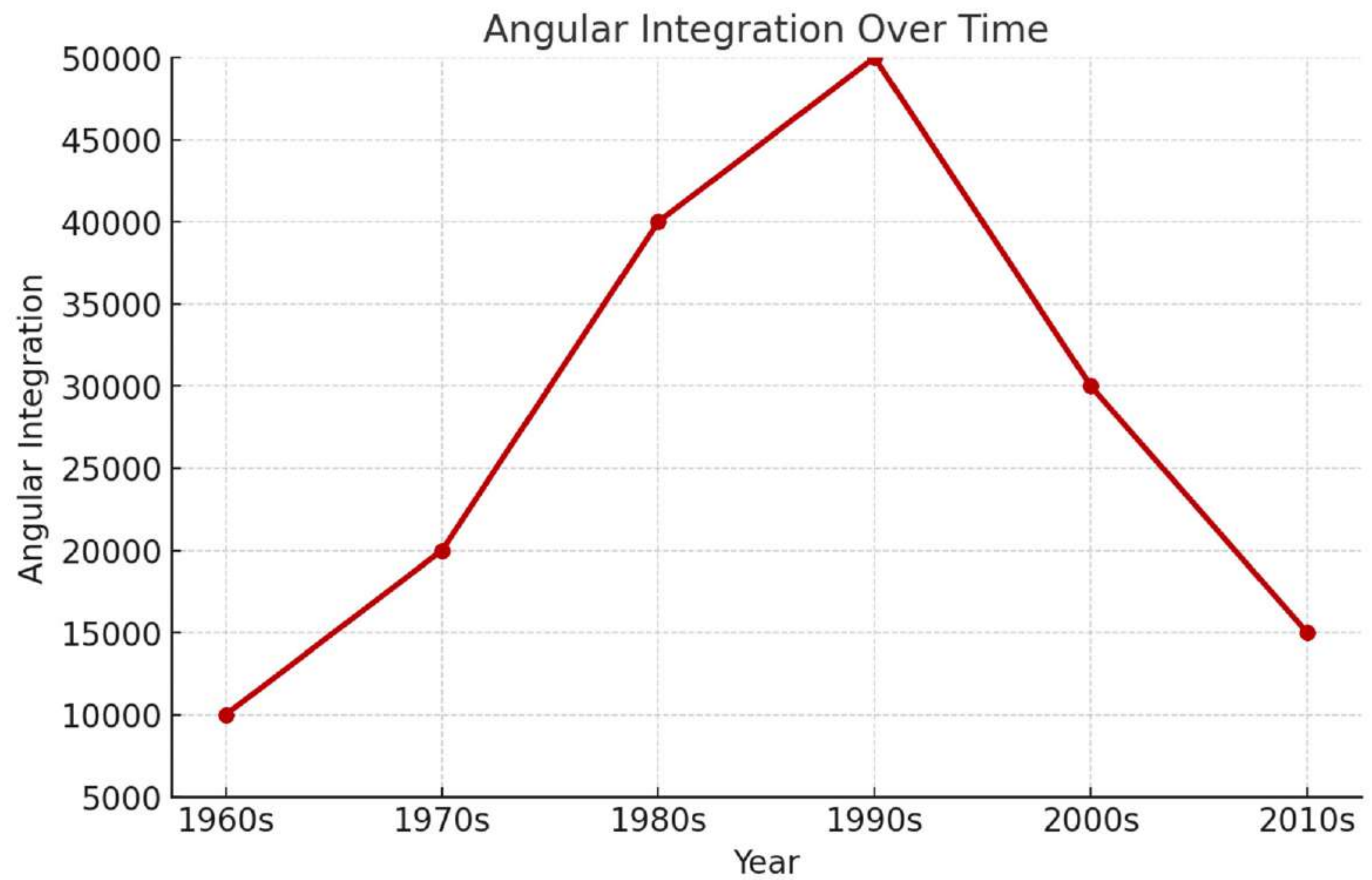


Figure 9. Angular integration over time in Bergsjön. Produced by author based on QGIS angular integration analysis, 2026.

Angular integration over time in Bergsjön.

The angular integration diagram suggests that Bergsjön's network condition has changed over time. The increase in integration during the later twentieth century indicates a period of stronger spatial connection and network consolidation. However, the later decline suggests that new development and changing urban structures did not necessarily produce a more integrated everyday environment. This supports the thesis argument that spatial isolation should not only be understood through the presence or absence of facilities, but also through the changing relationships between streets, paths, buildings, and public spaces.

Bergsjön in The Urban System

Figure 12. Network centrality and angular integration analysis in Bergsjön. Produced by author using QGIS, 2026.

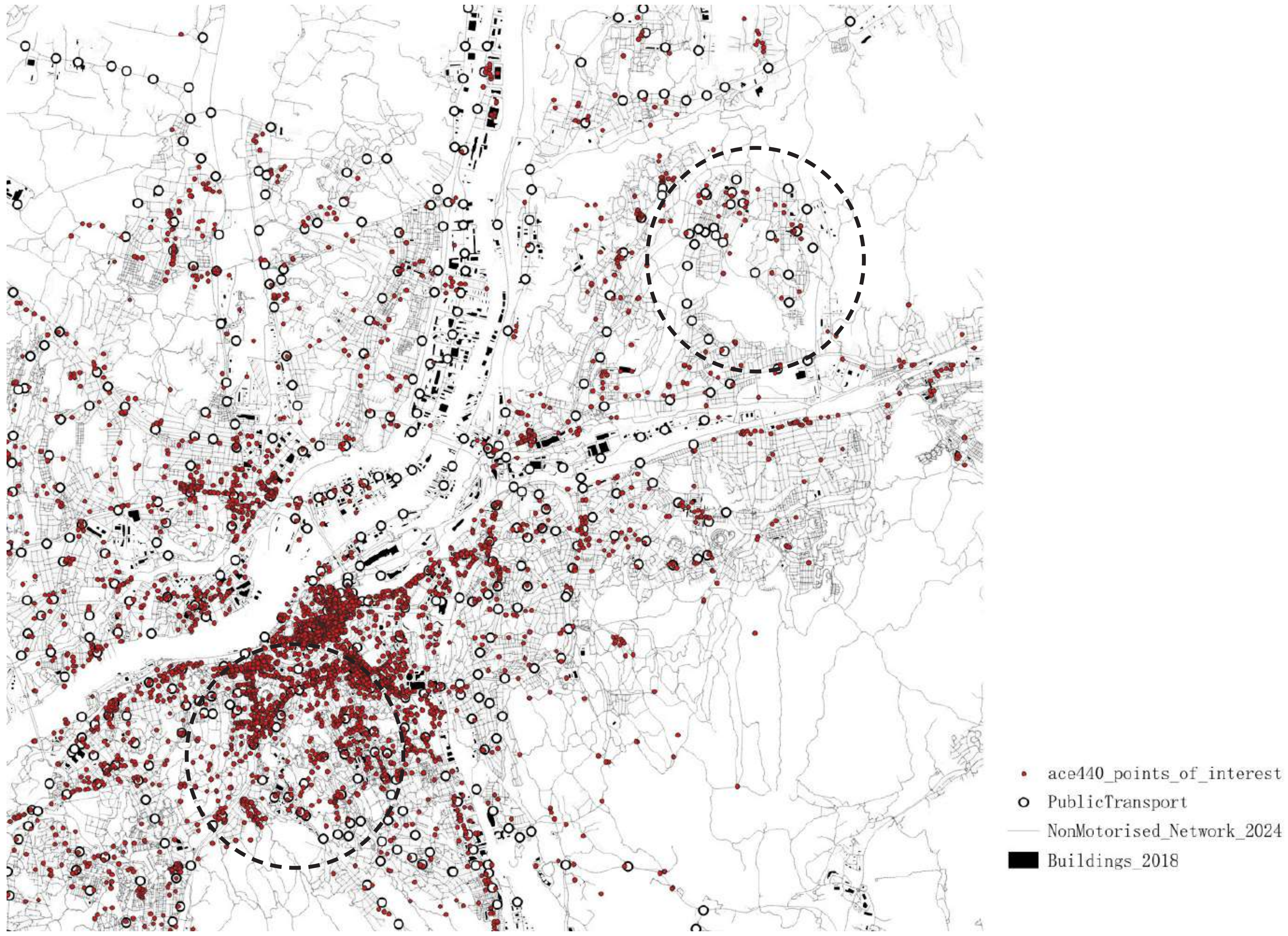


Figure 11. Distribution of points of interest and everyday resources in Bergsjön. Produced by author using QGIS, 2026.

Network Centrality:

The centrality analysis reveals that Bergsjön's spatial network contains both integrated corridors and more isolated internal areas. Some routes have stronger movement potential and act as structural connectors, while others remain peripheral within the local network. This suggests that isolation is not only related to distance from facilities, but also to the position of each area within the wider path system.

POI Distribution

The POI analysis shows that everyday facilities are not evenly distributed across Bergsjön. Local resources tend to cluster around specific centres, while some residential areas have weaker access to daily services such as shops, schools, community facilities, and public transport stops. This uneven distribution becomes an important basis for constructing the isolation proxy and later risk modelling.

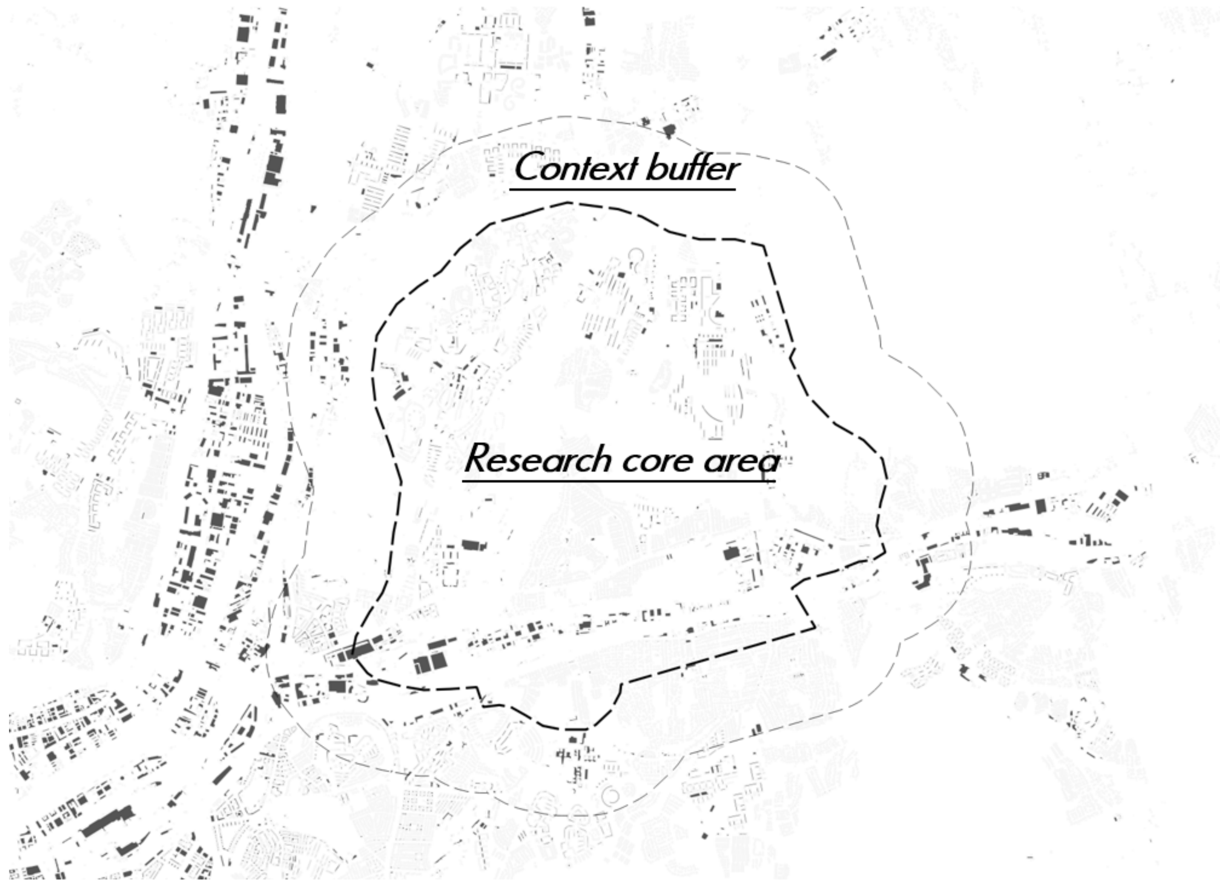


Figure 14. Research core area and context buffer. Produced by author using QGIS, 2026.

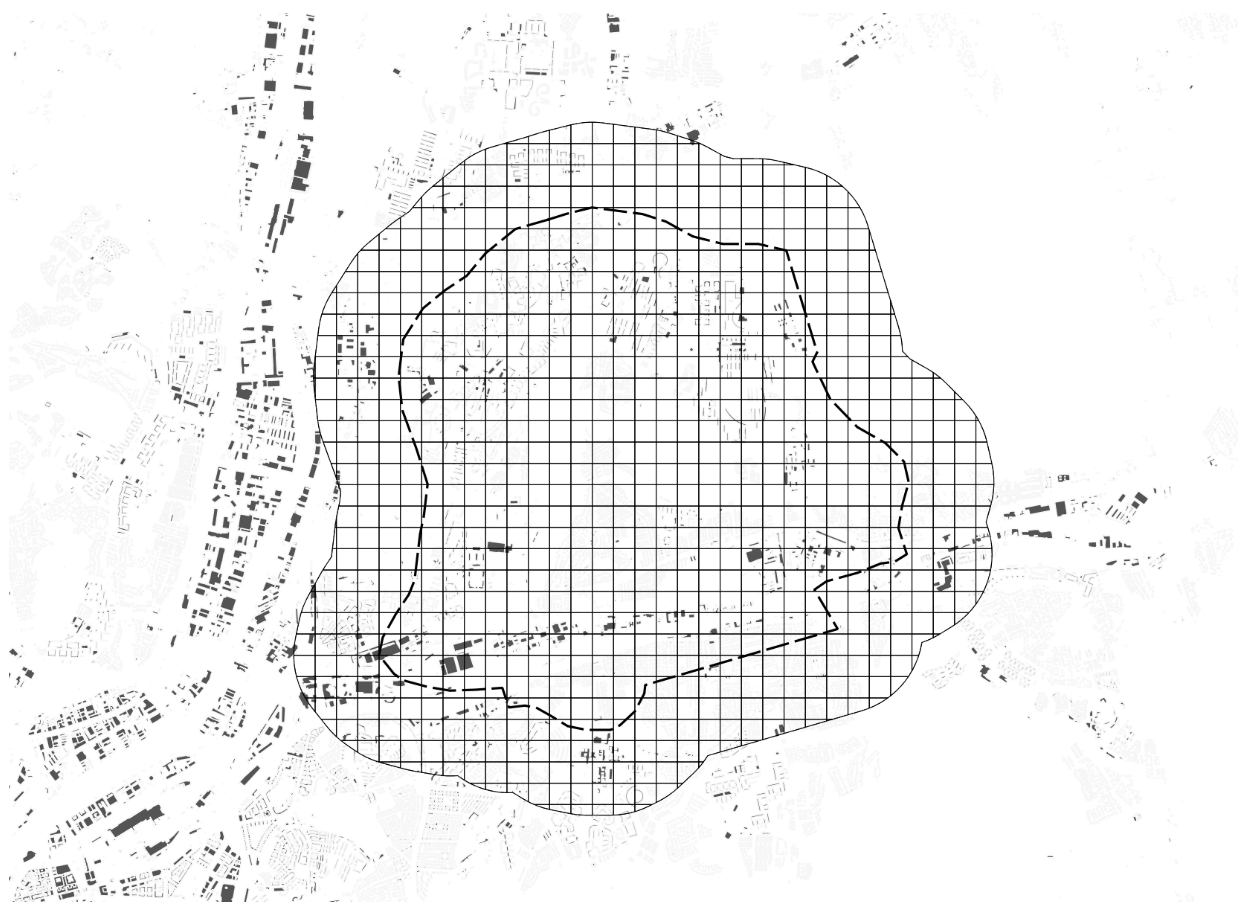


Figure 15. Regular grid as spatial unit. Produced by author using QGIS, 2026.. Produced by author using QGIS, 2026.

3.3 Scope And Delimitations.

This thesis focuses on structural social isolation as a spatial and urban design issue. It does not attempt to measure subjective loneliness, individual social networks, or psychological experiences of isolation. Instead, the study examines spatial conditions that may increase isolation risk, such as weak accessibility, fragmented pedestrian connections, uneven access to everyday facilities, and poor integration between residential areas and public spaces.

The geographical scope is limited to Bergsjön and its immediate urban context. The thesis does not study the entire city of Gothenburg in detail. Bergsjön is selected as a case study because it contains spatial conditions that are relevant to the research question, including large-scale residential areas, strong green edges, infrastructural boundaries, and uneven access to local resources. Within the analysis, a distinction is made between a research core area and a context buffer. The core area is used for modelling, interpretation, and design judgement, while the surrounding buffer is included to calculate spatial metrics more accurately and reduce boundary effects caused by artificially cutting off the urban network.

A regular grid is used as the unified spatial unit of analysis. This allows different types of spatial data, including POI accessibility, angular integration, density, and risk probability, to be compared within the same analytical framework. The grid also avoids relying only on administrative units, which may be uneven in size and less suitable for translating analytical findings into design decisions. In this thesis, the grid functions as a bridge between computational analysis and later spatial intervention.

The design scope is also delimited. The thesis does not propose a comprehensive masterplan for the whole of Bergsjön. Instead, the analytical results are used to identify high-risk spatial patterns and support the selection of one focused design site. The final proposal is developed at a community scale, with emphasis on external connectivity, a community spine, social nodes, and targeted block-level intervention. This delimitation allows the thesis to test how AI-supported spatial analysis can inform specific and evidence-based urban design strategies, rather than producing a general redevelopment plan.

4. AI-BASED SPATIAL MODELLING METHODOLOGY

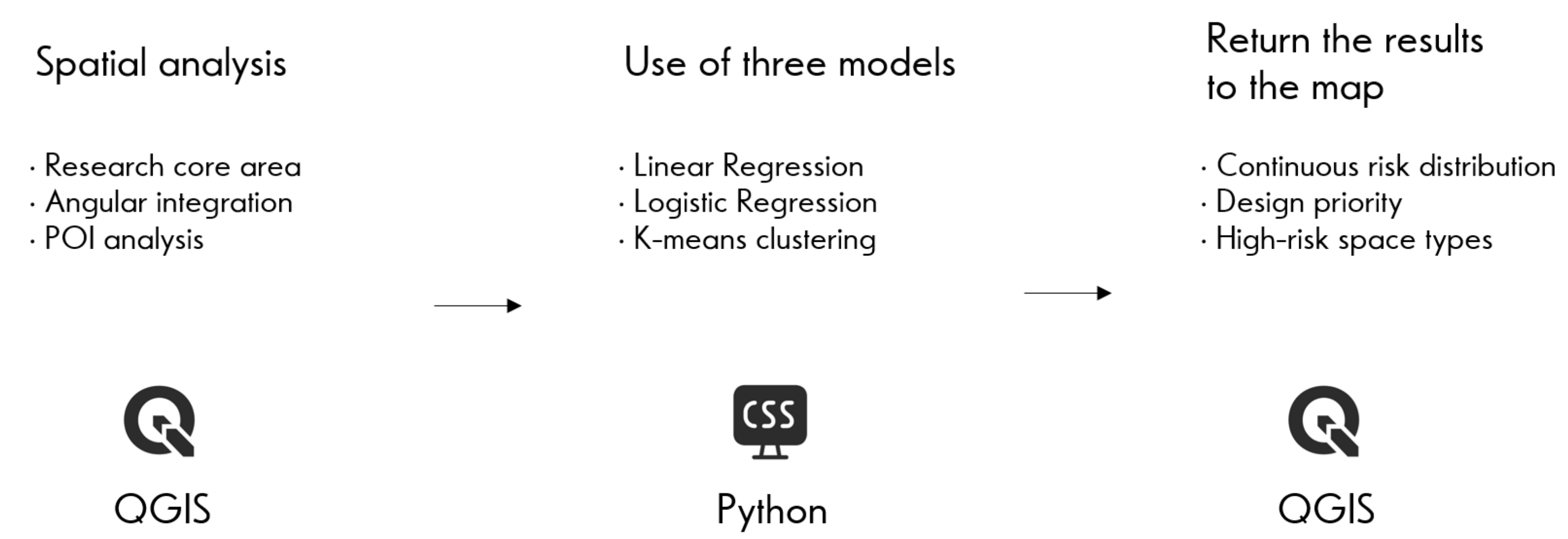


Figure 16. Methodological workflow from spatial data preparation to design-oriented mapping. Produced by author, 2026.

4.1 Workflow.

The methodology follows a three-step workflow from spatial preparation to design-oriented interpretation. First, QGIS is used to define the research core area, context buffer, and regular grid as the basic spatial unit. This creates a consistent framework for calculating and comparing spatial indicators.

Second, the grid-based data are processed in Python through three models: linear regression, logistic regression, and K-means clustering. These models are used to examine spatial relationships, estimate P_iso risk probability, and classify high-risk areas into different spatial types.

Finally, the modelling results are returned to QGIS as maps. The outputs include continuous risk distribution, design priority levels, and high-risk spatial types. In this way, the workflow connects spatial data, AI-supported analysis, and evidence-based design decisions.

4.2 Preliminary Proxy.

Since social isolation cannot be directly measured through the available spatial dataset, this thesis constructs a preliminary proxy to represent potential structural isolation. The proxy is based on POI accessibility, because previous studies have linked access to everyday facilities with urban opportunity, social capital, and the possibility of social participation (Ashik et al., 2024; Östh et al., 2018; Kveladze, 2025).

The proxy combines two accessibility indicators: distance to the nearest POI and the number of POIs within 1000 metres. A longer distance suggests weaker immediate access, while fewer nearby POIs indicate a lower availability of everyday resources. Both variables are standardised using z-scores so they can be combined despite having different units.

$$Preliminary\ Proxy = z(dist\_poi\_min) - z(poi\_within\_1000m)$$

Figure 17. Construction of the preliminary isolation proxy based on POI accessibility. Produced by author, 2026.

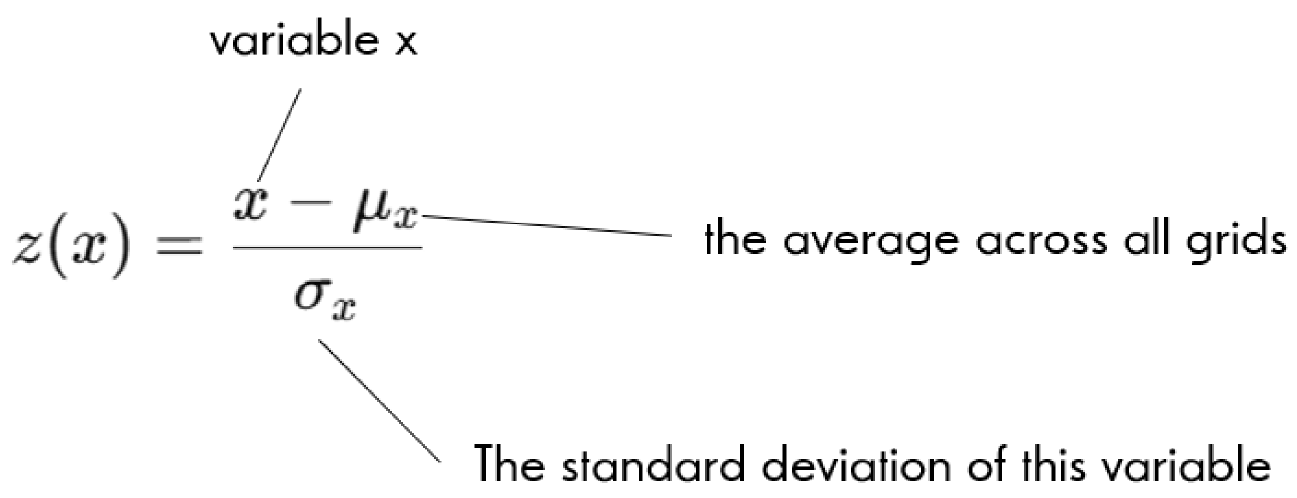


Figure 18. Explanation of z-score standardisation used to combine variables with different units. Produced by author, 2026.

In this formula, dist_poi_min represents the distance from each spatial unit to its nearest point of interest, while poi_within_1000m represents the number of POIs within a 1000-metre walking distance. Higher preliminary proxy values therefore indicate weaker everyday accessibility: the spatial unit is farther from nearby facilities and has fewer reachable resources.

This proxy does not claim to measure social isolation in its full social or psychological meaning. Instead, it functions as an initial spatial indicator of potential structural isolation. In the following steps, preliminary proxy is used to support regression analysis and to define the high-risk label for the logistic regression model, which later produces P_iso as the probability-based isolation risk output.

Situation	Preliminary Proxy	Interpretation
Far + Few	Very high	High isolation risk
Far + Many	Medium	Weak immediate access, but some resources nearby
Near + Few	Medium	Close access, but limited resource diversity
Near + Many	Very low	Low isolation risk

Table 1. Interpretation of the preliminary proxy based on POI distance and POI availability. Produced by author, 2026.

The interpretation of preliminary proxy is based on the combined effect of distance and facility availability. Spatial units that are far from the nearest POI and have few POIs within walking distance receive the highest proxy values, indicating a higher preliminary risk of structural isolation. In contrast, spatial units that are close to a POI and have many reachable facilities receive the lowest values, suggesting stronger everyday accessibility and lower isolation risk. The two intermediate conditions, Far + Many and Near + Few, represent mixed accessibility situations: either resources exist but are not immediately accessible, or nearby access is present but resource diversity remains limited. Therefore, preliminary proxy does not measure isolation directly, but provides a structured way to translate POI accessibility into an initial spatial indicator for later modelling.

4.3 Linear Regression.

Linear regression is used as an explanatory step rather than a direct prediction of social isolation. Its purpose is to examine how selected spatial variables are associated with the Preliminary Proxy, which is calculated from POI accessibility. The choice of variables is based on the idea that structural social isolation is related not only to access to everyday facilities, but also to spatial centrality and built intensity. POI accessibility indicates opportunities for daily participation, while street centrality, measured through local angular integration, is linked to co-presence and social separation. Previous work by Legeby shows that low spatial integration is associated with lower co-presence, while more central streets and public spaces can support encounter and social inclusion (Legeby, 2013; Legeby, Berghauser Pont and Marcus, 2015). GFA density is included because built intensity can create conditions for everyday activity, movement, and social contact.

Role	Variable	Type	Meaning
X	Local angular integration, R = 500 m	Independent variable	Reflects local-scale network accessibility and spatial embedding within the non-motorised network.
X	GFA_density	Independent variable	Reflects built-up intensity and potential activity capacity.
Y	Preliminary Proxy	Dependent variable	A calculated proxy representing structural social isolation.

Table 2. Variables used in the linear regression framework. Produced by author, 2026.

In the regression, the dependent variable is the Preliminary Proxy, and the independent variables are local angular integration, R = 500 m, and GFA density. POI distance and POI count are excluded as independent variables because they are already used to construct the proxy.

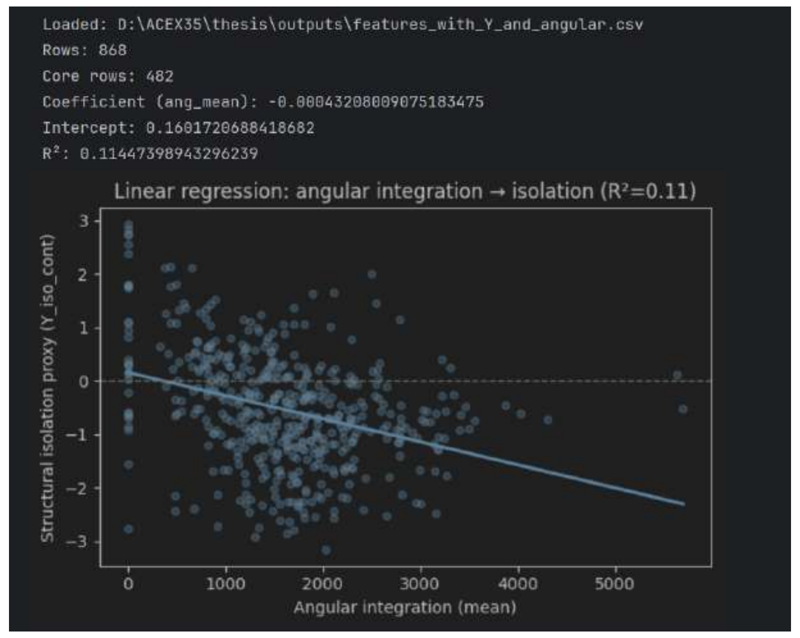


Figure 19. Linear regression between angular integration and the preliminary isolation proxy. Produced by author based on QGIS and Python spatial analysis, 2026.

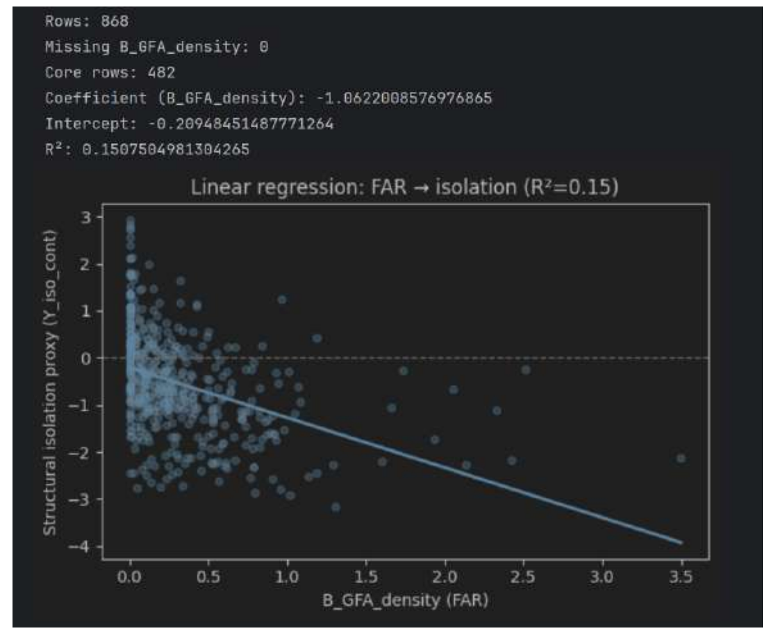


Figure 20. Linear regression between GFA density and the preliminary isolation proxy. Produced by author based on QGIS and Python spatial analysis, 2026.

The regression results indicate that the preliminary isolation proxy is related to three spatial dimensions: network integration, built density, and POI accessibility. Lower angular integration and lower GFA density tend to correspond with higher proxy values, while greater distance to POIs shows the strongest positive relationship. This supports the transition from exploratory regression to the later logistic regression model, where these spatial variables are used to estimate P_iso.

4.4 Logistic Regression and Piso.

While linear regression explains the relationship between spatial variables and the preliminary proxy, it does not directly identify which areas should be prioritised for intervention. For design translation, this thesis needs a probability-based risk value that can be mapped, compared, and classified. Logistic regression is therefore used to estimate the likelihood that each spatial unit belongs to a high structural isolation-risk condition.

The process begins with the continuous preliminary proxy. To train the logistic regression model, a binary label is generated using the 75th percentile of the preliminary proxy as the threshold. Spatial units above this threshold are labelled as high-risk samples, while the remaining units are labelled as lower-risk samples.

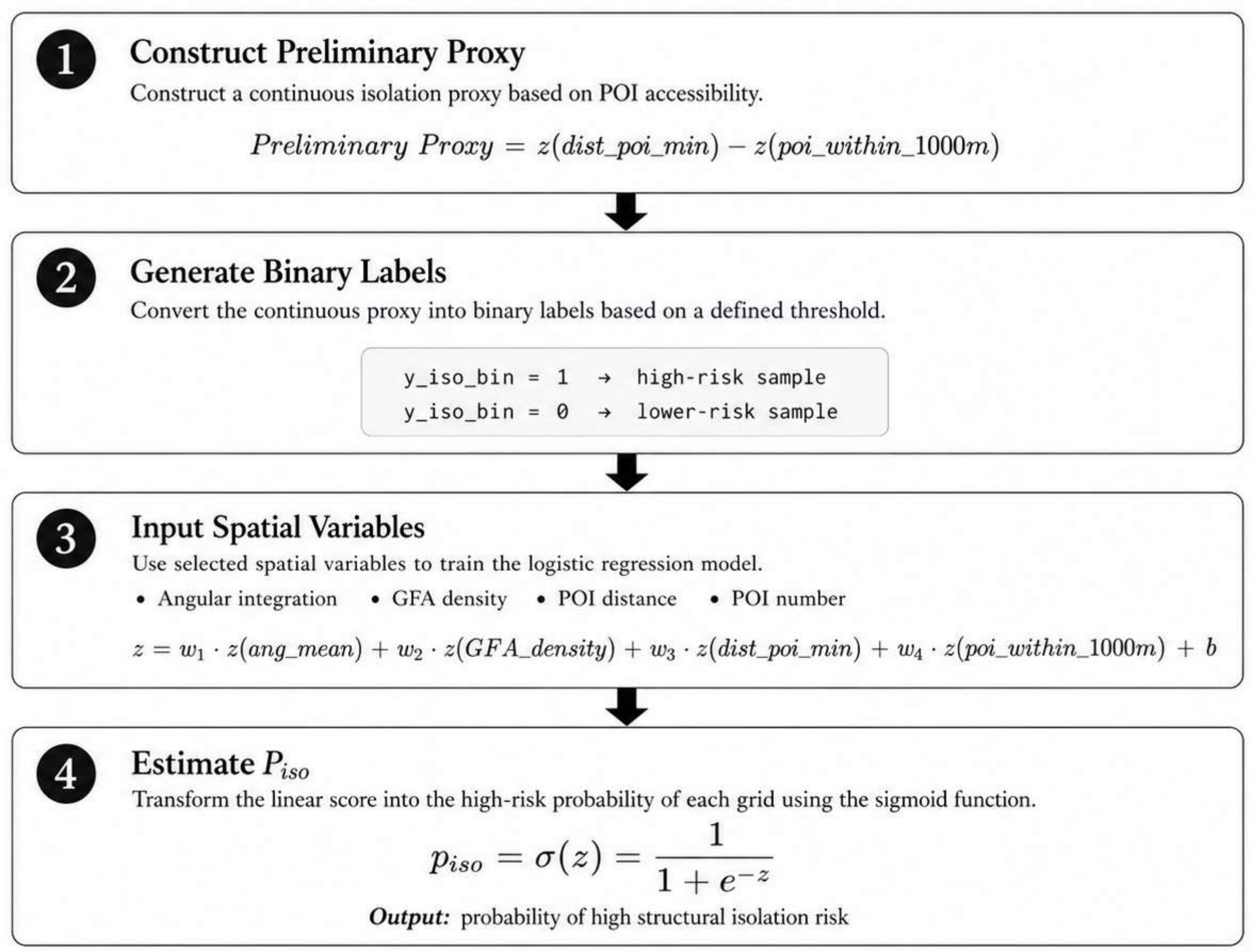


Figure 21. Flowchart of Logistic Regression. Produced by author, 2026.

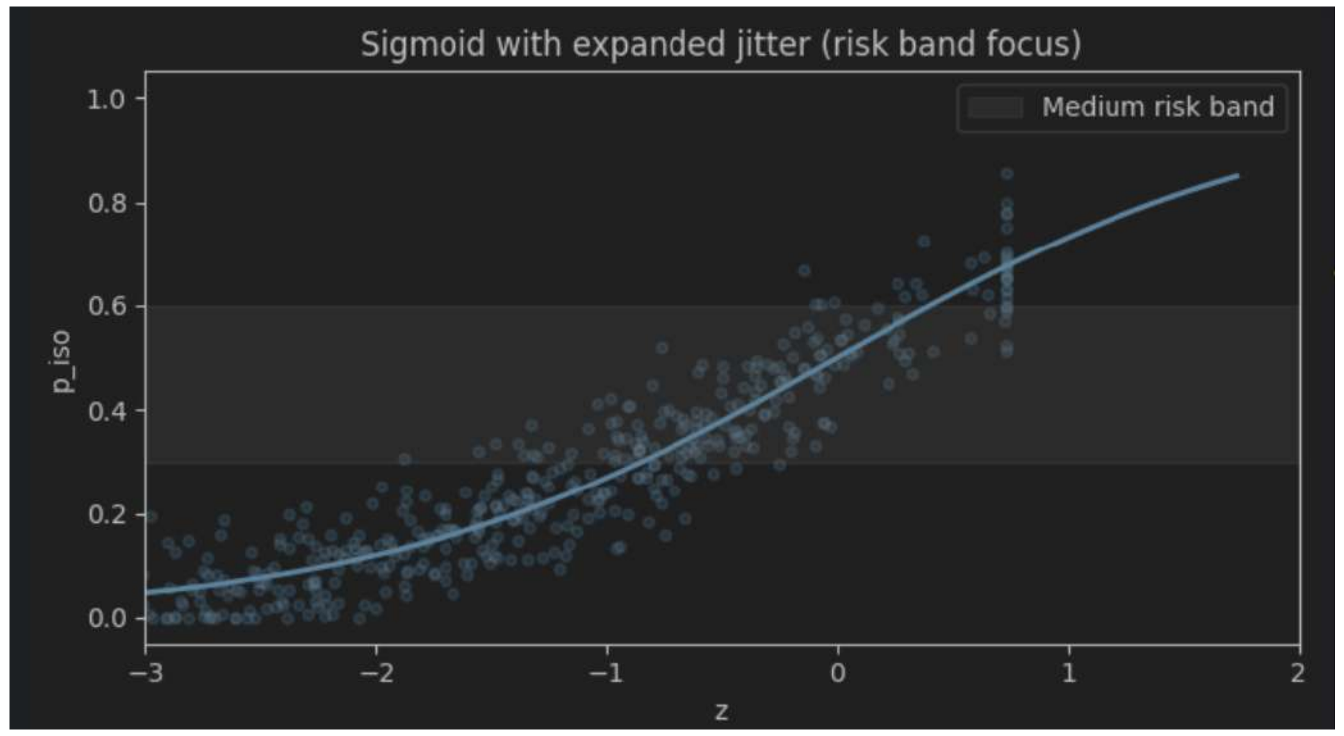


Figure 22. Sigmoid transformation from logistic regression score to P_iso probability. Produced by author based on Python modelling and QGIS spatial analysis, 2026.

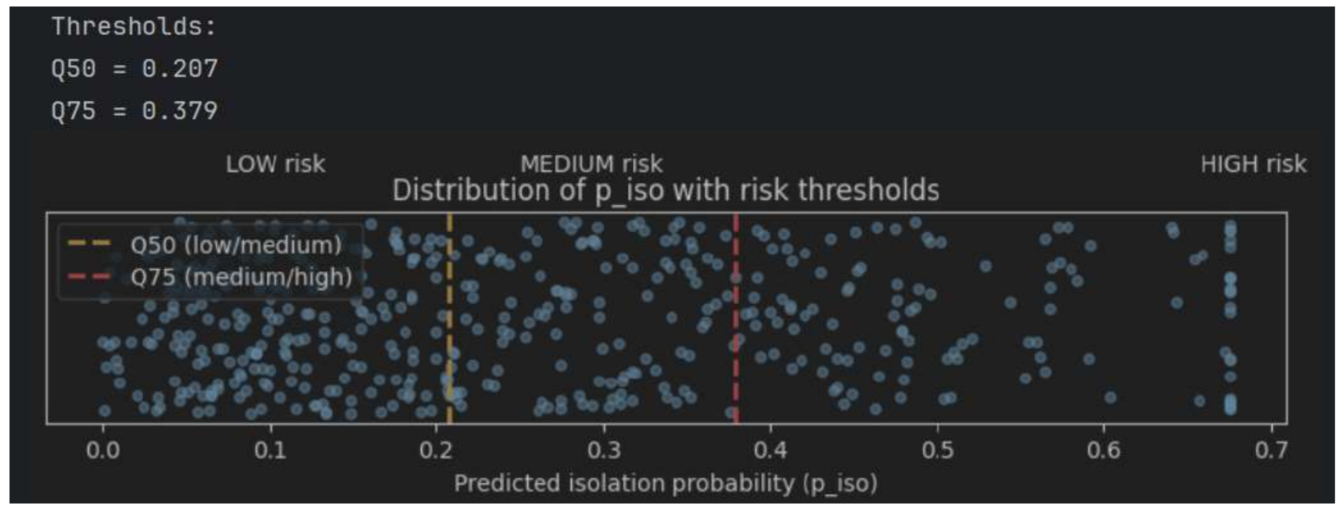


Figure 23. Classification of P_iso into low, medium, and high risk levels using Q50 and Q75 thresholds. Produced by author based on Python modelling and QGIS spatial analysis, 2026.

The output of the model is P_iso, which represents the estimated probability that each grid unit belongs to the high-risk category. P_iso ranges from 0 to 1: higher values indicate a higher probability of structural isolation risk, while lower values indicate lower estimated risk. In this thesis, P_iso is not interpreted as an absolute measurement of social isolation, but as a relative spatial risk indicator within the study area.

After the model estimates P_iso, the probability values are further classified into three risk levels for design interpretation. Areas with P_iso below 0.50 are defined as low risk, areas with P_iso between 0.50 and 0.75 are defined as medium risk, and areas with P_iso above 0.75 are defined as high risk. This classification helps translate the probability output into design priority levels.

4.5 Risk Levels and K-Means Clustering.

After logistic regression, each grid unit receives a continuous P_iso value, representing the estimated probability of belonging to a high structural isolation-risk condition. To make the result useful for spatial interpretation and design decision-making, the probability values are classified into three risk levels: low, medium, and high. In this thesis, areas with P_iso < 0.50 are defined as low risk, areas with 0.50 ≤ P_iso < 0.75 are defined as medium risk, and areas with P_iso ≥ 0.75 are defined as high risk.

However, high-risk areas should not be understood as one uniform spatial condition. Different high-risk grids may be produced by different combinations of spatial variables. For this reason, K-means clustering is applied only to the high-risk grid units. The purpose is not to create another risk ranking, but to identify different spatial types within the high-risk areas.

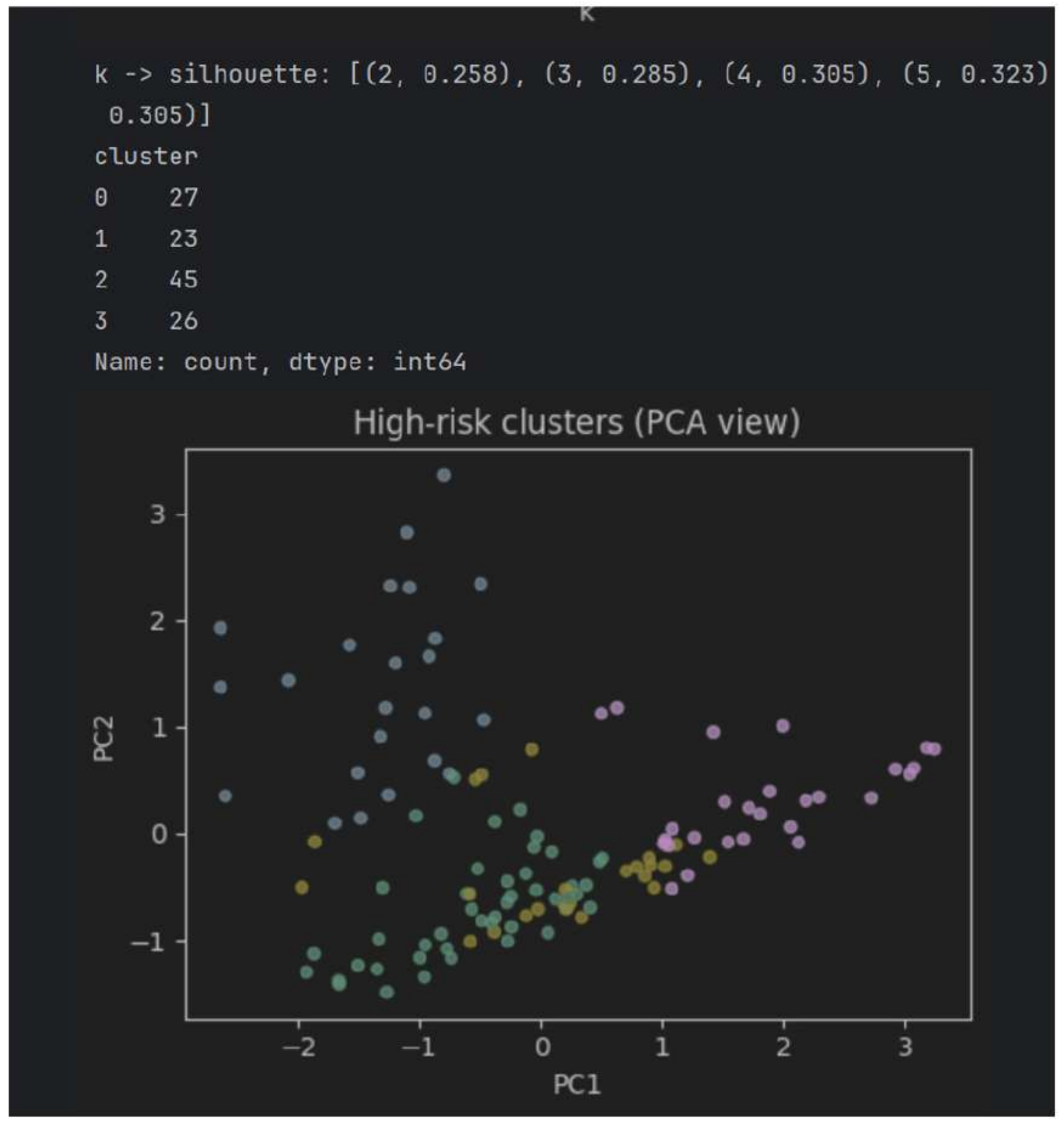


Figure 24. K-means clustering result of high-risk grid units based on spatial variables, shown in PCA view. Produced by author based on Python clustering analysis and QGIS spatial data, 2026.

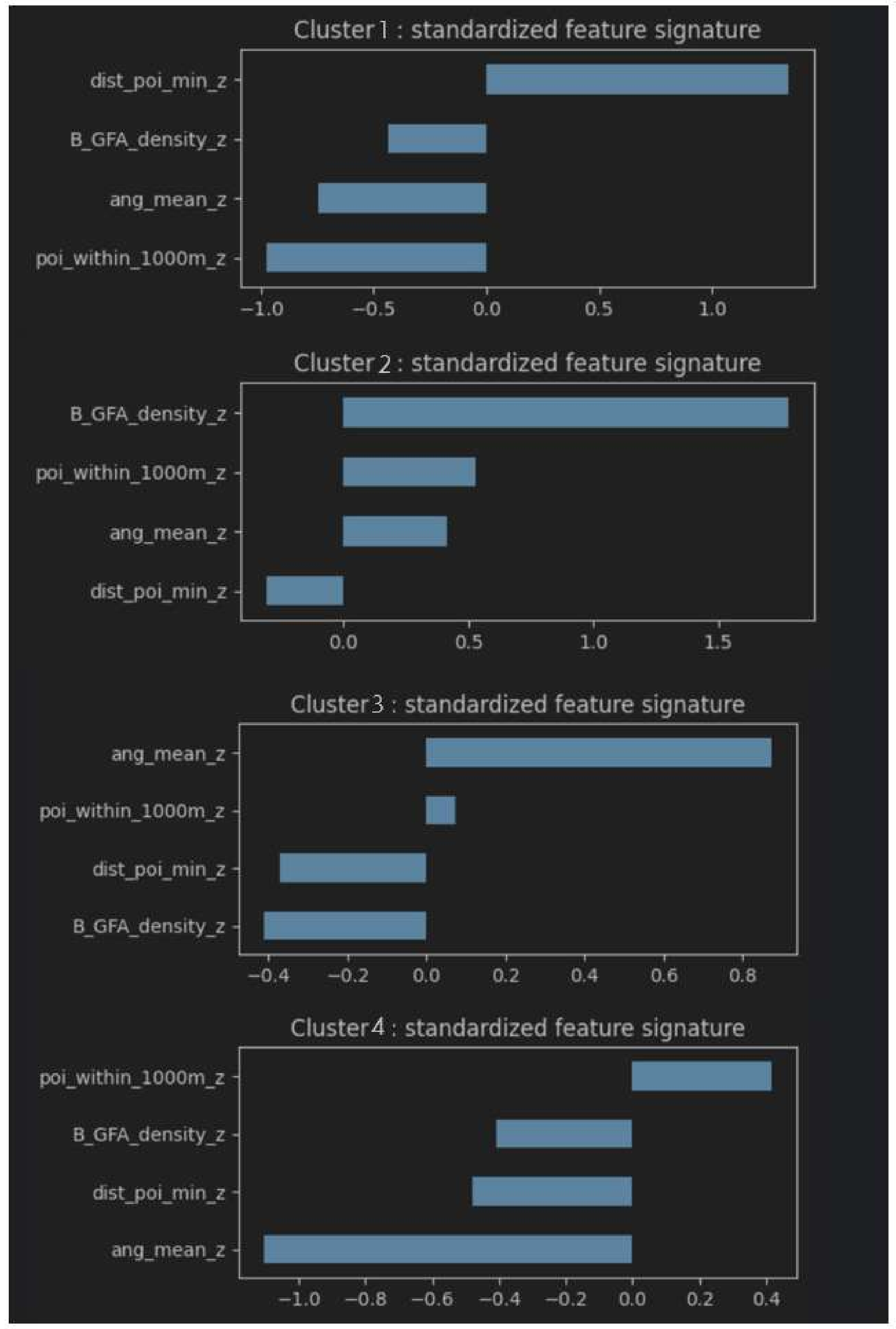


Figure 25. Standardised feature of the four K-means clusters. Produced by author based on Python clustering analysis and QGIS spatial data, 2026.

The input variables for K-means clustering include local angular integration, GFA density, POI distance, and POI number. These variables allow the model to group high-risk areas according to similarities in local network accessibility, built intensity, and facility accessibility. The resulting clusters are then interpreted in the following chapter as different spatial mechanisms of structural isolation risk.

5. RESULTS AND SPATIAL INTERPRETATION

The K-means clustering output assigns each high-risk grid unit to a cluster. Each cluster is not interpreted as a different level of risk, but as a different combination of spatial variables. The interpretation in Table 3 is derived from the standardised feature signatures in Figure 25 and then combined with map-based spatial reading. Therefore, the table does not directly translate data into lived experience, but identifies possible spatial mechanisms behind structural isolation risk.

Cluster	Data-based feature profile from Figure 25	Spatial interpretation based on map reading	Possible mechanism
Cluster 1	Low local integration, low GFA density, poor POI accessibility	Areas with weak network embedding, low built intensity, and limited nearby resources	Low accessibility and low activity capacity may reinforce structural isolation risk
Cluster 2	Higher local integration, low GFA density, medium–poor POI accessibility	Well-connected routes with limited built intensity and few everyday destinations	Movement potential exists, but social/programmatic support is weak
Cluster 3	Medium local integration, higher GFA density, medium–good POI accessibility	Denser built areas where resources exist, but spatial organisation may still be insufficient	Physical proximity does not automatically create social interface or encounter
Cluster 4	Low–medium local integration, medium GFA density, medium POI accessibility	Transitional edge areas with moderate resources but weaker spatial embedding	Risk may come from fragmented connections and unclear interfaces rather than absolute lack of resources

Table 3. Spatial interpretation of K-means clusters based on the standardised feature signatures in Figure 25 and map reading. Produced by author, 2026.

Based on Figure 25 and Table 3, the four clusters show that high-risk areas are produced by different spatial conditions. Cluster 1 is mainly related to low local integration, low density, and poor POI accessibility. Cluster 2 has stronger movement potential, but limited built intensity and weak programmatic support. Cluster 3 shows that density and resource proximity do not automatically create social interface or encounter. Cluster 4 represents a transitional edge condition, where risk may come from fragmented connections and unclear interfaces rather than a complete lack of resources.

5.1 Piso Risk Distribution Map.

The P_iso risk distribution represents the probability-based output of the logistic regression model. Each grid cell receives a value between 0 and 1, indicating its estimated probability of belonging to a high structural isolation-risk condition. Rather than showing social isolation as a fixed or directly observed phenomenon, the map visualises relative spatial risk within the Bergsjön study area.

The continuous P_iso map shows that risk is not evenly distributed. Higher-risk cells tend to appear around the edges of the research core area, near forest boundaries, infrastructural corridors, and fragmented residential areas. Lower-risk cells are more visible in areas with stronger accessibility, better spatial integration, and closer connection to everyday facilities. This suggests that structural isolation risk is shaped by the combined effect of accessibility, network position, and the distribution of local resources.

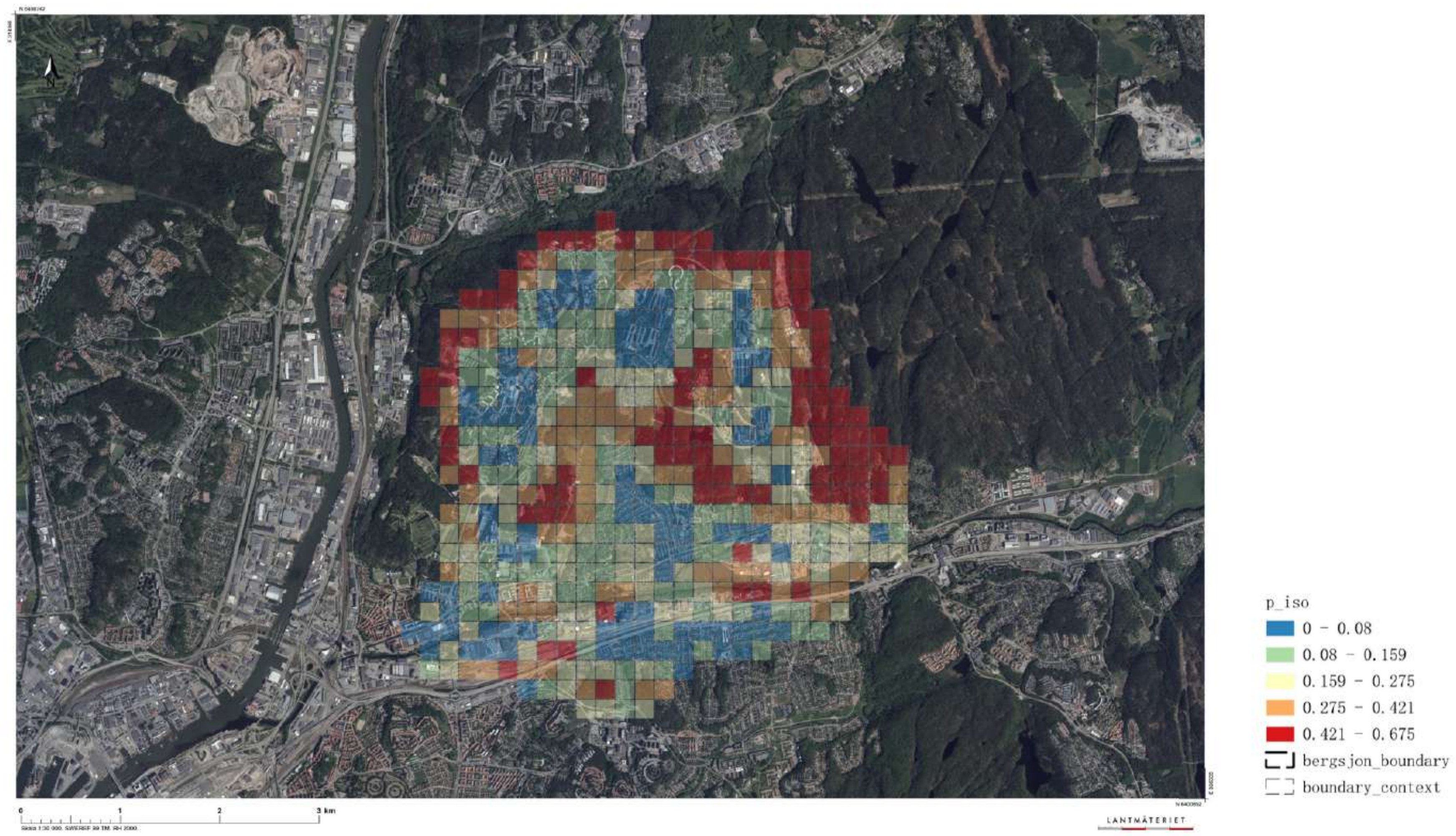


Figure 26. Continuous P_iso risk distribution. Produced by author using Python and QGIS; base map from Lantmäteriet, 2026.

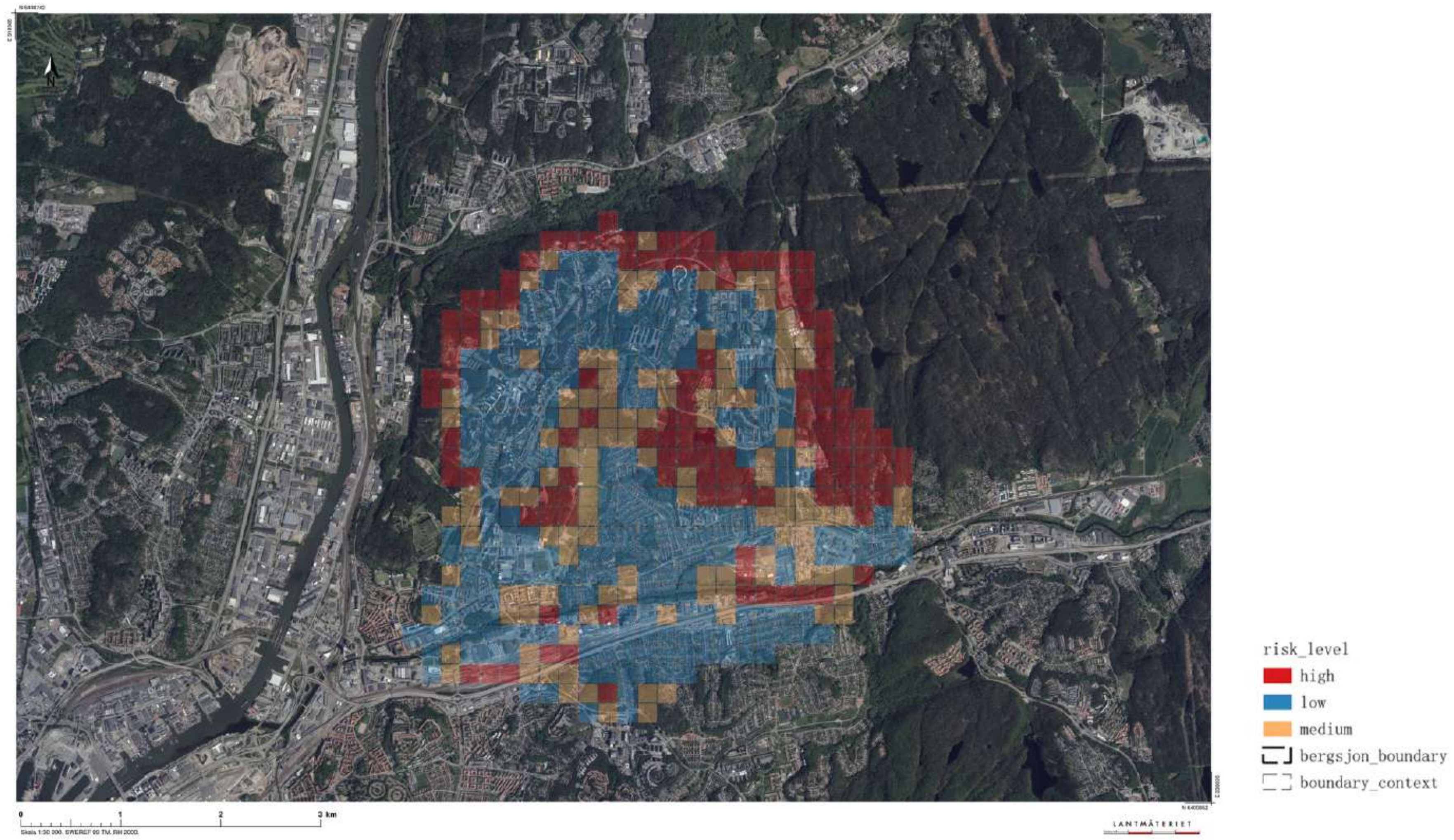


Figure 27. P_iso risk-level classification. Produced by author using Python and QGIS; base map from Lantmäteriet, 2026.

To support design interpretation, the continuous probability values are further classified into low, medium, and high risk levels. The high-risk areas indicate priority zones for closer spatial reading, while the medium-risk areas are interpreted as transitional zones where small changes in connectivity, accessibility, or public space structure may have significant design relevance. This classification provides the basis for the following cluster analysis, which examines whether high-risk areas share similar spatial characteristics or represent different types of isolation conditions.

5.2 Pattern Recognition and Spatial Mechanisms.

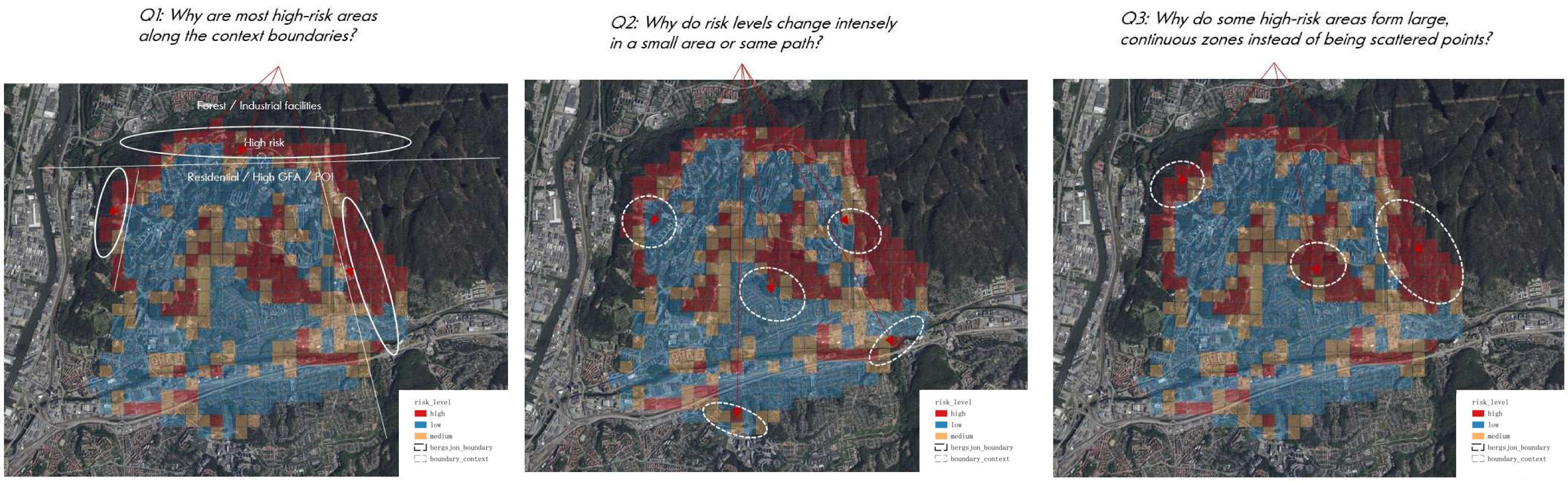


Figure 28. Pattern recognition of high-risk areas through annotated overlay analysis. Produced and annotated by author based on Python logistic regression results and QGIS mapping; orthophoto base map from Lantmäteriet, 2026.

After the P_iso risk levels are mapped, the results are further interpreted through zoom-in analysis of characteristic areas. The aim of this step is not only to identify where high-risk cells are located, but to understand why they appear in particular spatial patterns. Three recurring mechanisms can be observed: boundary effects, fragmented social functions along paths, and the formation of continuous high-risk zones.

First, many high-risk areas appear along the edges of the research core area, especially near forests, infrastructure, industrial land, or large undeveloped spaces. These areas are not necessarily isolated because they are physically far from the city, but because the boundary condition creates a sudden reduction in spatial opportunities. Routes, facilities, and everyday destinations become less continuous at the edge. Therefore, reducing the isolating effect of boundaries becomes an important design focus.

Second, some areas show strong variation in risk levels along the same path or within a small area. This suggests that physical continuity alone is not enough to support social connection. A path may be spatially continuous, but the social functions it carries can still be fragmented. In design terms, this means that movement routes should not only connect places, but also support encounter, visibility, and everyday use.

Third, some high-risk areas form larger continuous zones instead of scattered points. This indicates that isolation risk becomes more structural when several unfavourable spatial conditions overlap, such as weak accessibility, low integration, poor facility access, and edge conditions. In these cases, single-point interventions are likely to be insufficient. Instead, the design response needs to address the spatial system through connected routes, social nodes, and a broader reorganisation of public space.

Together, these patterns show that structural isolation in Bergsjön is not produced by one factor alone. It emerges through the relationship between boundaries, movement networks, everyday functions, and spatial continuity. This interpretation provides the basis for the following cluster reading and later design translation.

6. DESIGN TRANSLATION

6.1 Cluster-Based Strategies.

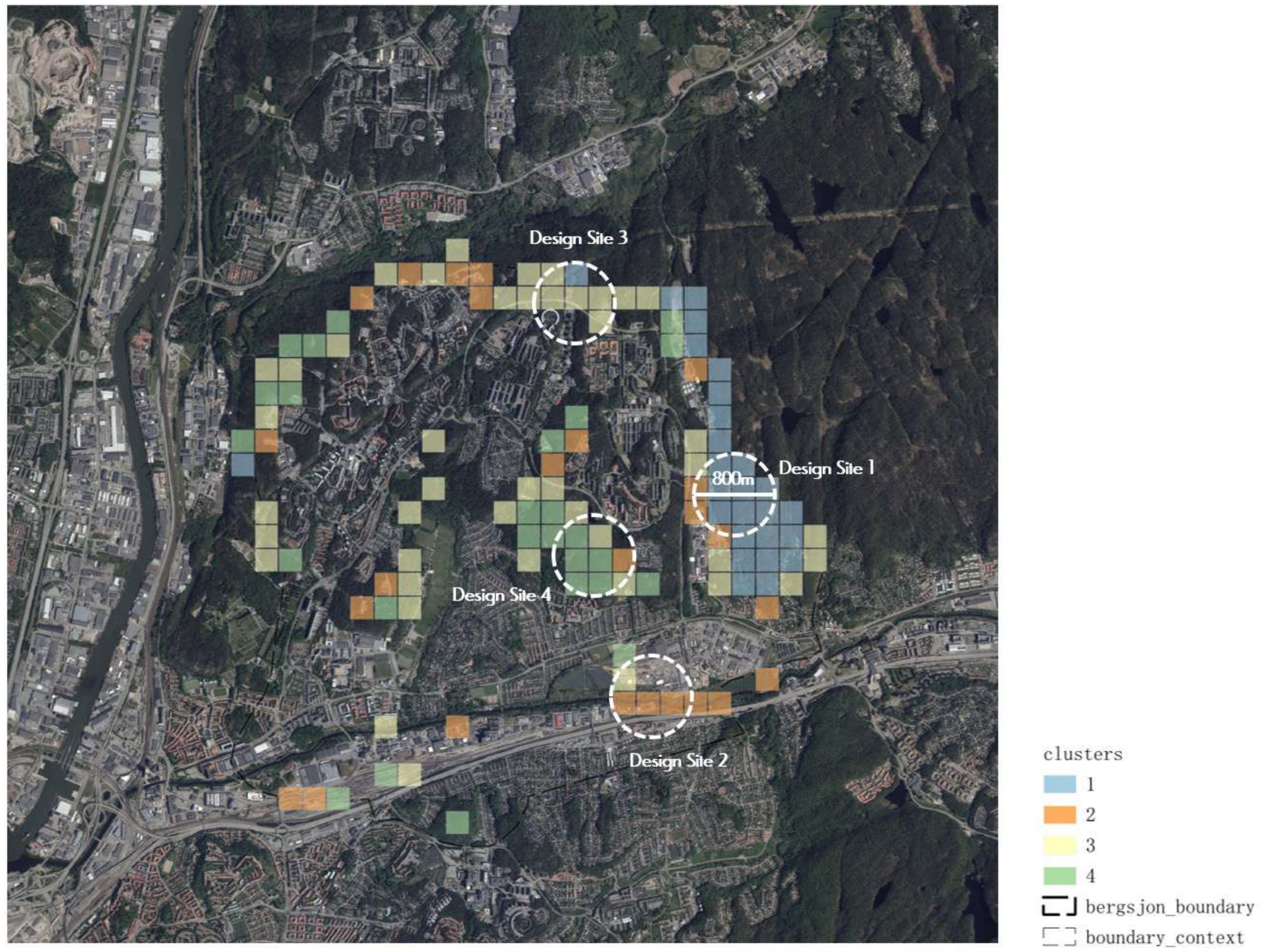


Figure 26. Continuous P_iso risk distribution. Produced by author using Python and QGIS; base map from Lantmäteriet, 2026.

The previous analysis shows that high-risk areas in Bergsjön do not share a single spatial condition. Through K-means clustering, the high-risk grid cells are grouped into four cluster types, each representing a different combination of accessibility, integration, density, and edge conditions. This means that the design response should not be based on one universal solution, but should respond to the specific spatial mechanism behind each cluster.

The cluster map is therefore used as a bridge between risk analysis and design strategy. Instead of treating all high-risk areas as equal design targets, the thesis reads each cluster as a different type of spatial problem. Some areas require stronger connections to everyday facilities, while others need improved path continuity, better use of green edges, or more active public interfaces. In this way, clustering helps translate statistical results into differentiated design actions.

This step also supports the selection of design locations. The aim is not to choose the area with the highest risk value only, but to identify sites where the source of risk is spatially clear and where design intervention can produce wider effects. The selected design site should therefore have both a clear relationship to the cluster interpretation and the potential to influence broader patterns of access, movement, and encounter.

Based on this logic, the thesis develops cluster-based strategies before zooming into one focused site. Each cluster is interpreted as a design condition with its own spatial priority, allowing the later proposal to move from general risk mapping toward targeted, evidence-based urban design.

Cluster-Based Strategies - Cluster 1

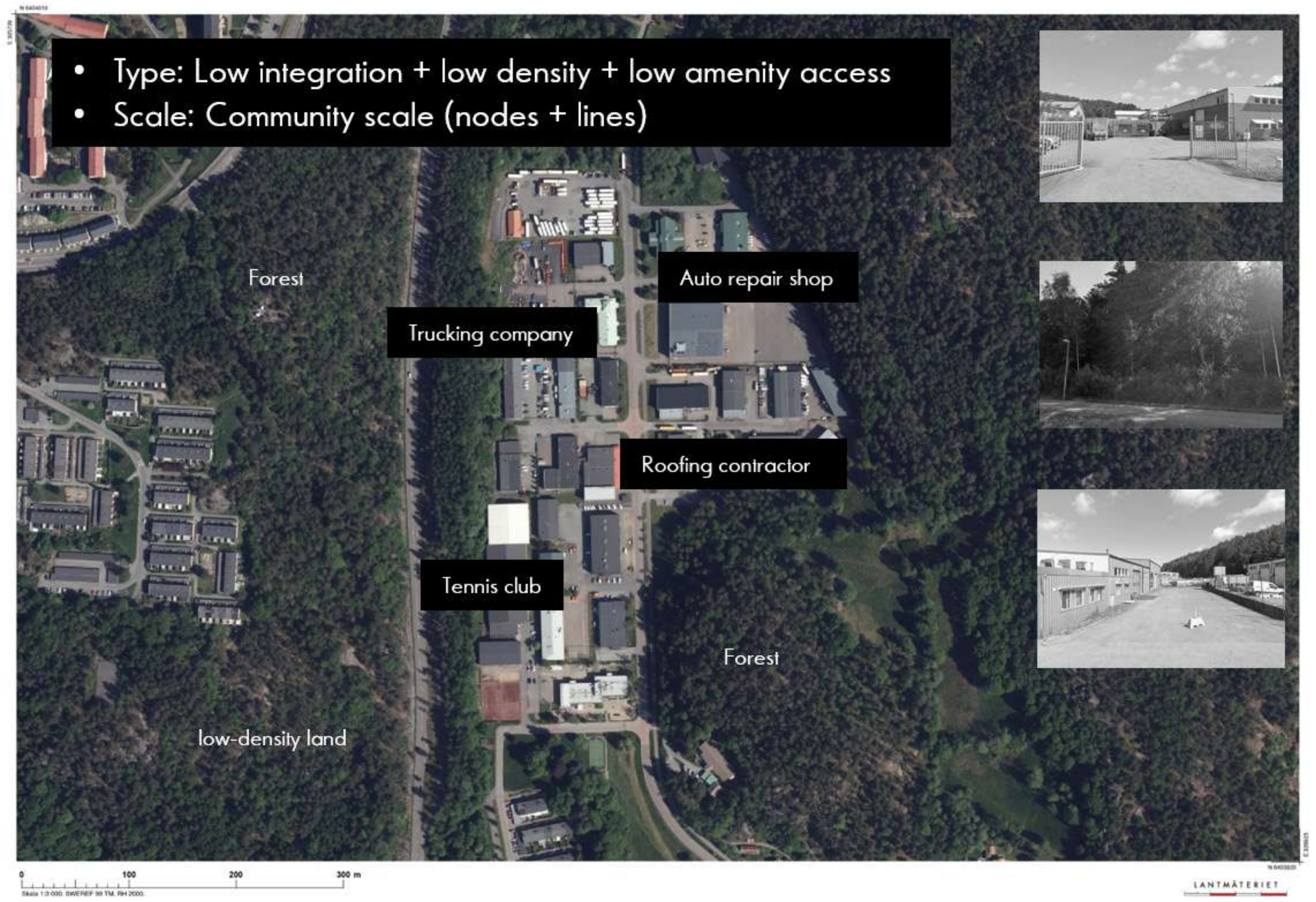


Figure 27. Existing spatial condition of Design Site 1, showing industrial and service functions, forest edges, and low-density surrounding land. Produced and annotated by author; orthophoto base map from Lantmäteriet, 2026.

Cluster 1 is characterised by low local integration, low GFA density, and poor POI accessibility. This means that the high-risk condition is not only caused by a lack of everyday amenities, but also by weak network embedding and low activity capacity. The area currently functions mainly as a service and industrial landscape, with limited public use and weak connections to nearby residential clusters.

Therefore, the design response must address all three high-risk factors. Low integration is addressed by strengthening pedestrian and cycling connections to the surrounding residential areas, especially the residential clusters to the west. Low density is addressed through selective mixed-use densification around a community anchor, rather than full redevelopment. Poor POI accessibility is addressed by adding everyday community functions and connecting them to the movement network. In this way, Cluster 1 is treated not as an isolated activity island, but as a potential community edge linked to the wider neighbourhood.

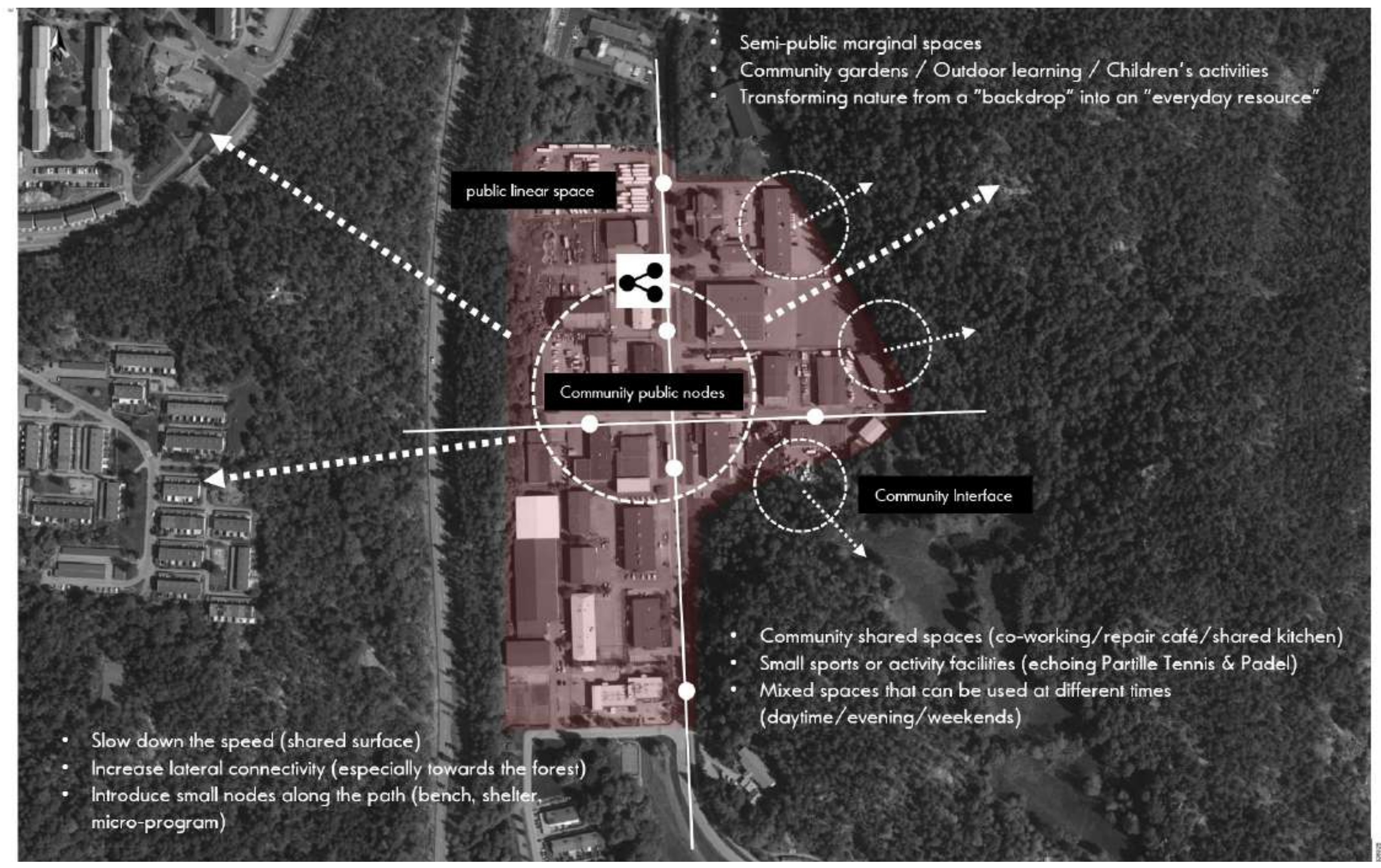


Figure 28. Design strategy overlay for Cluster 1, showing proposed community nodes, public linear space, and forest-edge interfaces. Produced and annotated by author; orthophoto base map from Lantmäteriet, 2026.

Strategy	High-risk factor addressed	Design response
1. External Connection to Residential Clusters *(line)*	Low integration	Create stronger pedestrian and cycling links between the site and nearby residential clusters, especially to the west. This turns the area from an isolated service island into part of a wider everyday route.
2. Selective Mixed-Use Densification *(node / density)*	Low density + low amenities	Add small-scale mixed-use and community functions near the central node, such as workshop, local service, shared activity space, or community facility, to increase everyday use and activity capacity.
3. Forest and Service Edge as Interface *(boundary)*	Weak public interface	Transform the forest and service edges into accessible public interfaces with paths, entrances, and small staying spaces, so the edge becomes part of daily movement rather than a passive boundary.

Table 4. Cluster 1 design strategies. Produced by author, 2026.

The Cluster 1 strategy is organised around three responses to the diagnosed high-risk factors. First, new external connections respond to low integration by linking the area to nearby residential clusters and wider pedestrian routes. Second, selective mixed-use densification responds to low density by increasing everyday activity capacity around the community anchor. Third, new local amenities and activated forest edges respond to poor POI accessibility by creating daily destinations and usable public interfaces.

Cluster-Based Strategies - Cluster 2

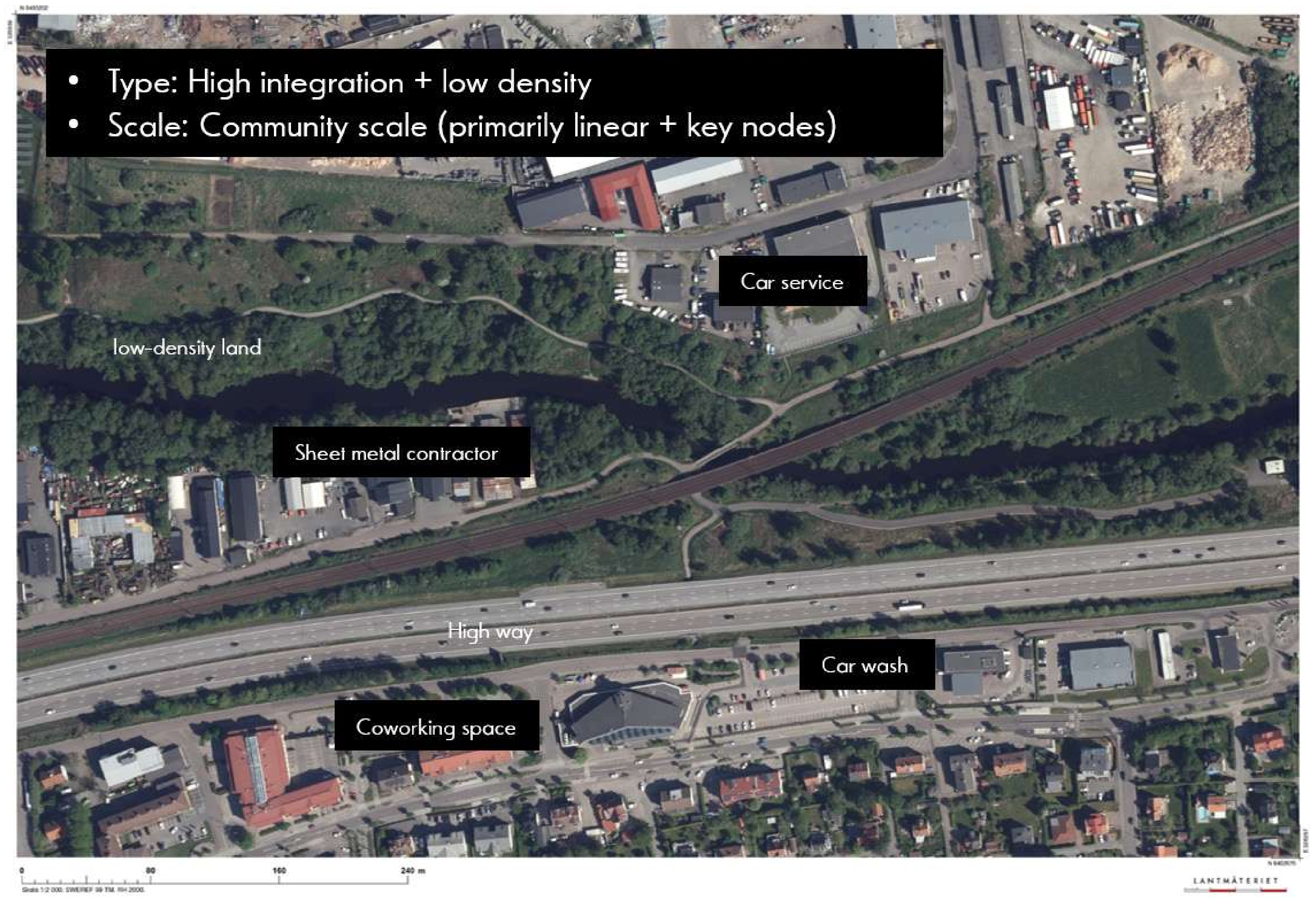


Figure 29. Existing spatial condition of Design Site 2, showing the linear infrastructure corridor, surrounding low-density land, and service-oriented functions. Produced and annotated by author using Lantmäteriet orthophoto, 2026.

Cluster 2 is characterised by relatively high local integration, but low GFA density and medium–poor POI accessibility. This means that the high-risk condition is not caused by disconnection, but by an imbalance between movement potential and everyday social support. The corridor is spatially accessible, but the surrounding built density, public functions, and local destinations are too weak to transform movement into social encounter.

Therefore, the design response should not only improve the route itself, but also add reasons to stop, use, and connect along the corridor. High integration is used as an opportunity to support a public linear space. Low density is addressed through selective programmatic intensification at key nodes, while weak amenity access is addressed by adding small everyday functions and connecting them to nearby residential and service areas.

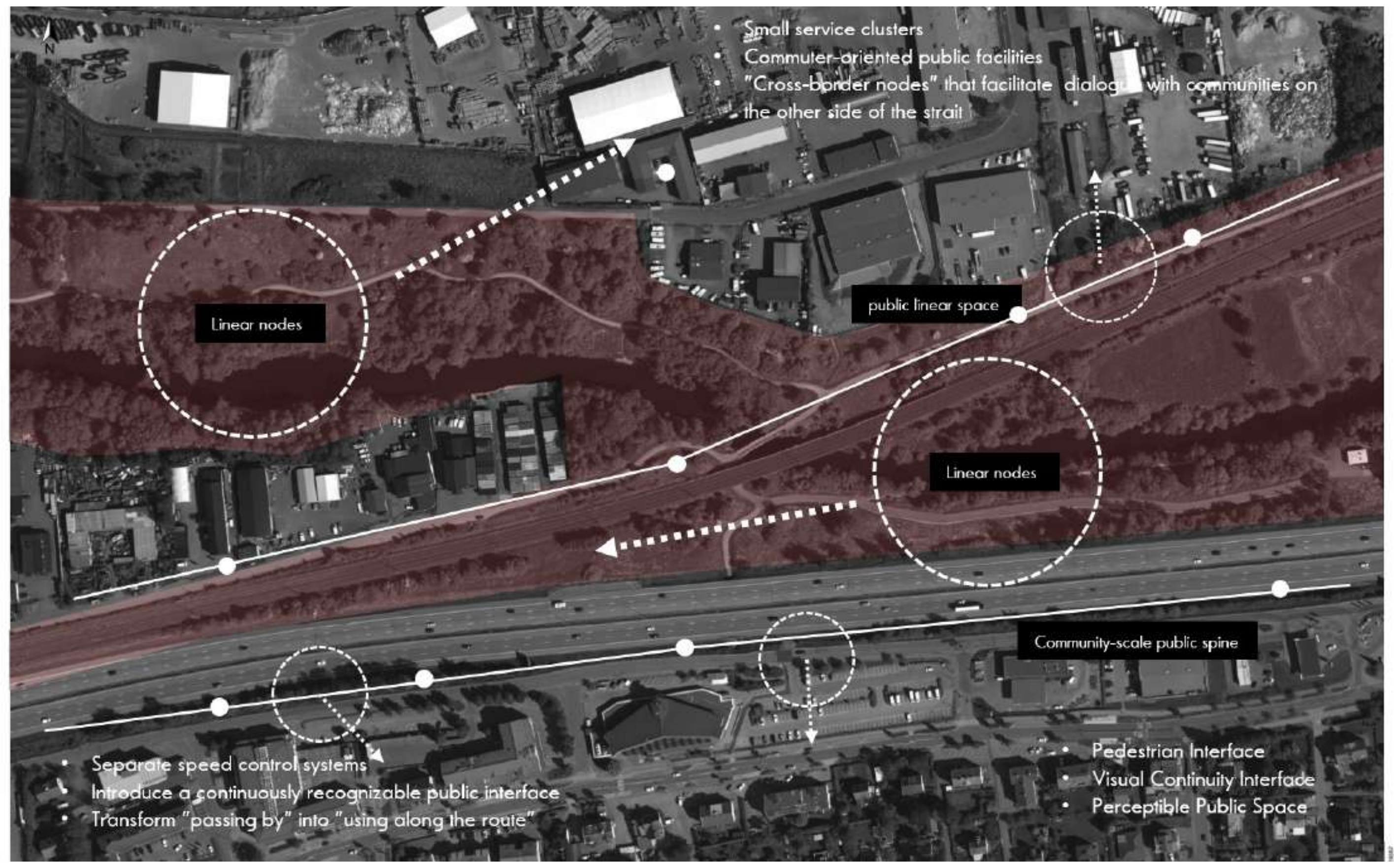


Figure 30. Design strategy overlay for Cluster 2, showing the transformation of the infrastructure corridor into a public linear space with linear nodes and community-scale interfaces. Produced and annotated by author; orthophoto base map from Lantmäteriet, 2026.

Strategy	High-risk factor addressed	Design response
1. Social Linear Spine *(line)*	High integration but weak social use	Use the existing movement potential to create a slower and more comfortable public route, with seating, lighting, pedestrian-friendly surfaces, and clearer crossings.
2. Programmatic Micro-Nodes *(node / density)*	Low density + weak activity capacity	Add small activity nodes along the corridor, such as kiosks, workshops, play points, shelters, or shared service spaces, to increase everyday use and local intensity.
3. Edge Connection and Interface *(boundary)*	Weak POI accessibility + disconnected edges	Strengthen connections between the corridor, adjacent buildings, green spaces, and nearby residential areas through entrances, crossings, active edges, and semi-public interfaces.

Table 5. Cluster 2 design strategies. Produced by author, 2026.

The Cluster 2 strategy responds to the diagnosed imbalance between strong integration and weak local activity. Because the corridor already has movement potential, the aim is not simply to add new paths, but to transform existing movement into social value. The linear spine uses the high integration condition as a design opportunity, while micro-nodes and edge connections address the lack of density, amenities, and everyday stopping points.

These interventions should work together. If the corridor is only improved as a route, it may remain a passage space. By adding small programmatic nodes and stronger connections to adjacent areas, the corridor can become a sequence of usable public moments rather than only an infrastructure edge.

Cluster-Based Strategies - Cluster 3

Figure 31. Existing spatial condition of Design Site 3, showing residential areas, local facilities, community garden, and surrounding low-density land. Produced and annotated by author using Lantmäteriet orthophoto, 2026.

Cluster 3 is characterised by higher GFA density, medium local integration, and medium–good POI accessibility. Unlike Cluster 1 and Cluster 2, the high-risk condition here is not caused by a complete lack of buildings or resources. Instead, the problem is that existing density, facilities, and routes do not yet form a continuous social structure.

The area already contains residential buildings, internal paths, local facilities, and nearby green spaces. However, medium integration suggests that the internal network is not strong enough to organise everyday movement into a clear public spine. Although POI accessibility is relatively better, these resources remain spatially fragmented. Therefore, the design response should focus on reorganising existing residential density, strengthening internal connections, and transforming closed residential edges into semi-public interfaces.

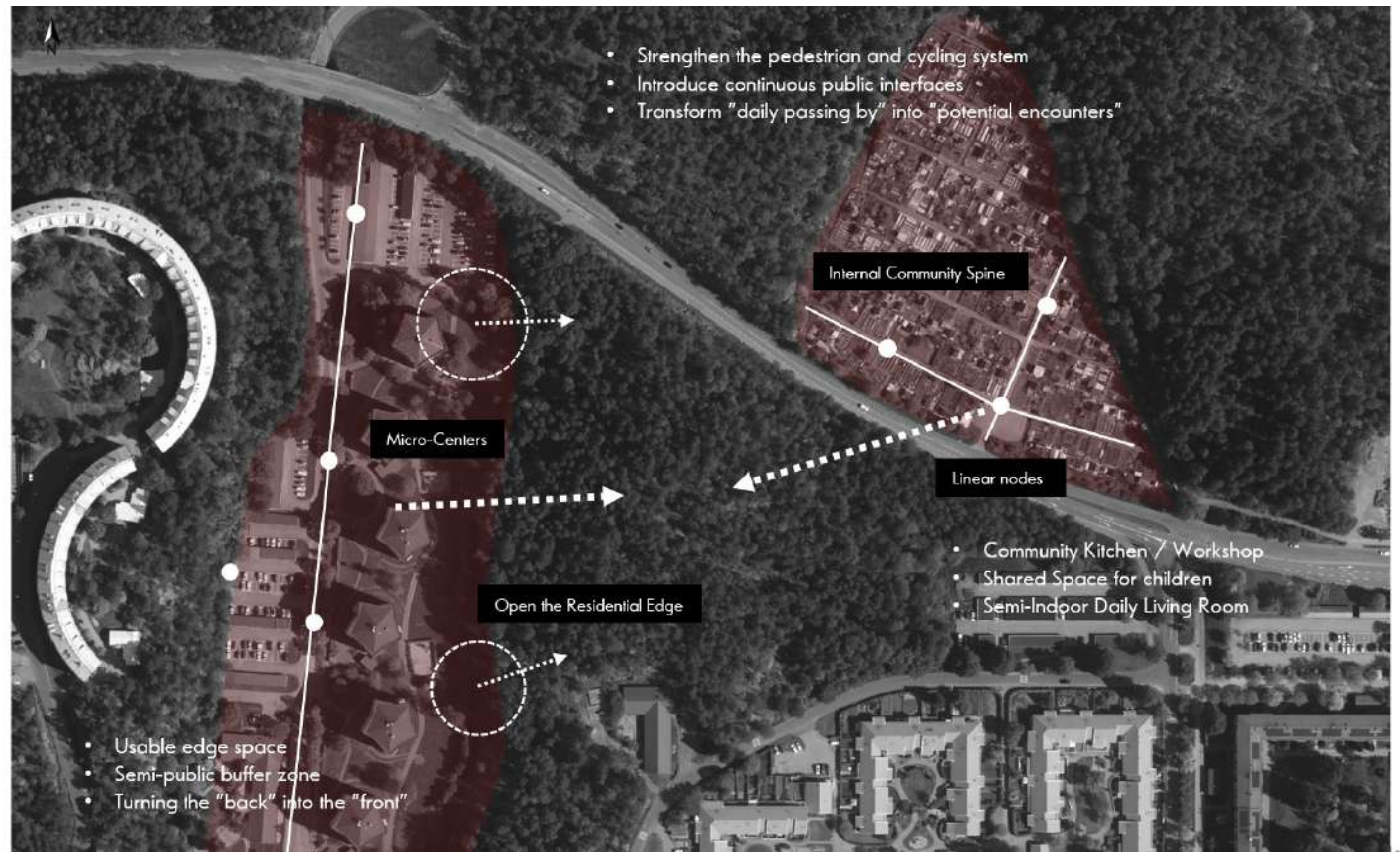


Figure 32. Design strategy overlay for Cluster 3, showing the internal community spine, micro-centres, linear nodes, and opened residential edges. Produced and annotated by author; orthophoto base map from Lantmäteriet, 2026.

Strategy	High-risk factor addressed	Design response
1. Internal Community Spine *(line)*	Medium integration	Strengthen the main internal pedestrian route and connect it to nearby facilities, entrances, and green spaces, so everyday movement becomes more continuous and legible.
2. Shared Micro-Centres *(node / programme)*	Existing density but weak social organisation	Insert small shared nodes between residential clusters, such as seating areas, play spaces, community rooms, or shared gardens, to turn residential density into social capacity.
3. Open Residential Edge *(boundary / interface)*	Fragmented POI access + weak interface	Transform closed residential edges into semi-public thresholds with entrances, visual openings, and small usable edge spaces, linking housing to public routes and local resources.

Table 6. Cluster 3 design strategies. Produced by author, 2026.

The Cluster 3 strategy responds to a condition where density and resources already exist, but are not sufficiently organised into a social structure. Therefore, the aim is not large-scale redevelopment, but the reconfiguration of internal routes, shared nodes, and residential interfaces.

The internal community spine addresses medium integration by clarifying everyday movement through the residential area. Shared micro-centres respond to the underused potential of existing density by creating smaller places for meeting and staying. Open residential edges connect housing, public routes, and nearby facilities more directly. Together, these strategies turn existing proximity into a more legible and socially supportive neighbourhood structure.

6.2 Why Choose Cluster 4.

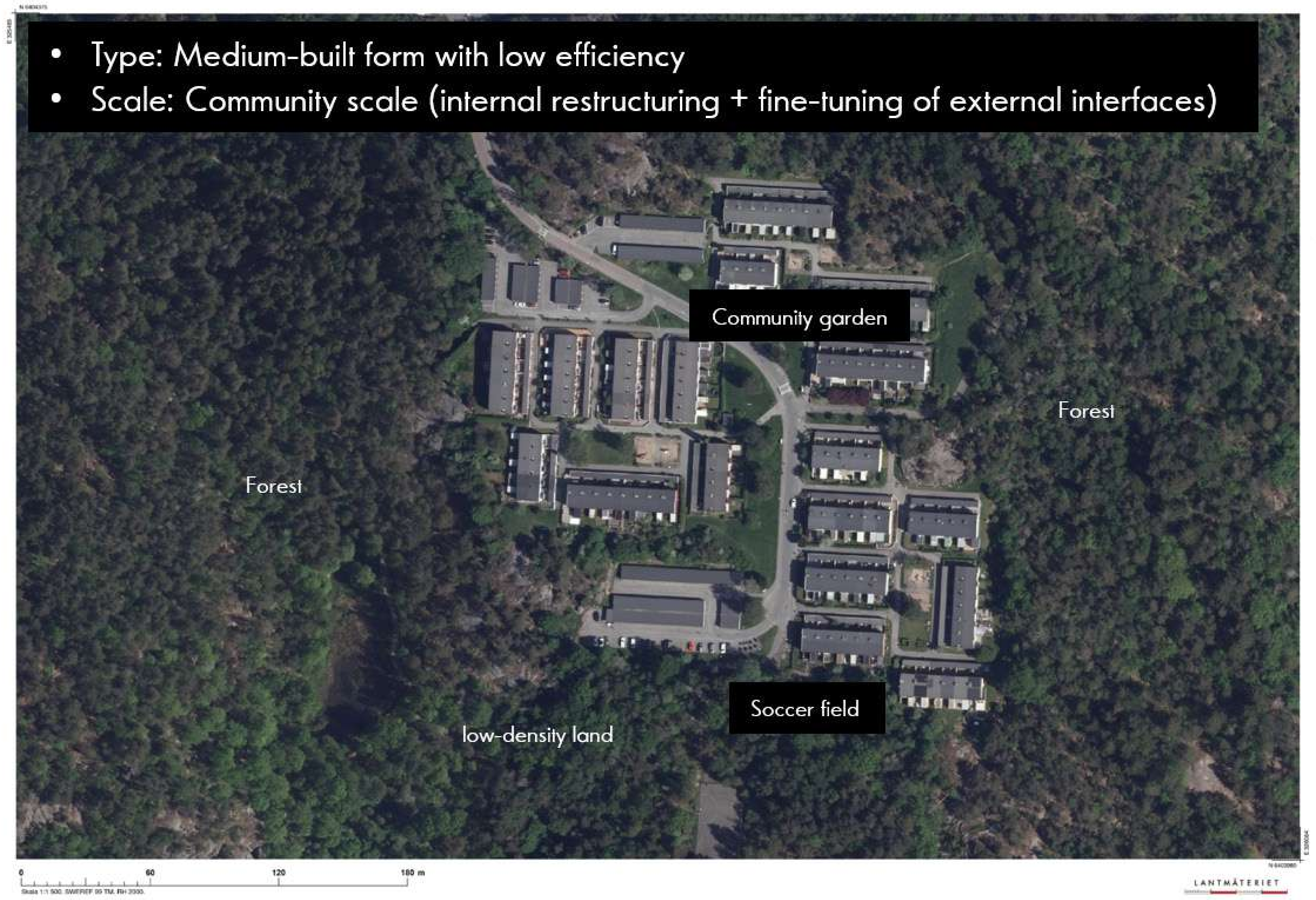


Figure 33. Existing spatial condition of Design Site 4, showing the residential enclave, surrounding forest, low-density land, community garden, and sports field. Produced and annotated by author using Lantmäteriet orthophoto, 2026.

Cluster 4 is selected for in-depth design because it represents a critical transitional condition rather than the most extreme high-risk case. Statistically, many of its indicators appear relatively average when compared with other clusters. However, this is precisely what makes the cluster important for design. It is located in a sensitive zone where small spatial changes may shift the area either towards higher isolation risk or towards stronger everyday connectivity.

From the perspective of logistic regression, the medium-risk range is especially significant. Areas around the middle of the probability curve are more sensitive to changes in input variables, because small adjustments in accessibility, integration, or facility distribution can produce a larger change in estimated risk probability. Therefore, medium-risk and transitional areas should not be treated as less important than high-risk areas. Instead, they can be understood as spatial tipping points where targeted design intervention may have stronger preventive effects.

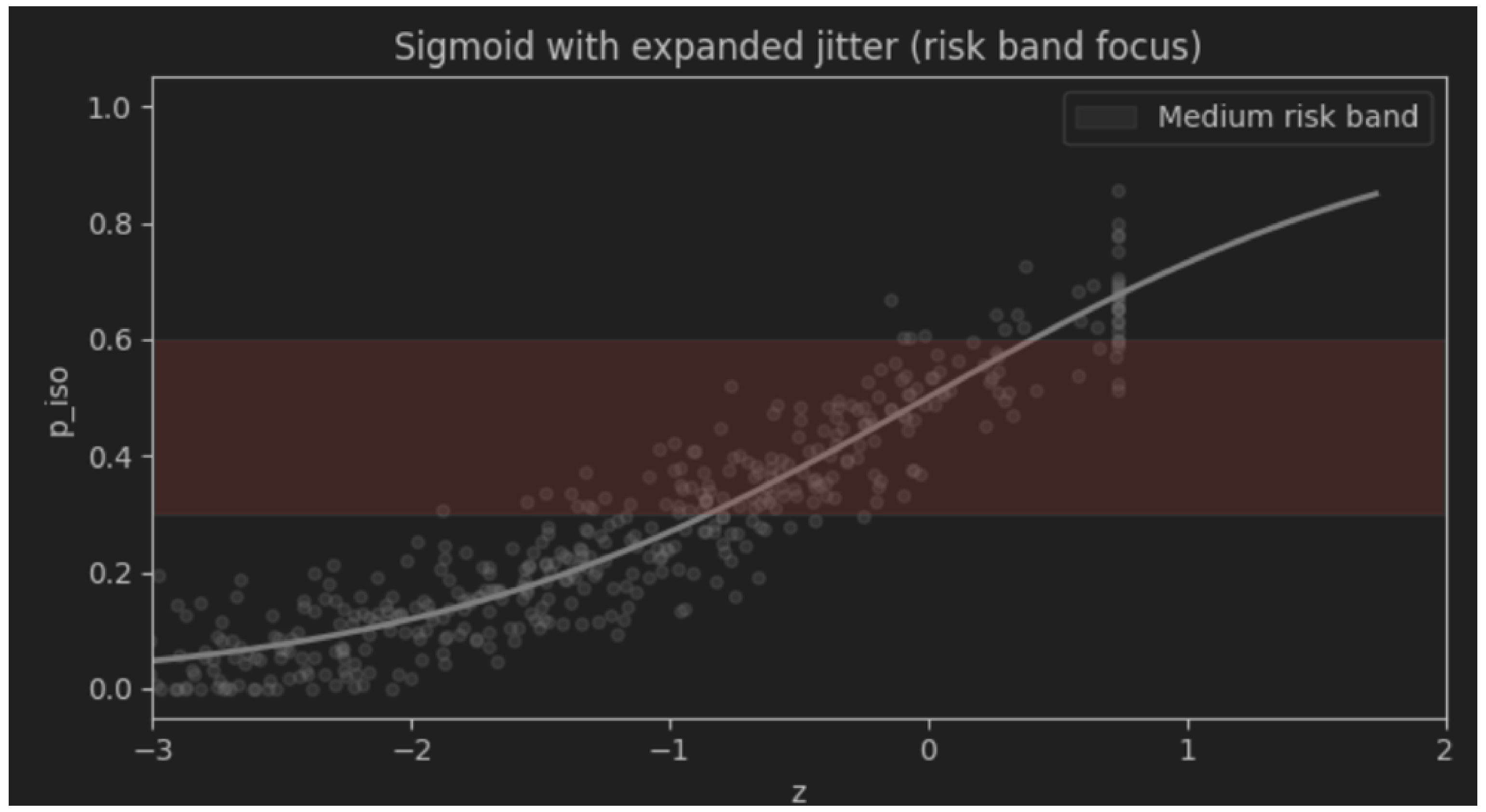


Figure 34. Medium-risk band in the logistic regression output, showing the sensitive probability range used to support the selection of Cluster 4. Produced by author based on Python logistic regression analysis, 2026.

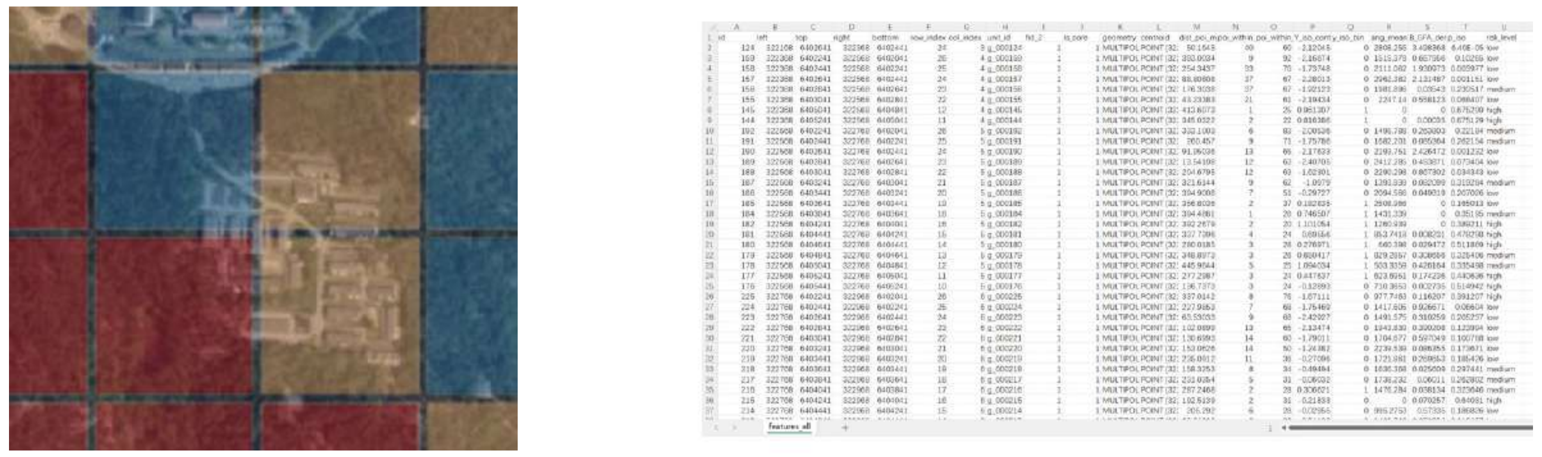


Figure 35. Zoom-in of adjacent risk grid cells and Attribute table of spatial units used for Cluster 4 interpretation, including selected spatial indicators and risk-level information. Produced by author based on QGIS and Python spatial analysis, 2026.

Urban spatial interpretation also supports the choice of Cluster 4. The cluster is positioned at the intersection of several mechanisms: residential edges, forest boundaries, fragmented paths, and uneven access to everyday facilities. These overlapping conditions create abrupt changes between adjacent grid cells and reveal structural fractures in the urban fabric. The area is not only a problem zone, but also a place where relationships between housing, landscape, movement, and community life can be reconfigured.

For this reason, the value of Site 4 lies not in being the “worst” area, but in being the most redesignable. Its risks are spatially clear, its intervention scale is manageable, and its condition has wider relevance for similar residential-edge environments in Bergsjön. By focusing on Cluster 4, the thesis can test how risk mechanisms identified through spatial analysis can be translated into implementable design strategies at the community scale.

7. SITE DESIGN DEVELOPMENT

7.1 Design Methodology.

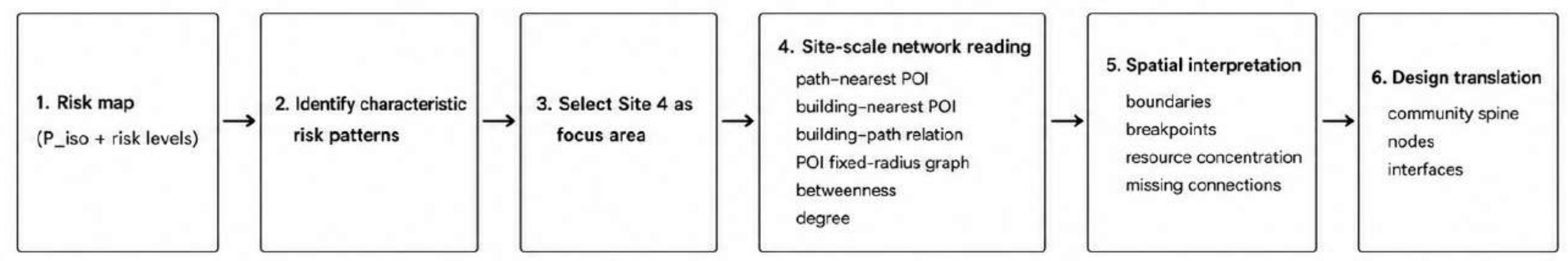


Figure 36. Design translation workflow from risk mapping to site-scale design strategy. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

After P_iso risk mapping and cluster-based interpretation, Site 4 is selected as the focus area for design development. The previous analysis identifies where structural isolation risk is concentrated and explains why Cluster 4 is a critical transition condition. However, district-scale risk mapping is not detailed enough to directly define the position of a community spine, social nodes, or spatial interfaces. A more precise site-scale reading is therefore required.

At this stage, City2Graph and Python-based network analysis are used to examine the relationships between buildings, paths, POIs, and local connection points within Site 4. The purpose is not to produce another final risk model, but to translate the previous spatial evidence into design-relevant rules. By analysing path–POI proximity, building–POI dependency, building–path relations, betweenness, and degree, the study can identify which routes carry strategic movement potential and which points are suitable for social activation.

This step forms a bridge between analysis and design. The network reading helps clarify where the community spine should be strengthened, where social nodes should be placed, and where existing boundaries should be transformed into more active spatial interfaces. In this way, graph-based analysis supports the transition from large-scale risk evidence to site-specific design decisions.

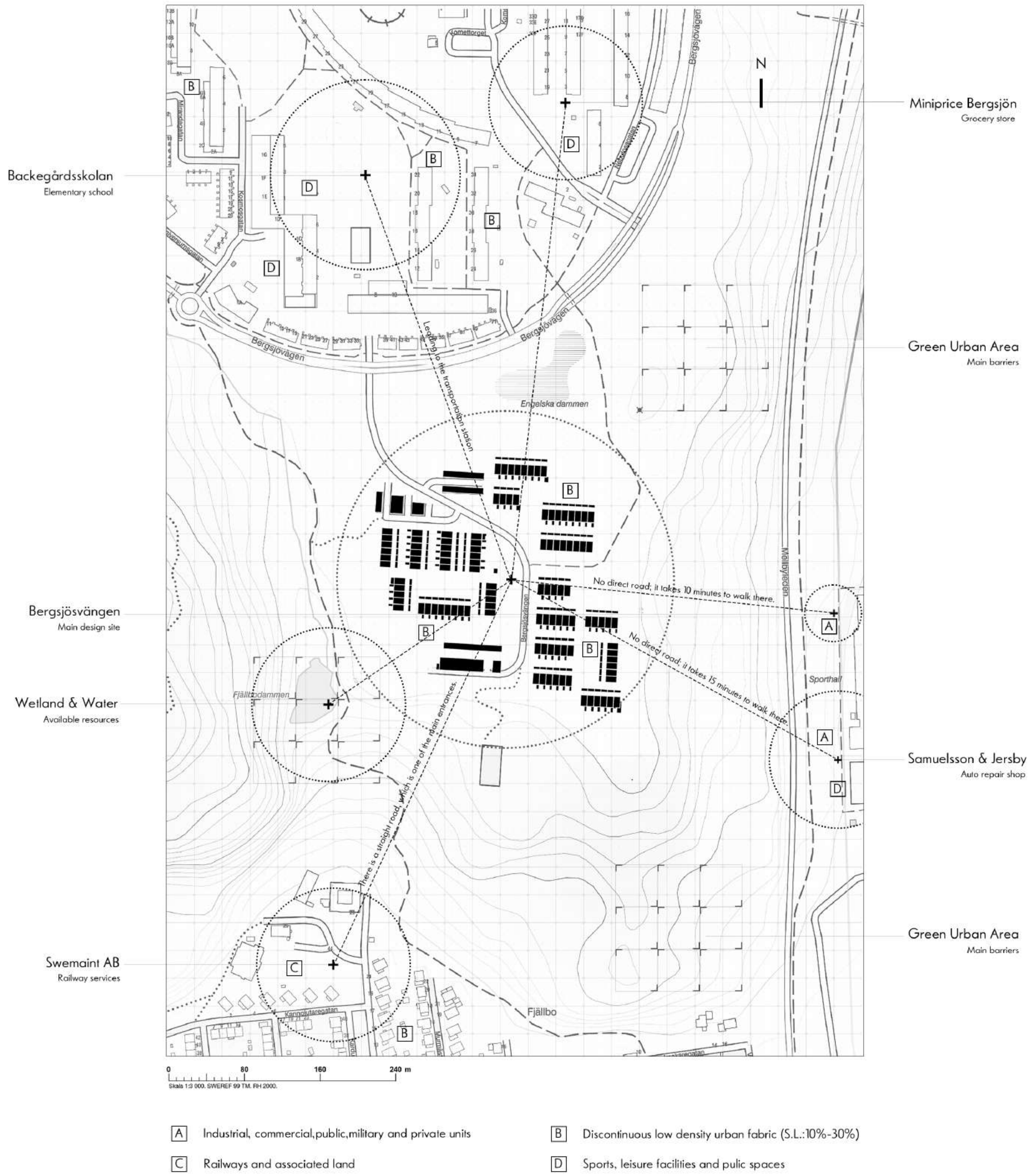


Figure 37. Site research map of Bergsjösvängen. Produced by author, 2026.

This map identifies the existing resources and barriers around the Bergsjösvängen design site. Although schools, shops, sports areas, wetlands, and service facilities are nearby, they are weakly connected to the residential area. Forest edges, topography, and fragmented paths create detours and reduce everyday accessibility. Therefore, the site does not lack resources, but lacks a continuous spatial structure to connect them.

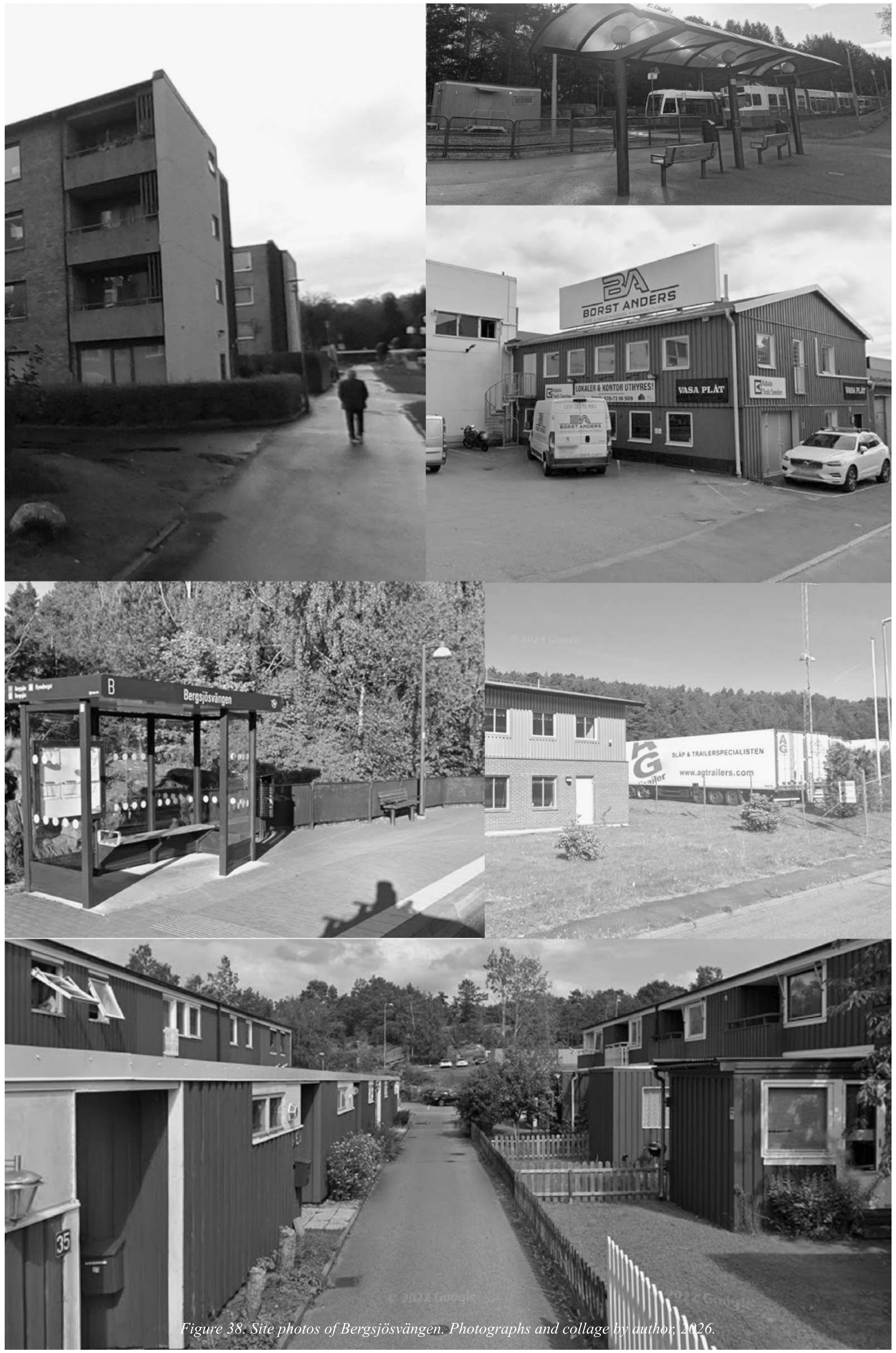


Figure 38. Site photos of Bergsjösvängen. Photographs and collage by author, 2026.

7.2 From Network Evidence To Design Structure.

Graph-Based Evidence for the Community Spine

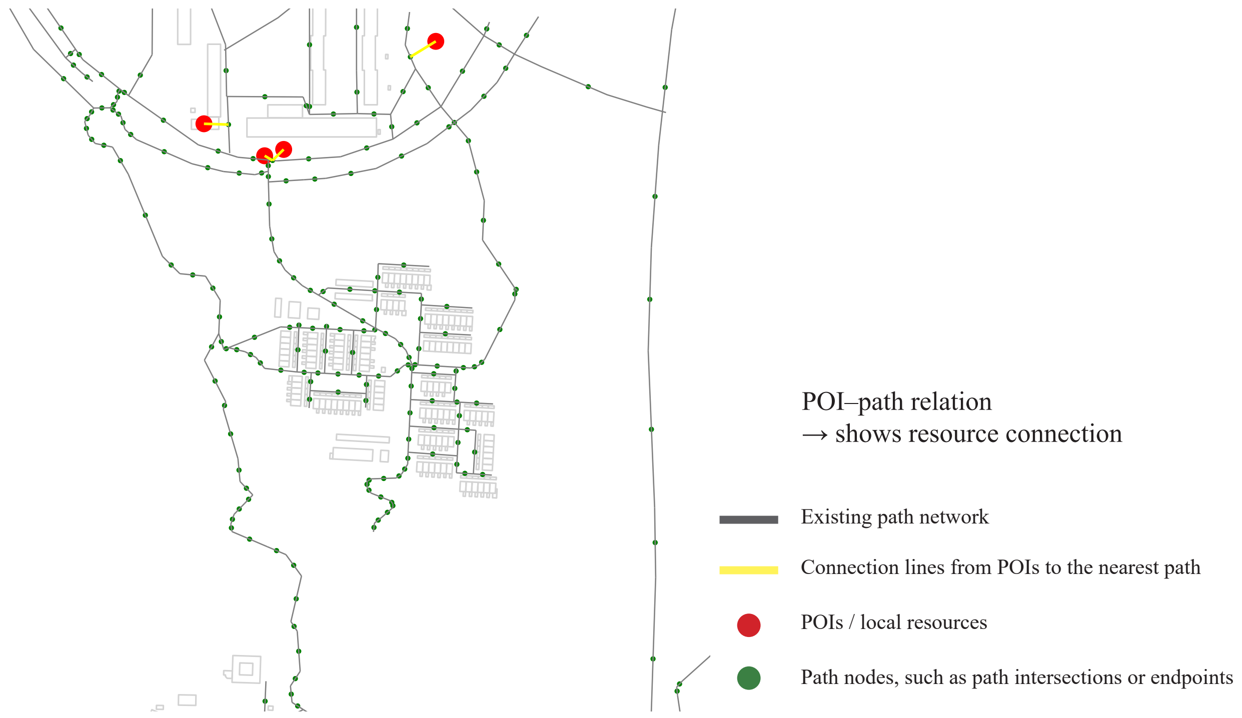


Figure 39. POI–path relation analysis in Site 4, showing how local resources connect to the existing path network. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

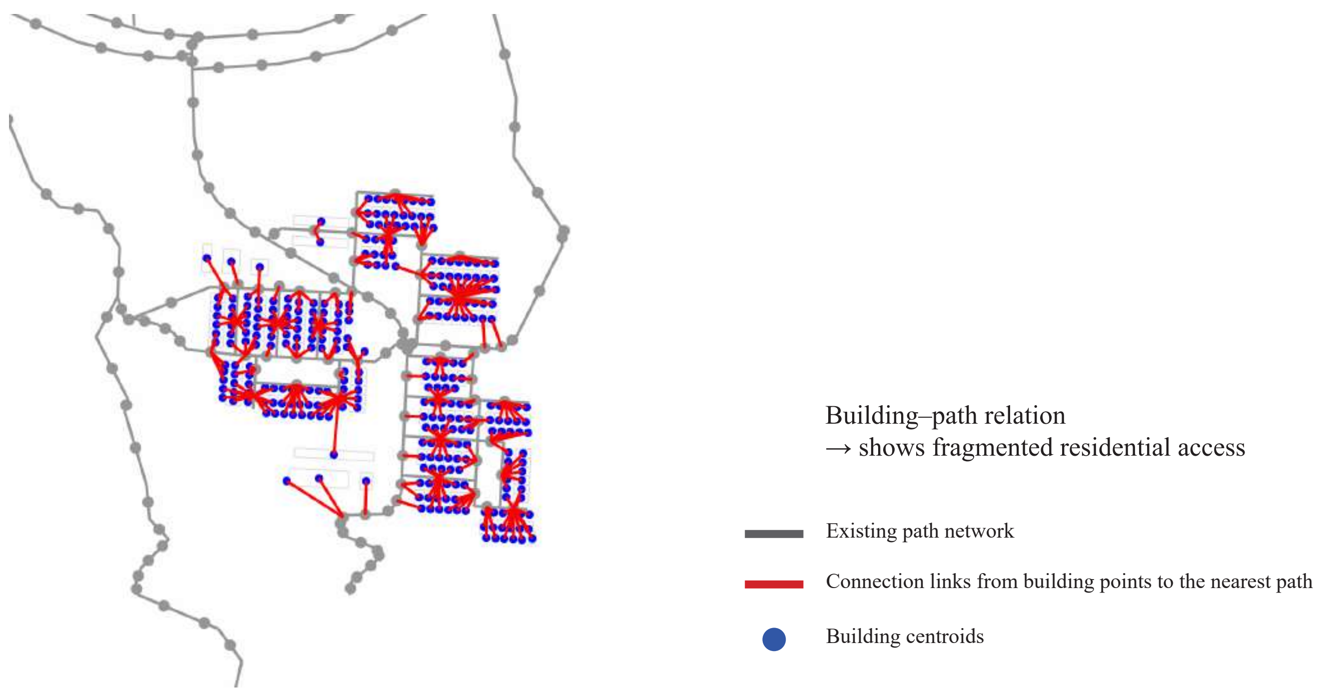


Figure 40. Building–path relation analysis in Site 4, showing the fragmented relationship between residential buildings and the local path system. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

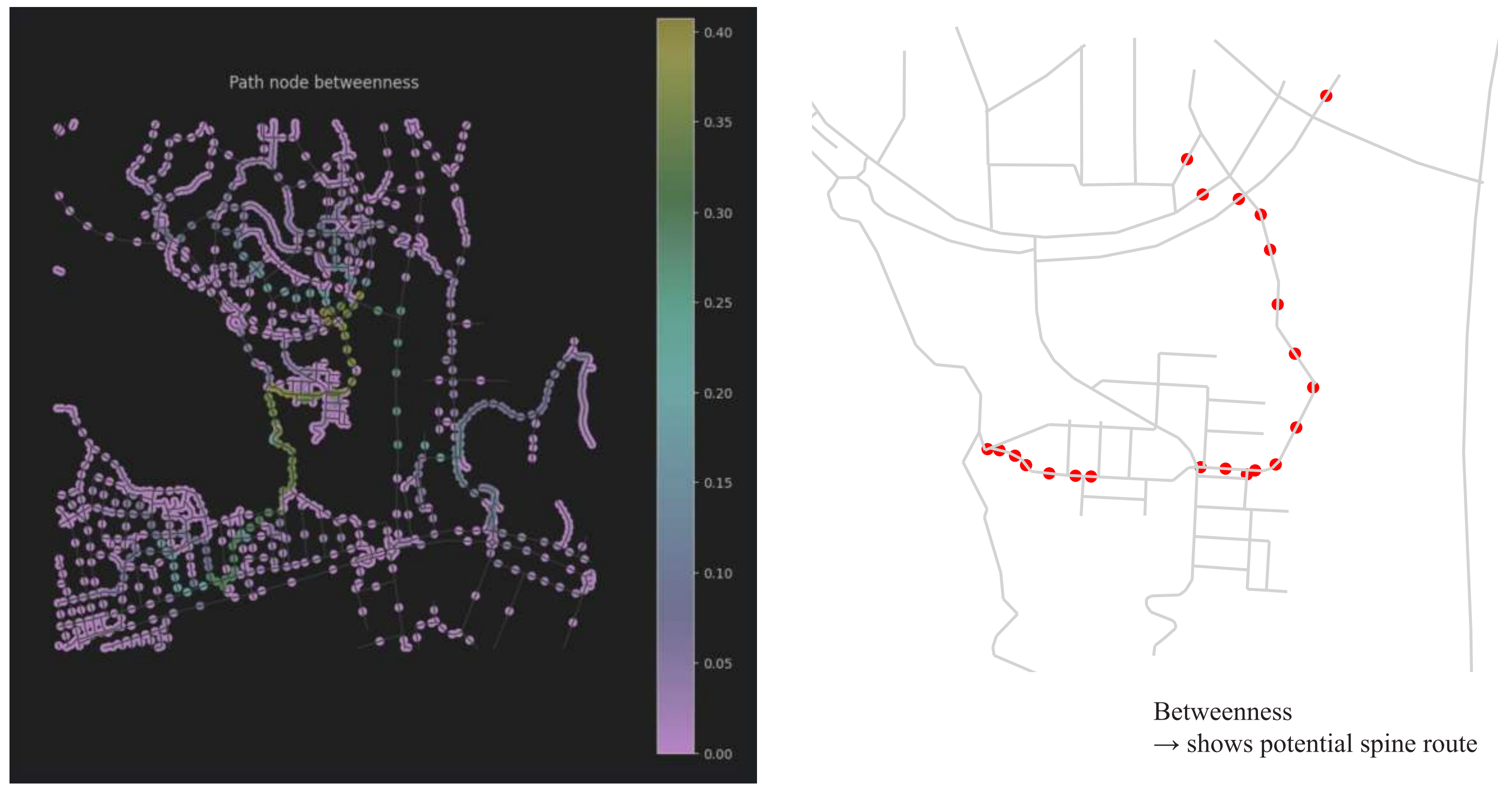


Figure 41.Path node betweenness analysis in Site 4, identifying key movement sequences with high potential for the community spine. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

These diagrams provide site-scale network evidence for the placement of the community spine. They help explain how the general Cluster 4 strategy is translated into a specific spatial route.

The POI–path relation shows that local resources are present around Site 4, but they are not yet organised as a continuous everyday structure. The building–path relation shows fragmented connections between residential buildings and the path network. Together, these diagrams suggest that the design should reconnect existing resources, buildings, and paths rather than simply add new facilities.

The betweenness analysis is used to identify routes with stronger through-movement potential. In graph theory, betweenness measures how often a node or path segment lies on the shortest routes between other parts of the network. A higher betweenness value means that the route is more likely to function as a connector between different areas. In this thesis, these high-betweenness sequences help indicate where a community spine can have the greatest spatial effect.

Therefore, the proposed spine is positioned to connect existing resources, strengthen fragmented building–path relations, and transform movement into everyday social encounter. In this way, the spine is developed from graph-based evidence rather than drawn as an arbitrary design line.

Graph-Based Evidence for Social Nodes

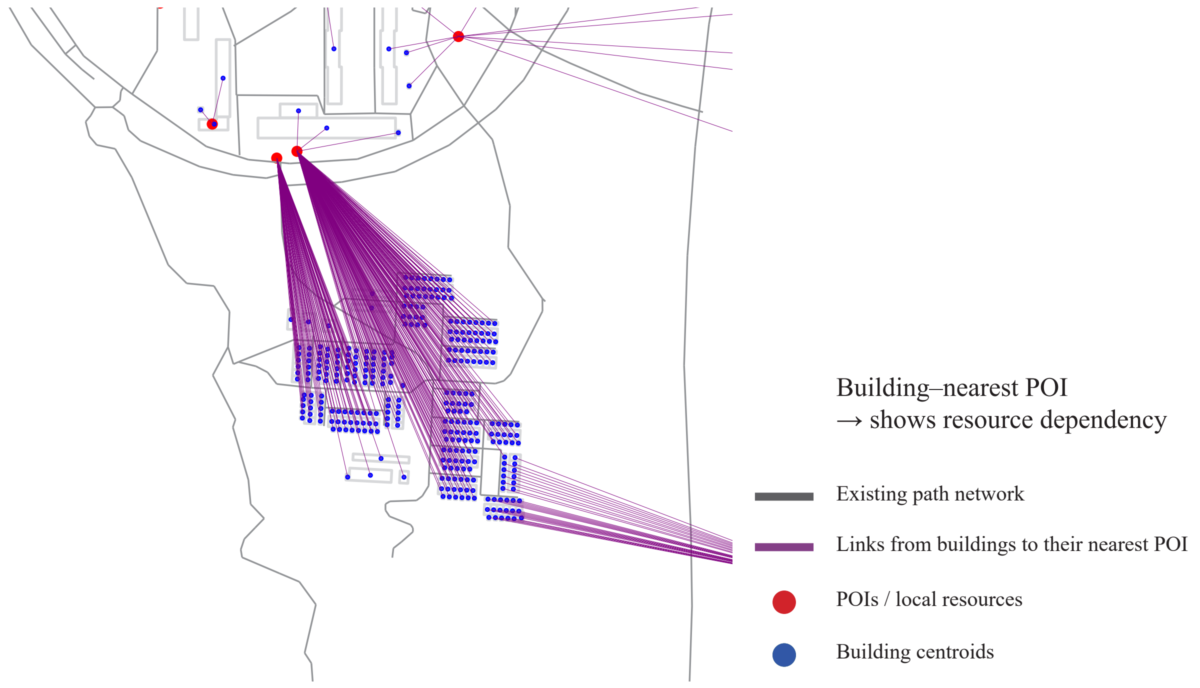


Figure 42. Building–nearest POI analysis in Site 4, showing how residential buildings depend on nearby everyday resources. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

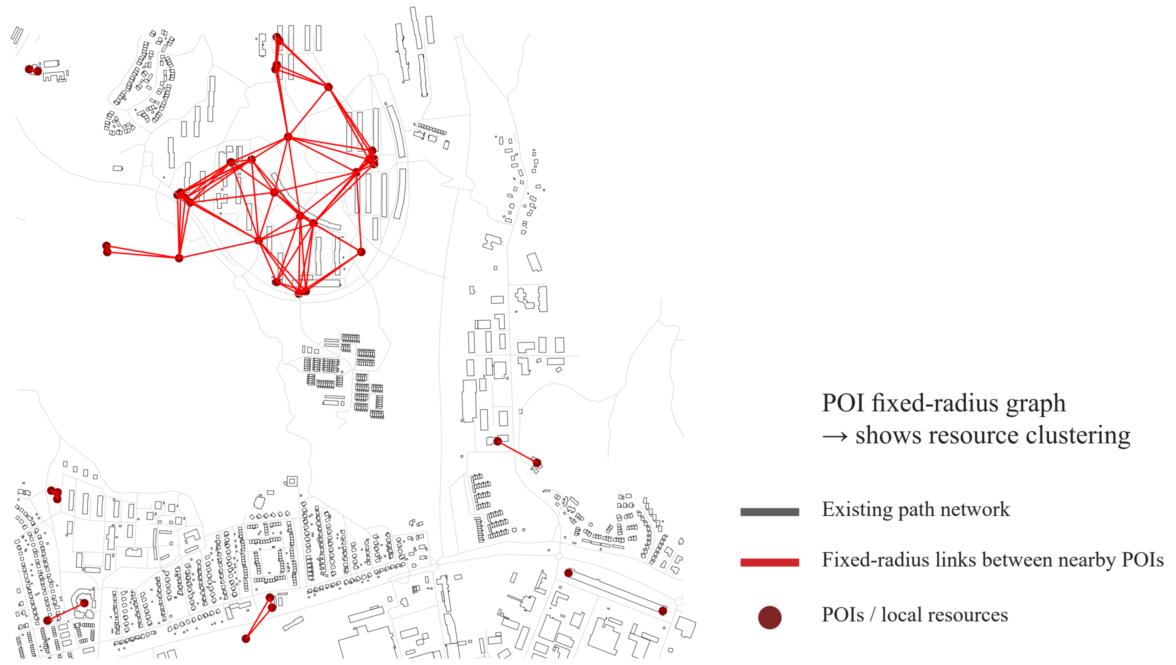


Figure 43. POI fixed-radius graph in Site 4, showing whether nearby POIs form a connected everyday resource network. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

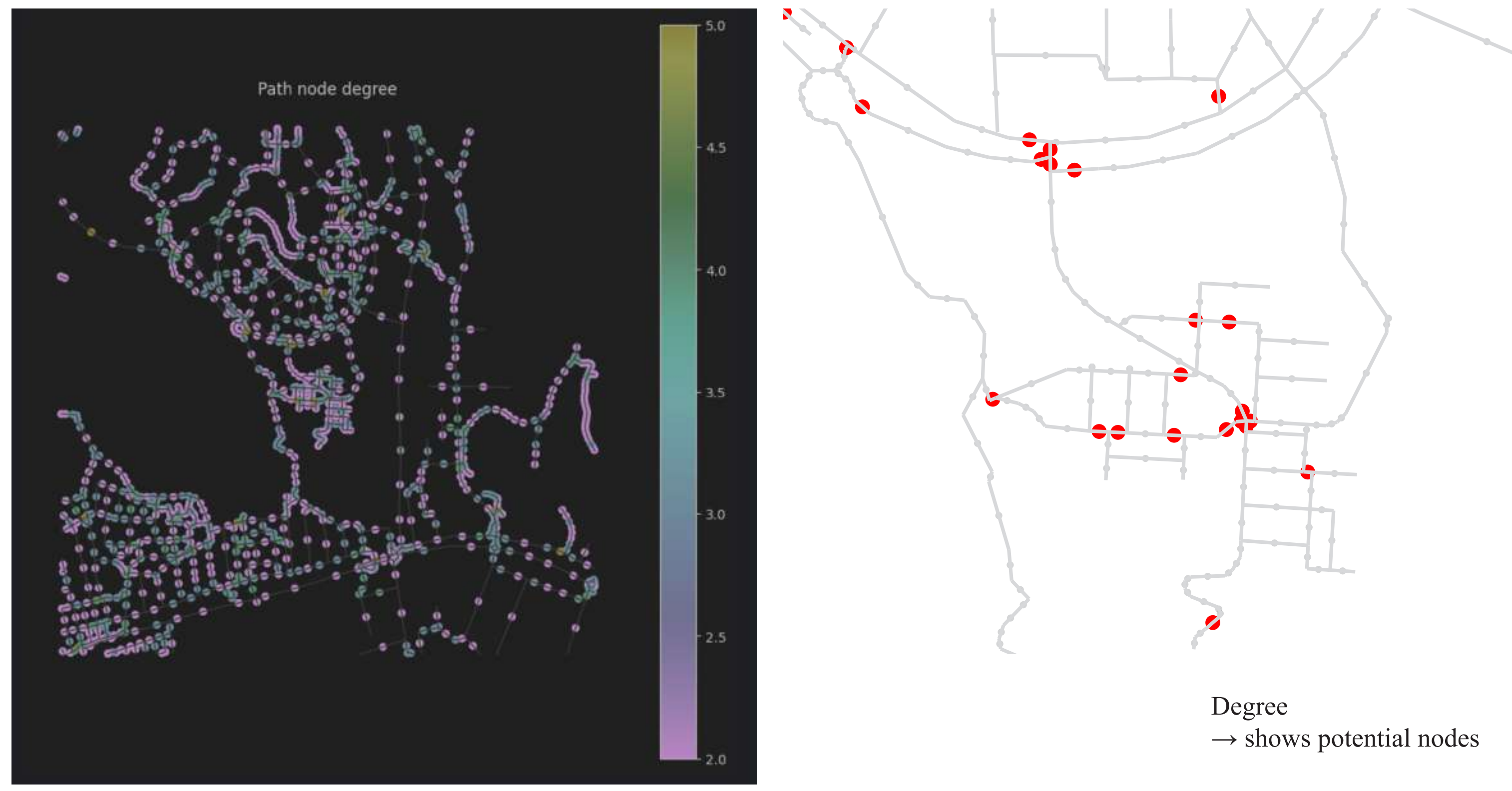


Figure 44. Path node degree analysis in Site 4, identifying local intersections and connection points suitable for social nodes. Produced by author based on QGIS, Python, and City2Graph analysis, 2026.

These diagrams provide site-scale network evidence for the placement of social nodes. While the community spine defines the main linear structure, the social nodes identify where this spine should be anchored, interrupted, or intensified to support everyday encounter.

The building–nearest POI analysis shows how residential buildings depend on nearby everyday resources. It indicates which facilities serve multiple buildings and where stronger connections between housing, paths, and resources may be needed. The POI fixed-radius graph shows whether nearby local resources form a connected resource network. Connected POI groups can support stronger social nodes, while isolated resources suggest the need for better path connections or additional small programmes.

The path node degree analysis identifies local connection points in the non-motorised network. In graph theory, degree measures how many direct edges are connected to a node. A higher degree value means that more paths meet at that point, such as at intersections, forks, or local access points. These locations are important because they can support route choice, orientation, and small-scale encounter.

Therefore, social nodes are placed where resource dependency, POI concentration, and local path connectivity overlap. In this way, the nodes are not placed randomly, but are informed by the relationship between housing, everyday resources, and the community spine.

Practice References

Figure 45. Parc de la Villette, Paris. Photograph by Nicolas Vigier, CC0 1.0, via Wikimedia Commons.

Parc de la Villette

Parc de la Villette is used as a reference for Cluster 4 because it shows how a large, low-density, and weakly integrated area can be activated through spatial structure rather than through conventional densification. For Design Site, the reference suggests that underused and service-oriented environments can be transformed by creating a clear public framework. The lesson is that activation does not always require high density; it can also be achieved by reorganising spatial relationships and introducing strategic public nodes.

Figure 46. Tingbjerg social housing, Copenhagen. Photograph by seier+seier, licensed under CC BY 2.0, via Wikimedia Commons.

Tingbjerg:

Tingbjerg Regeneration is used as a reference because it addresses a residential environment where the internal neighbourhood structure is relatively stable, but the surrounding green buffers and external interfaces produce spatial separation.For Site, this supports a design approach based on preserving existing buildings, improving connectivity, and turning forest edges into usable community resources.

7.3 Intervention Measures And Design Strategies

Function–Space Translation

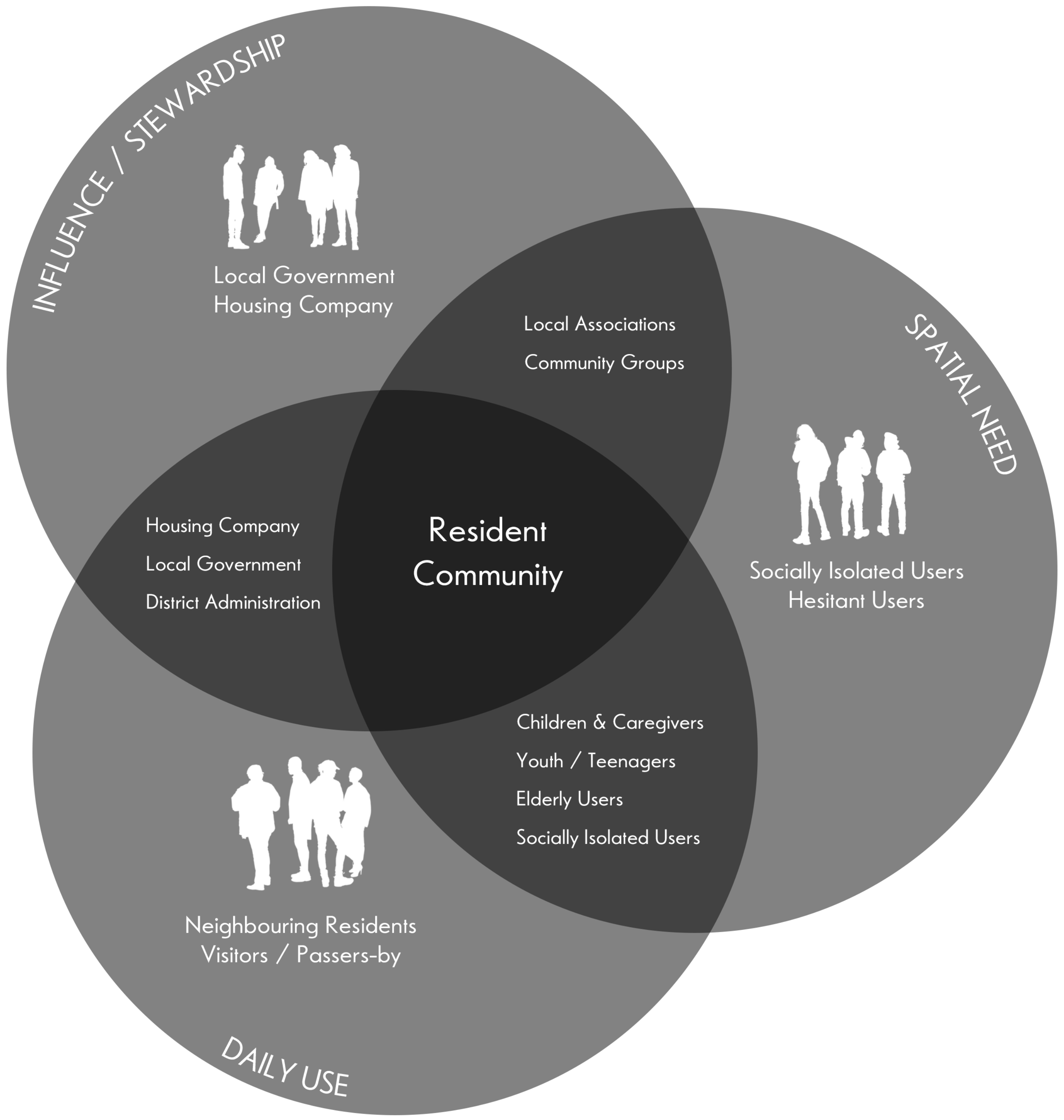
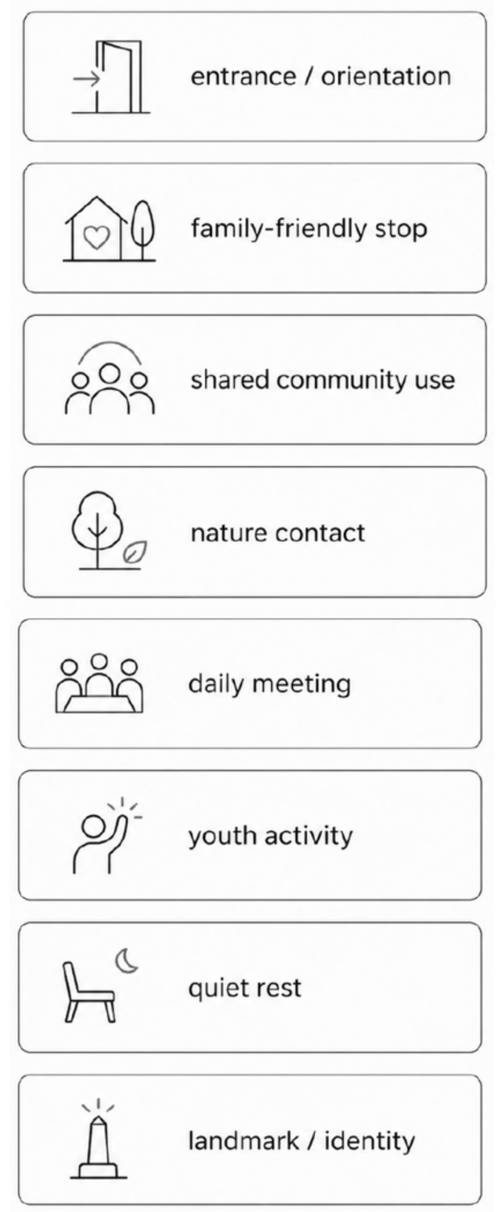


Figure 47. Function–space translation diagram. Produced by author, 2026.

"Function - Space List"

Necessary functions



- Entrance / Orientation
- Daily Meeting
- Family-Friendly Stop
- Youth Activity
- Shared Community Use
- Quiet Rest
- Nature Contact
- Small Landmark / Identity Element

This diagram translates the site analysis into a function–space list. The proposed programme is not based only on new facilities, but on the overlap between three needs: daily use, spatial need, and influence / stewardship. At the centre is the resident community, supported by children, elderly users, socially isolated users, neighbouring residents, local associations, housing actors, and public stakeholders. The resulting functions therefore focus on everyday accessibility, informal encounter, shared use, nature contact, and small identity elements. These functions become the basis for arranging the community spine and social nodes in the following design proposal.

Figure 48. Visibility and social capacity analysis of Site 4. Produced and annotated by author, 2026.

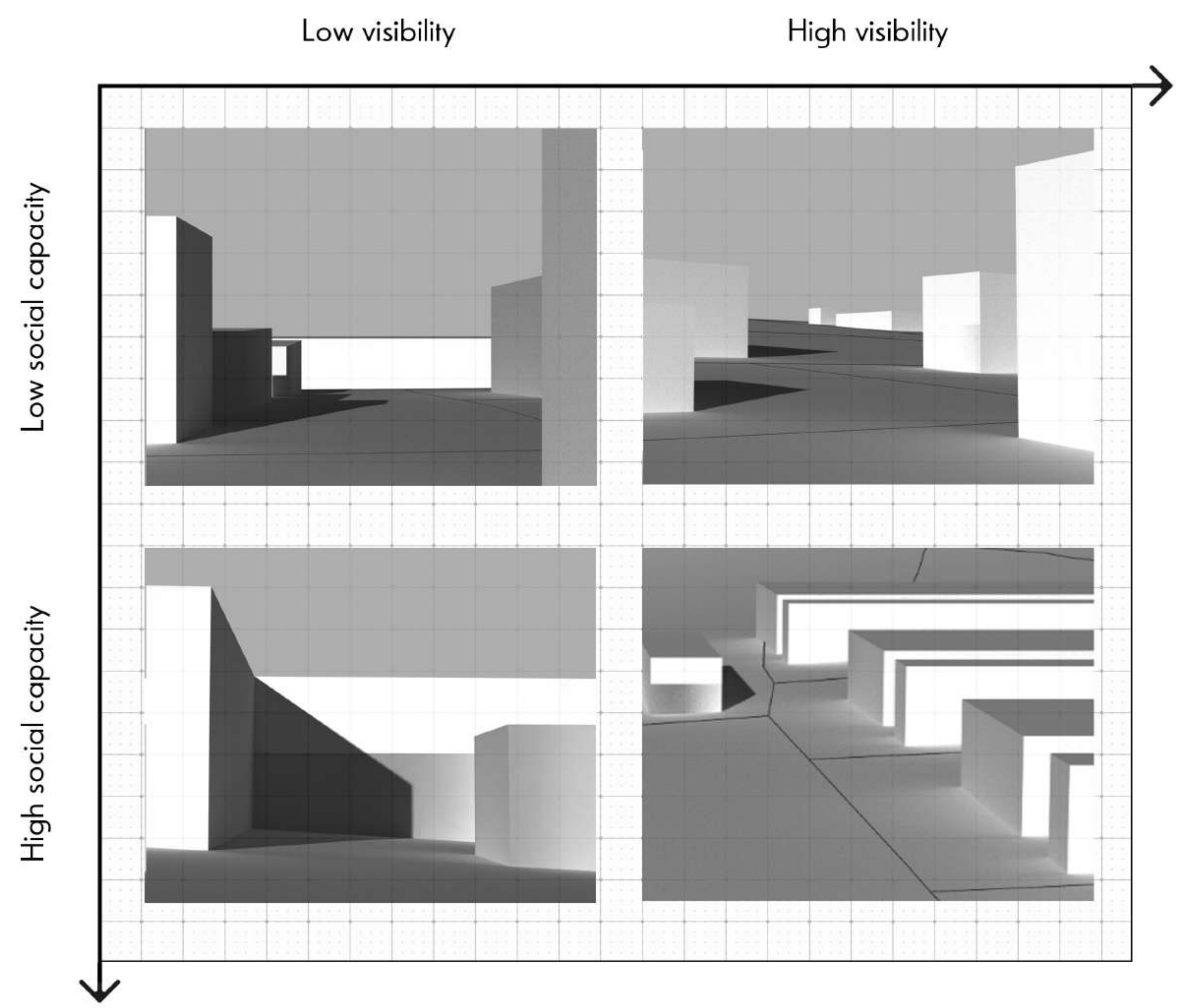


Figure 49. Function–space matrix based on visibility and social capacity. Produced by author, 2026.

The site is further interpreted through the relationship between visibility and social capacity. By combining these two dimensions, the site can be divided into different spatial conditions: hidden and quiet pockets, visible but low-capacity edges, enclosed social spaces, and open areas with stronger collective potential. This reading helps translate the existing spatial structure into design rules. Highly visible areas with stronger social capacity are suitable for community nodes, shared activities, and orientation points. Low-visibility areas are more suitable for quiet rest, framed views, or small-scale thresholds. In this way, the design does not apply the same programme everywhere, but matches each intervention to the spatial character of the site.

"Function - Space List"

Necessary space

- threshold
- elevated or terrain-based platform
- open clearing
- semi-enclosed pocket
- edge spaces
- framed corridor / view

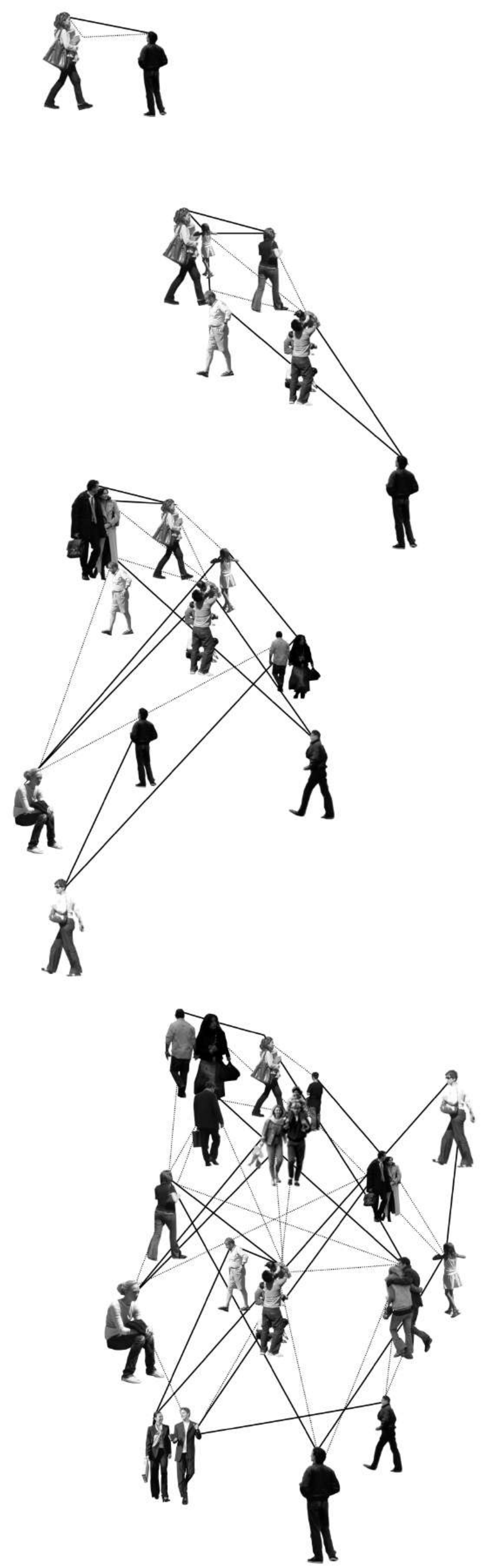


Figure 50. Sight design concept diagram. Produced by author, 2026.

"Sight Design" Principles Explanation

Sight design is introduced as an indirect anti-isolation strategy for Site 4. The aim is not to claim that visibility alone can solve social isolation, but to use visual connection as a spatial tool to support encounter, perceived safety, and everyday public use. In the existing site, many spaces are physically close to one another, but they are not always visually connected or easy to understand. Paths, entrances, forest edges, and shared spaces can therefore feel fragmented, hidden, or uncertain.

By strengthening lines of sight, the design makes the spatial structure more readable. Clear views towards entrances, activity nodes, and landscape edges help people understand where they are, where they can go, and where other people may be present. This can increase natural surveillance and reduce the feeling of being isolated in unclear or leftover spaces. Sight design therefore becomes a way to transform physical proximity into perceived connection.

In the design proposal, this principle is applied through framed views, opened thresholds, semi-transparent edges, and carefully positioned community nodes. These elements allow movement routes, public spaces, and residential edges to visually support one another. In this way, sight design connects the analytical findings with spatial intervention: it turns hidden or weakly perceived relationships into visible, legible, and socially supportive places.

Decision-Making Diagram

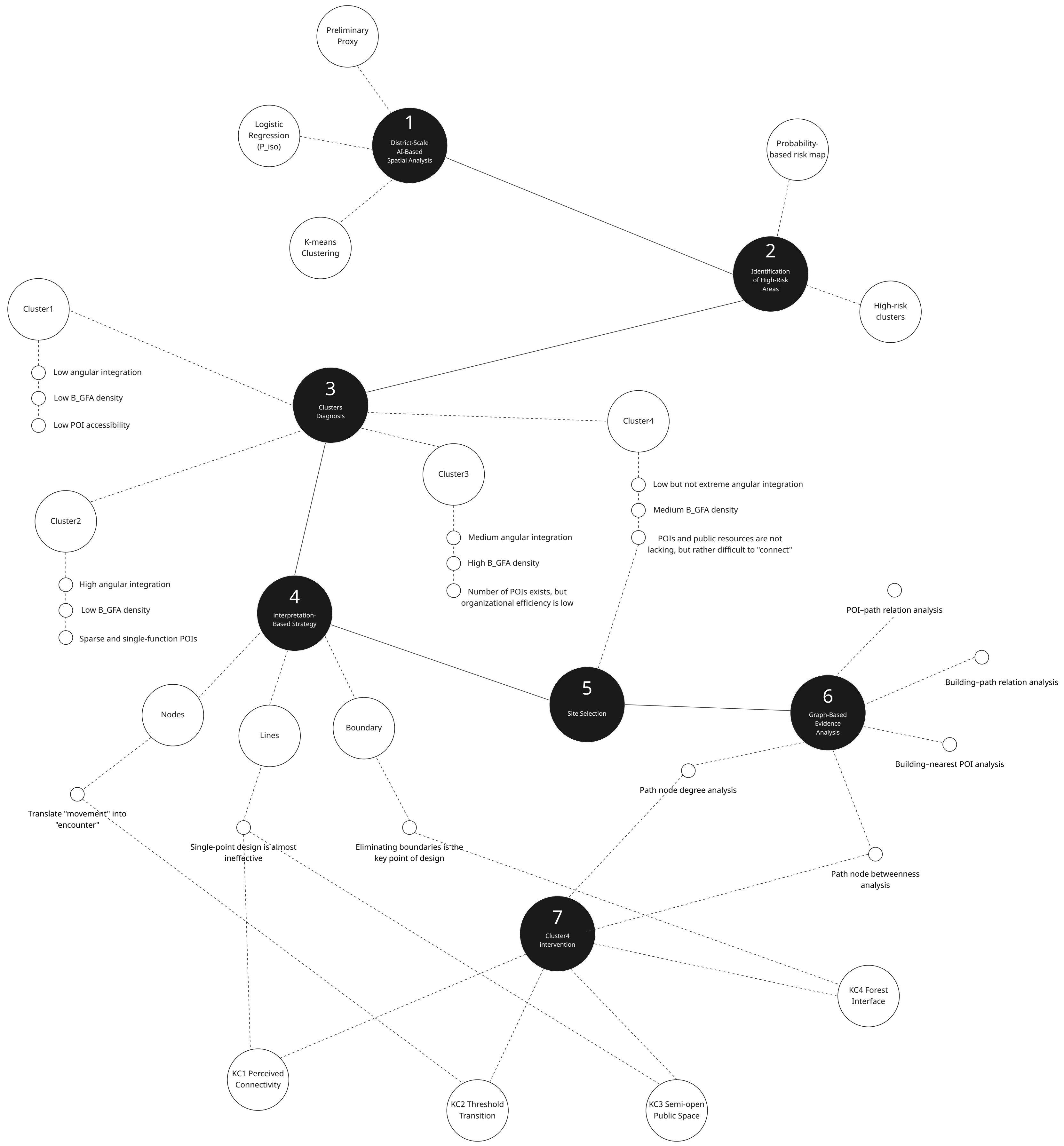


Diagram 1. Decision-making diagram from AI-based spatial analysis to Site 4 design translation. Produced by author, 2026.

From Spatial Analysis To Design Strategy

This diagram clarifies how the cluster-based analysis is translated into design strategies. The AI-based analysis first identifies high-risk areas through the P_iso risk map, and then uses K-means clustering to classify these high-risk areas into different spatial types. Each cluster is diagnosed through the variables that contribute to high-risk conditions: angular integration, B_GFA density, and POI accessibility. Therefore, the clusters are not treated only as different locations, but as different spatial mechanisms of structural isolation.

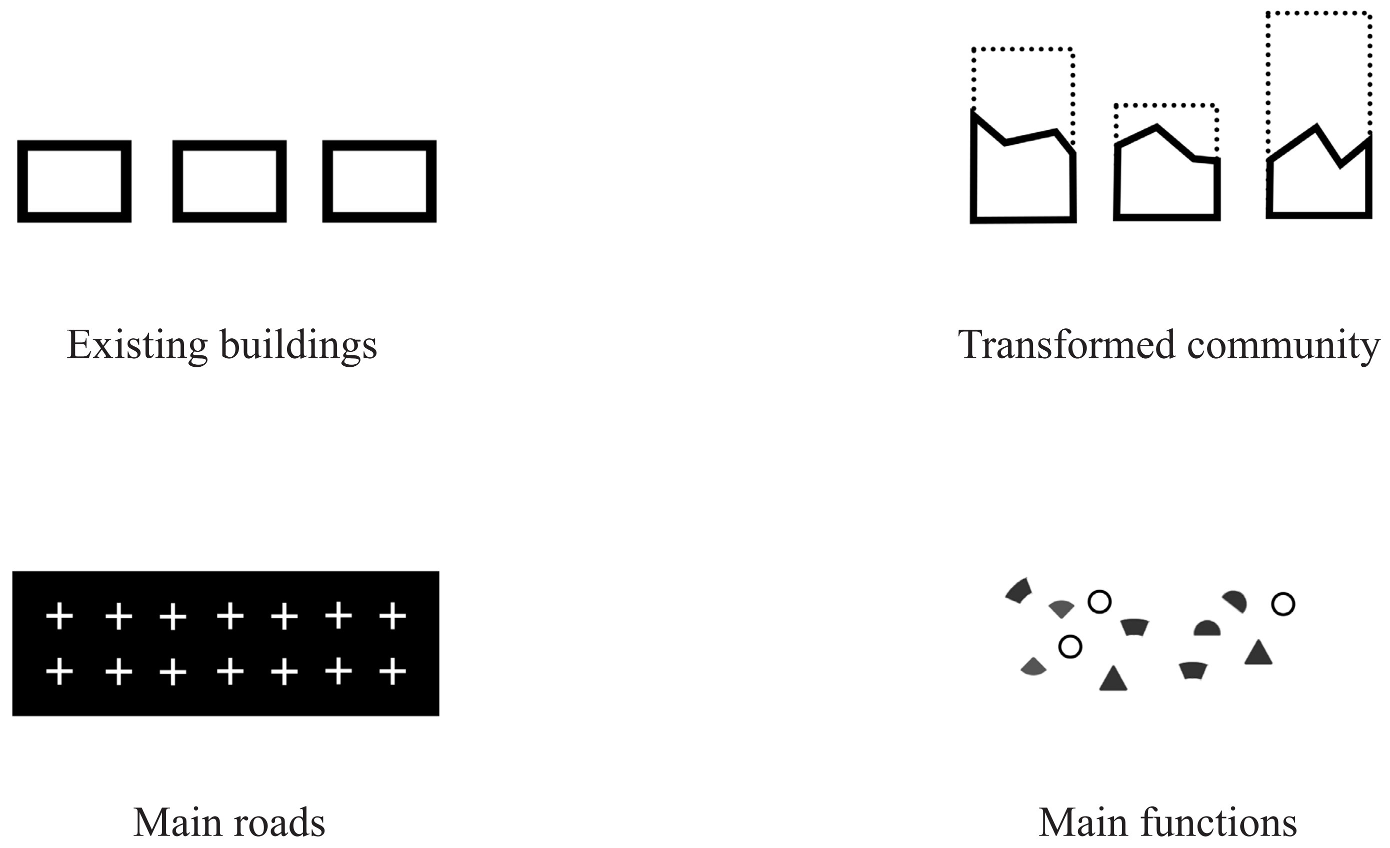
The interpretation-based strategy responds to these mechanisms through three design directions: line, node, and boundary. The line strategy addresses problems of weak integration and fragmented movement by improving connectivity and spatial continuity. The node strategy addresses low density, weak activity capacity, or insufficient everyday social anchors by creating places for encounter and shared use. The boundary strategy addresses unclear edges and disconnected interfaces by transforming passive boundaries into active spatial connections.

For Site 4, the selected condition is Cluster 4, where the problem is not a complete lack of buildings, POIs, or public resources. Instead, the analysis shows that resources are present but difficult to connect: angular integration is low but not extreme, B_GFA density is medium, and POIs exist but are not organised into a clear everyday structure. Therefore, the Site 4 design does not simply add new facilities. It develops the Cluster 4 strategy through four key concepts: perceived connectivity, threshold transition, semi-open public space, and forest interface. These interventions translate the general line, node, and boundary strategies into site-specific design actions.

In this way, the design proposal is linked back to the cluster-based analysis. The community spine responds to weak integration, social nodes respond to underused POI and public resources, and threshold/interface interventions respond to fragmented spatial boundaries. The diagram therefore shows that the Site 4 design is not an independent design proposal, but an elaboration of the diagnosed Cluster 4 mechanisms.

Concept Generation

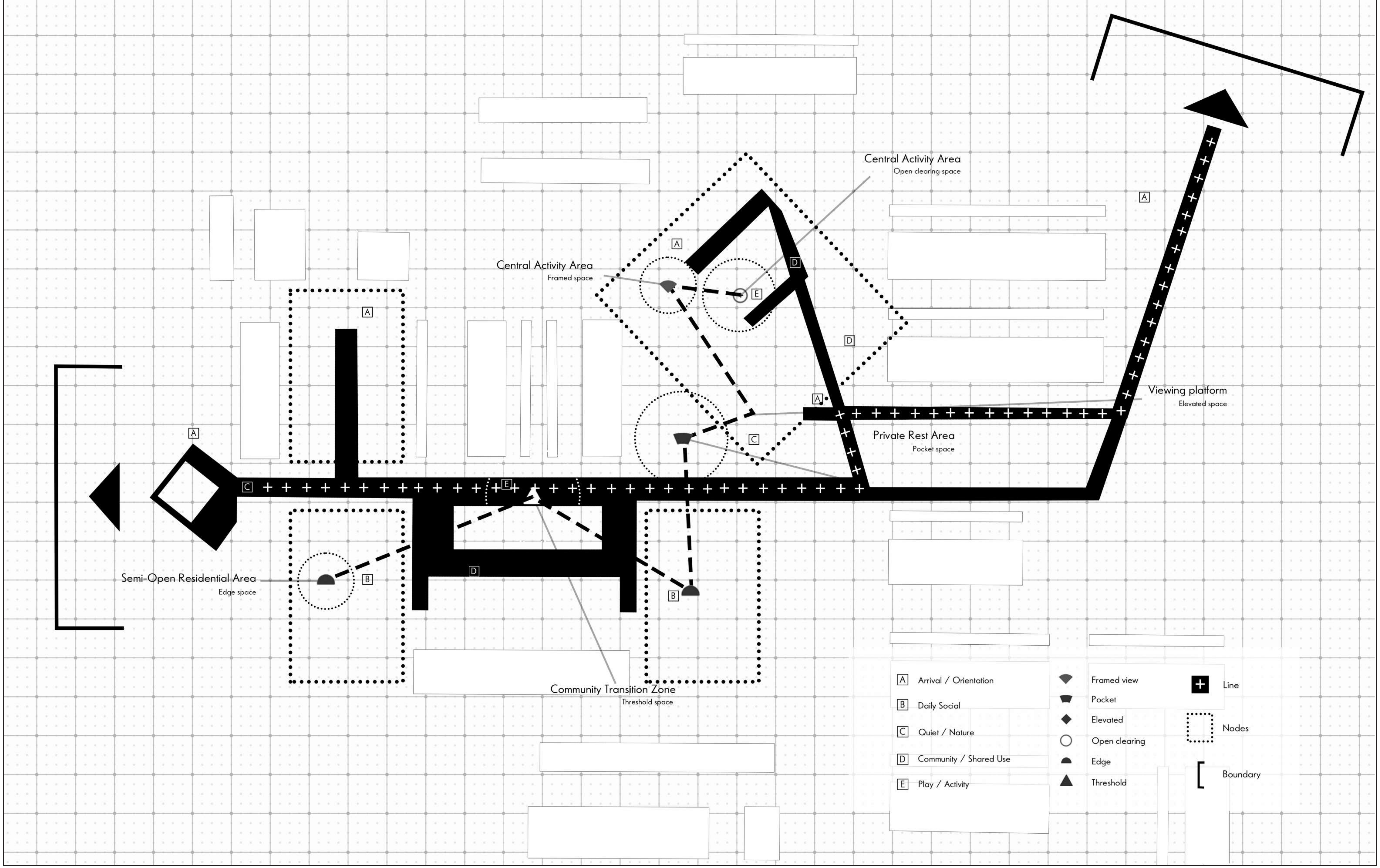
Diagram 2. Conceptual diagram of spine. Produced by author, 2026.



From Point To Line

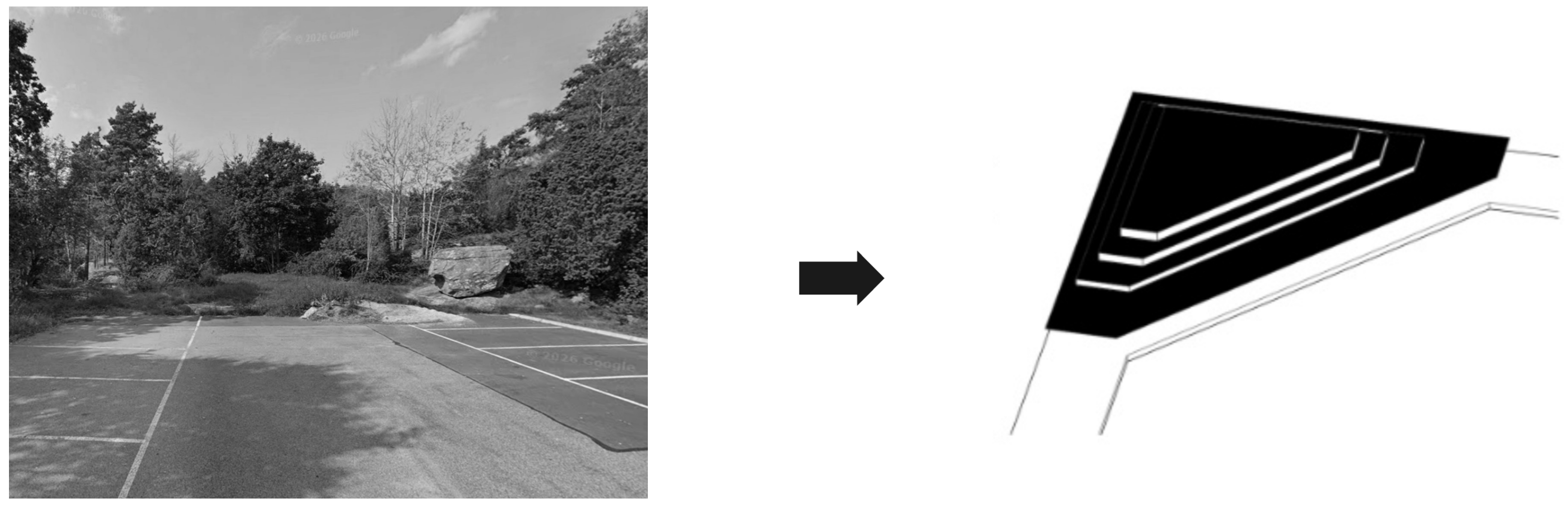
The community spine is generated as the main spatial device that translates the analytical findings into the site-specific design proposal. The Cluster 4 diagnosis shows that Site 4 does not completely lack resources, but lacks a clear everyday structure to connect housing, paths, POIs, public spaces, and forest edges. The graph-based analysis further identifies path sequences, connection points, and resource relations with stronger design potential. Based on this evidence, the spine is developed through four design actions: connect, organise, activate, and transform. It connects existing resources, organises movement continuity, activates key social nodes, and transforms weak residential and forest edges into semi-open social interfaces. In this way, the spine becomes the main structure through which movement, encounter, and everyday public life are reconnected.

Concept Generation



KC1. PERCEIVED CONNECTIVITY

Site 4 is not only challenged by insufficient physical connectivity, but also by weak perceived connectivity. Although several paths, nodes, and destinations already exist, they are not always visible, legible, or easy to understand from everyday movement routes. This makes the area feel fragmented even when spatial connections are present. The design therefore strengthens framed views, visual corridors, and aligned openings, so that routes, activities, and destinations become more recognisable and easier to follow.



Design Strategies

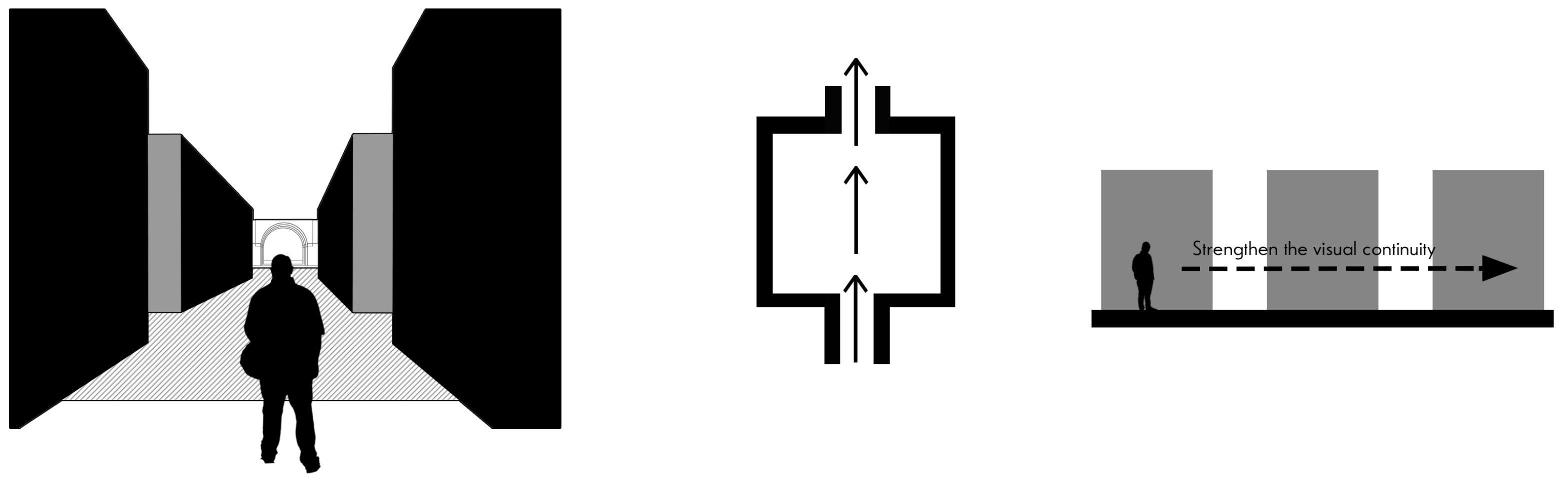


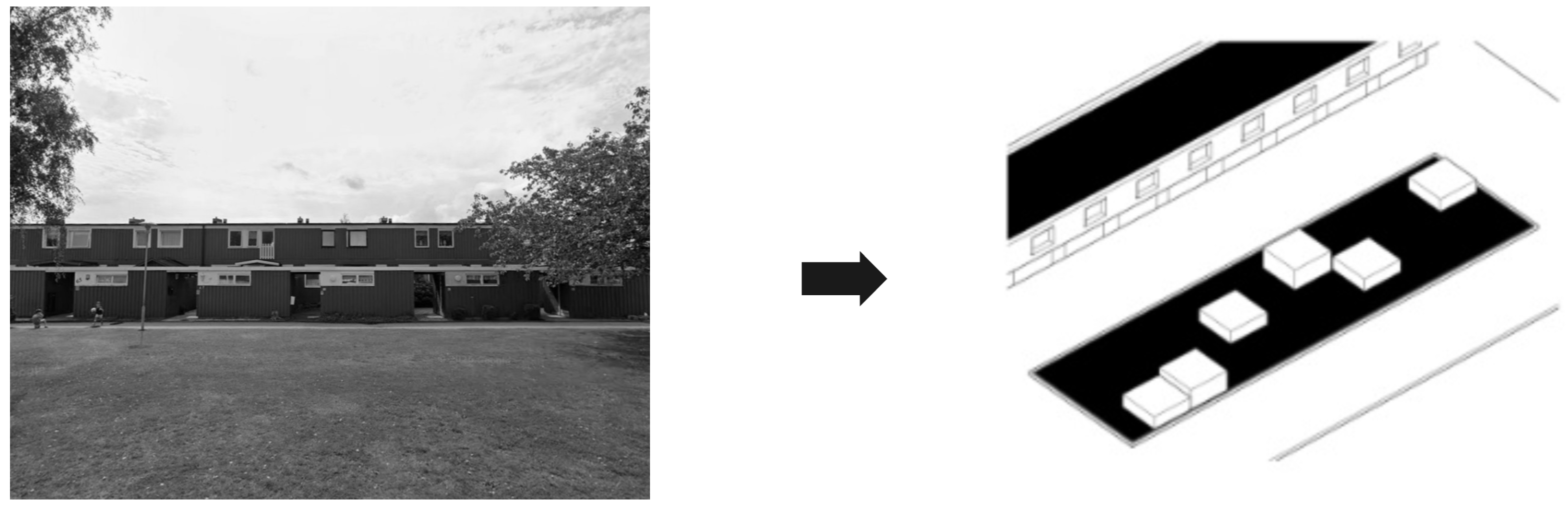
Figure 51. Diagram of sight-based design strategies. Produced by author, 2026.

DS1.1 Use framed views, visual corridors, and aligned openings to make routes and destinations more perceivable.

DS1.2 Strengthen the visual continuity of the spine so that movement is guided by visible sequences rather than abstract circulation

KC2. THRESHOLD TRANSITION

Thresholds are used to create softer transitions between private housing, shared circulation, public nodes, and landscape spaces. Instead of treating public space as something that is suddenly entered or passed through, the design introduces gradual changes in enclosure, surface, façade articulation, and spatial depth. These threshold conditions help residents move from familiar private environments into shared spaces with less psychological pressure, supporting a more comfortable and inclusive form of public life.



Design Strategies

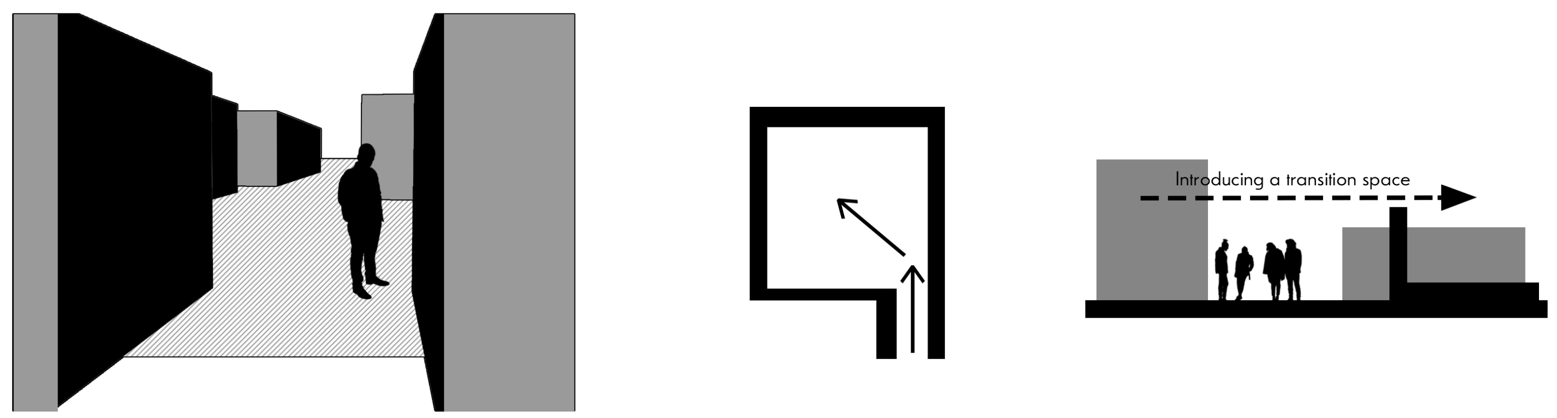


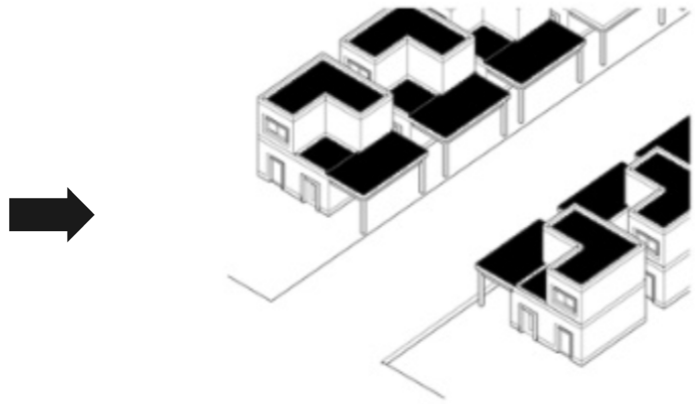
Figure 52. Diagram of sight-based design strategies. Produced by author, 2026.

DS2.1 Introduce threshold spaces between private housing, shared circulation, and public nodes.

DS2.2 Use changes in depth, enclosure, paving, and facade articulation to turn transition into spatial experience.

KC3. SEMI-OPEN PUBLIC SPACE

The existing residential edges are relatively closed, which weakens visual exchange between indoor life, outdoor spaces, and public routes. The design introduces semi-open interfaces to transform these edges from barriers into social filters. More windows, porches, covered spaces, buffer zones, and semi-open elements allow observation, informal contact, and everyday staying without forcing direct interaction. This creates a more gradual relationship between inside and outside, supporting both privacy and social presence.



Design Strategies

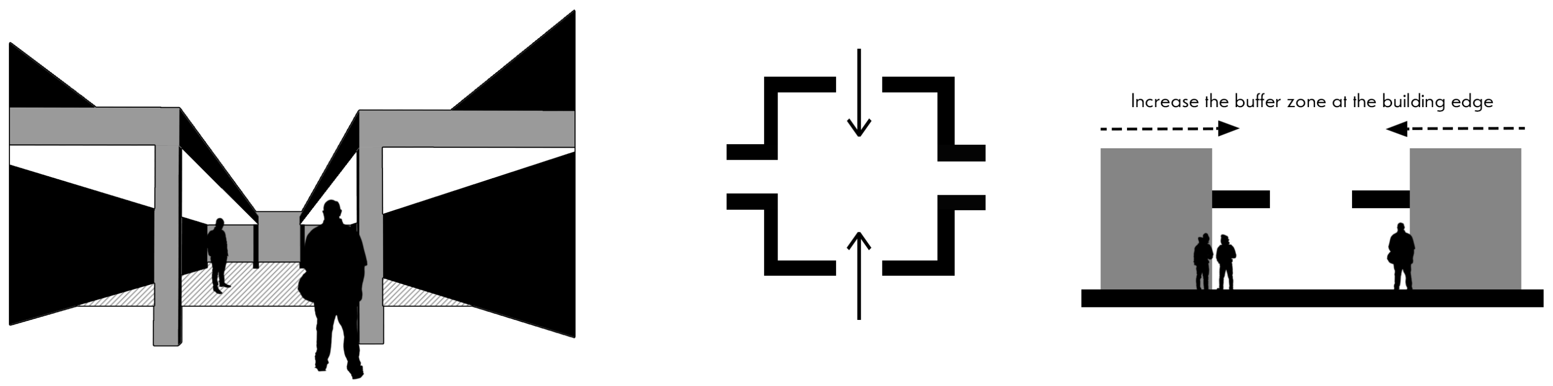


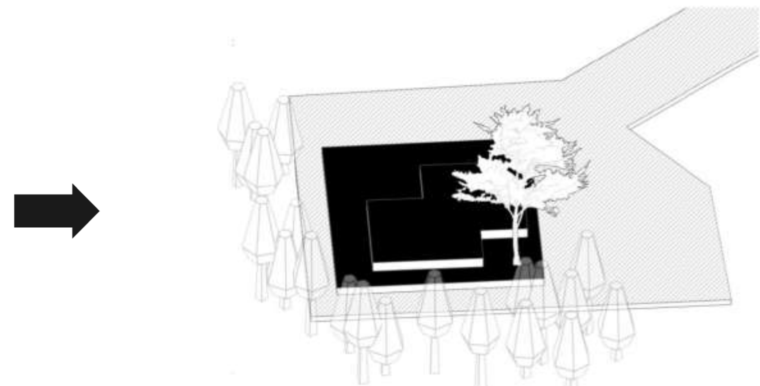
Figure 53. Diagram of sight-based design strategies. Produced by author, 2026.

DS3.1 Open up facades with more windows and semi-open elements to increase visual exchange between indoor and outdoor spaces.

DS3.2 Transform closed building edges into socially active interfaces through porches, covered spaces, and buffer zones.

KC4. FOREST INTERFACE

The surrounding forest is currently more often experienced as a boundary than as an everyday community resource. The design reinterprets the forest edge as social infrastructure, integrating paths, outlooks, quiet nodes, framed views, and small activity spaces into the landscape edge. In this way, nature is no longer only a backdrop or barrier, but becomes part of the social structure of the site. The forest edge supports rest, encounter, orientation, and ecological contact within the community spine.



Design Strategies

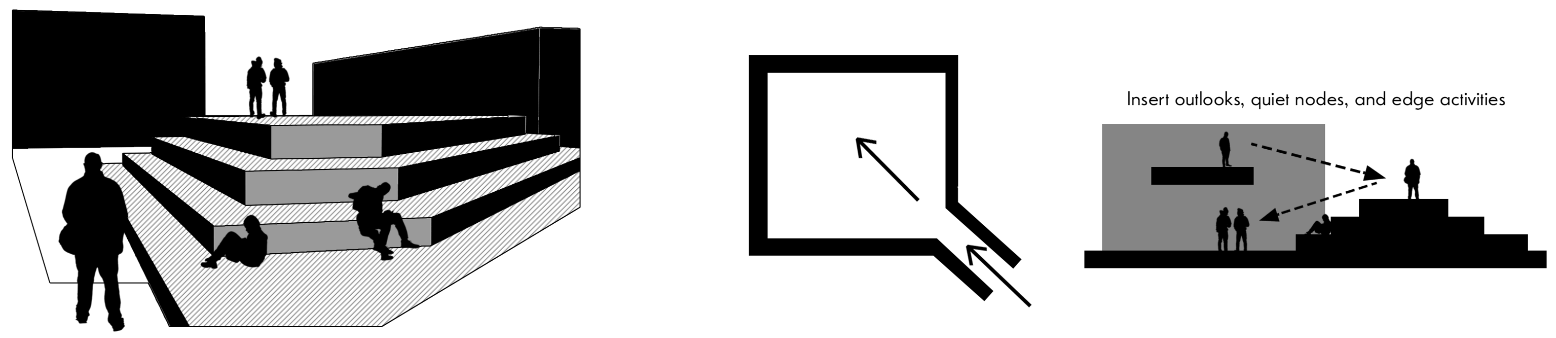


Figure 54. Diagram of sight-based design strategies. Produced by author, 2026.

DS4.1 Reconfigure the forest edge as a permeable and readable interface rather than a residual green barrier.

DS4.2 Insert outlooks, framed views, quiet nodes, and edge activities to make each part of the social structure of the site.

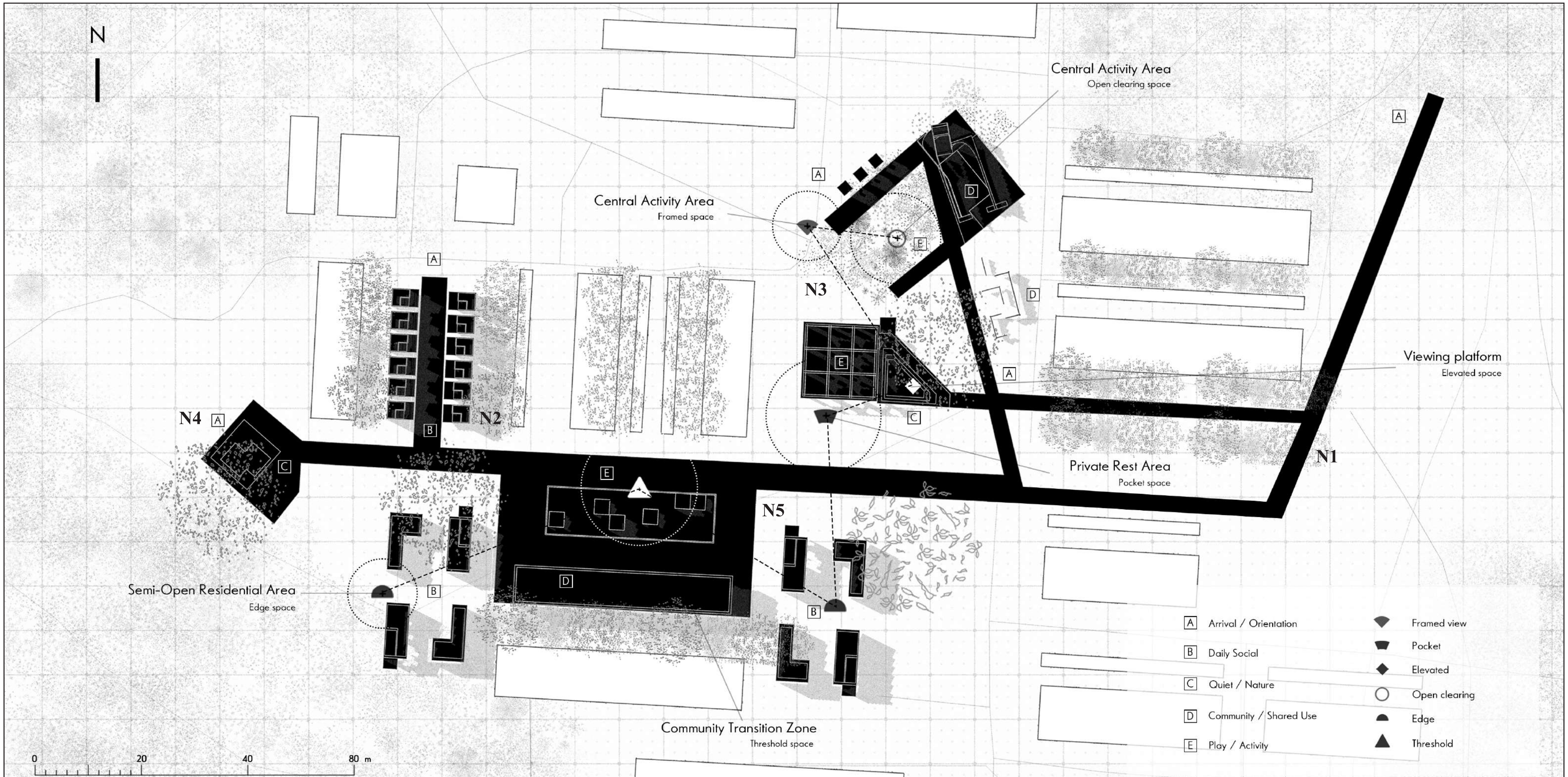


Figure 55. Overall design proposal plan for Site 4. Produced by author, 2026.

N1 Community Gateway

Function: Arrival + Shared Use
Space: Framed view + elevated

- Community Marker
- Bike Stop
- Meeting Point
- Light / Sign / Map

N2 Daily Meeting Node

Function: Daily Social
Space: Semi-enclosed + Edge

- Bench Cluster
- Shared Table
- Doorstep Terrace
- Planter / Small Garden
- Tiny Play Element

N3 Active Node

Function: Play / Activity
Space: Open

- Play Field
- Flexible Lawn
- Youth Platform
- Exercise Point
- Event Edge

N4 Forest Outlook Deck

Function: Quiet / Private
Space: Framed + Elevated Edge

- Overlook
- Quiet Deck
- Sitting Edge
- Nature Learning Point
- Rain Garden

N5 Social Threshold Node

Function: Daily Social + Orientation
Space: Threshold + Pocket + edge

- Lighting
- Sealing
- Small Shared Facility
- Highly Recognizable
- Small Structure

DESIGN PROPOSAL

This axonometric drawing presents the overall design proposal for Site 4. The project reorganises the existing residential area through a continuous community spine, connecting scattered entrances, shared spaces, landscape edges, and public nodes into one readable spatial sequence. The black elements indicate the main design interventions: new shared nodes, activated ground spaces, semi-open interfaces, and forest-edge platforms. These elements strengthen visual connection, slow down movement, and create more opportunities for everyday encounter. Through this structure, the site is transformed from a fragmented residential enclave into a more connected community environment where paths, buildings, and landscape support one another.

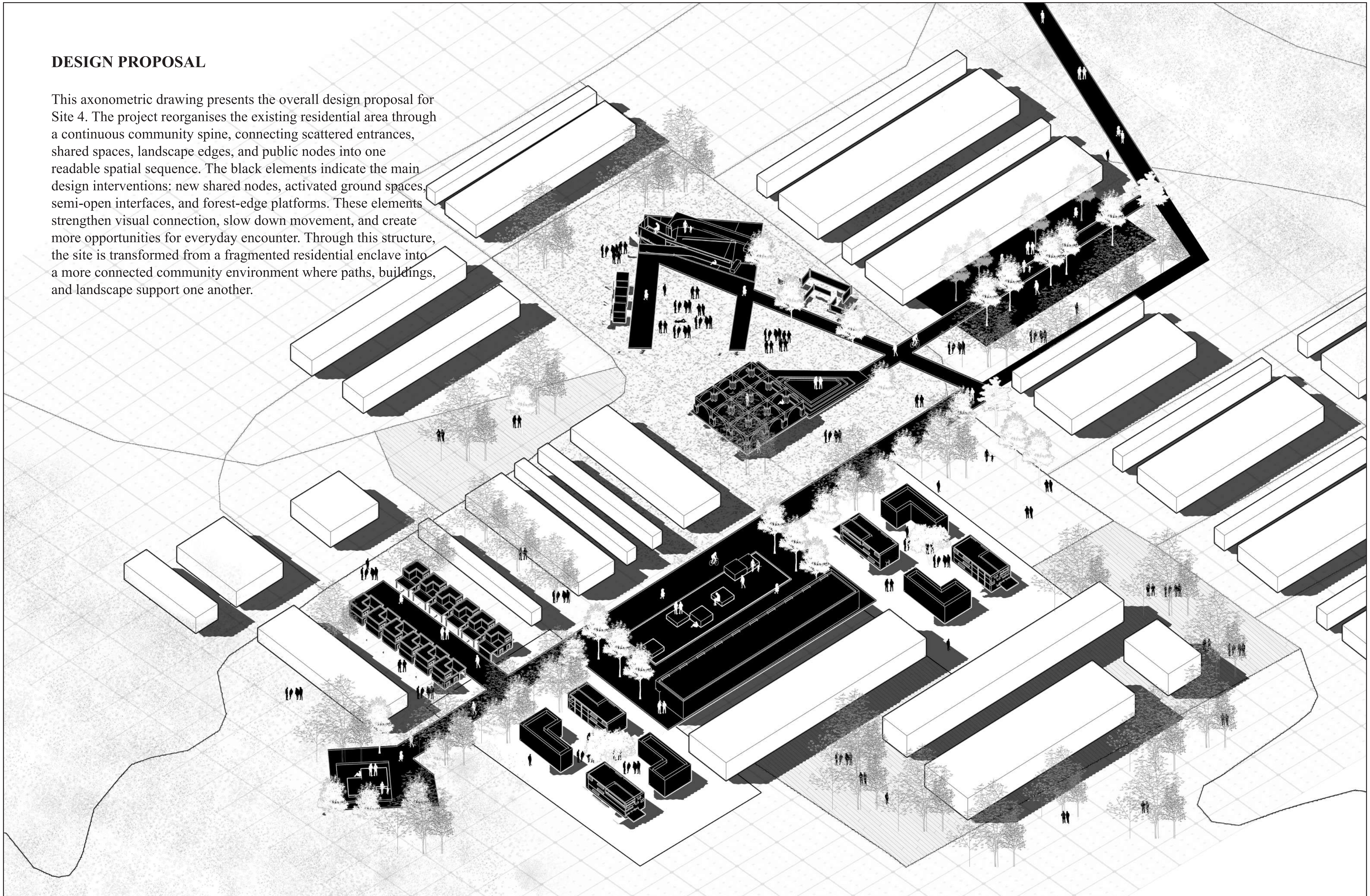


Figure 56. Overall design proposal axonometric drawing for Site 4. Produced by author, 2026.

THE RHYTHM AND TRANSITION OF SIGHT

This section drawing explains how the community spine works across different spatial conditions. The proposal does not treat the spine as a single uniform path, but as a sequence of thresholds, social edges, pocket spaces, and forest interfaces. Each segment responds to a different level of visibility, enclosure, and social capacity.

From the residential side to the forest edge, the design creates gradual transitions between private housing, shared outdoor space, and public landscape. Semi-open residential interfaces increase visual exchange between homes and public routes. Framed gateways and active pockets provide small places for meeting and staying, while forest outlooks and quiet thresholds turn the landscape edge into an everyday community resource. Together, these elements transform movement through the site into a more readable and socially supportive spatial experience.

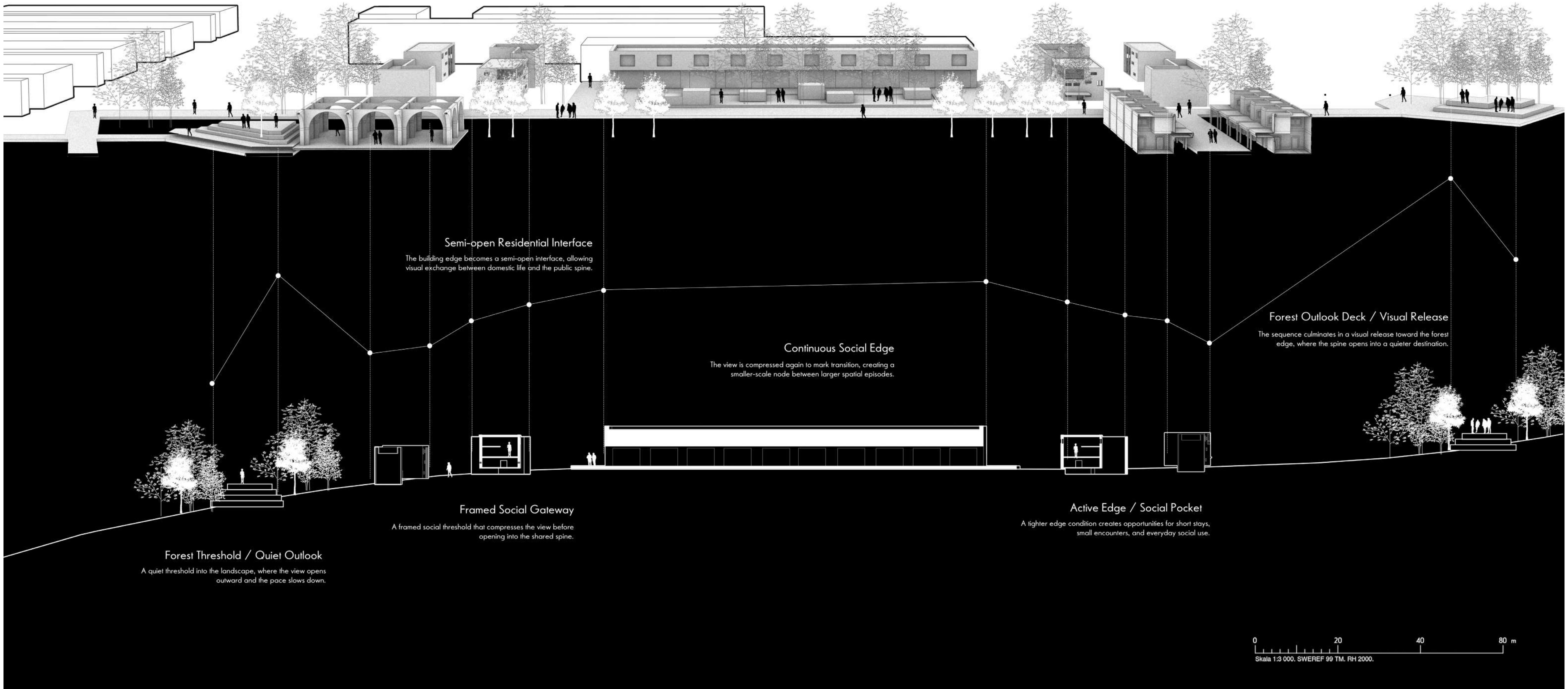


Figure 57. Section drawing showing the rhythm and transition of sight along the community spine. Produced by author, 2026.

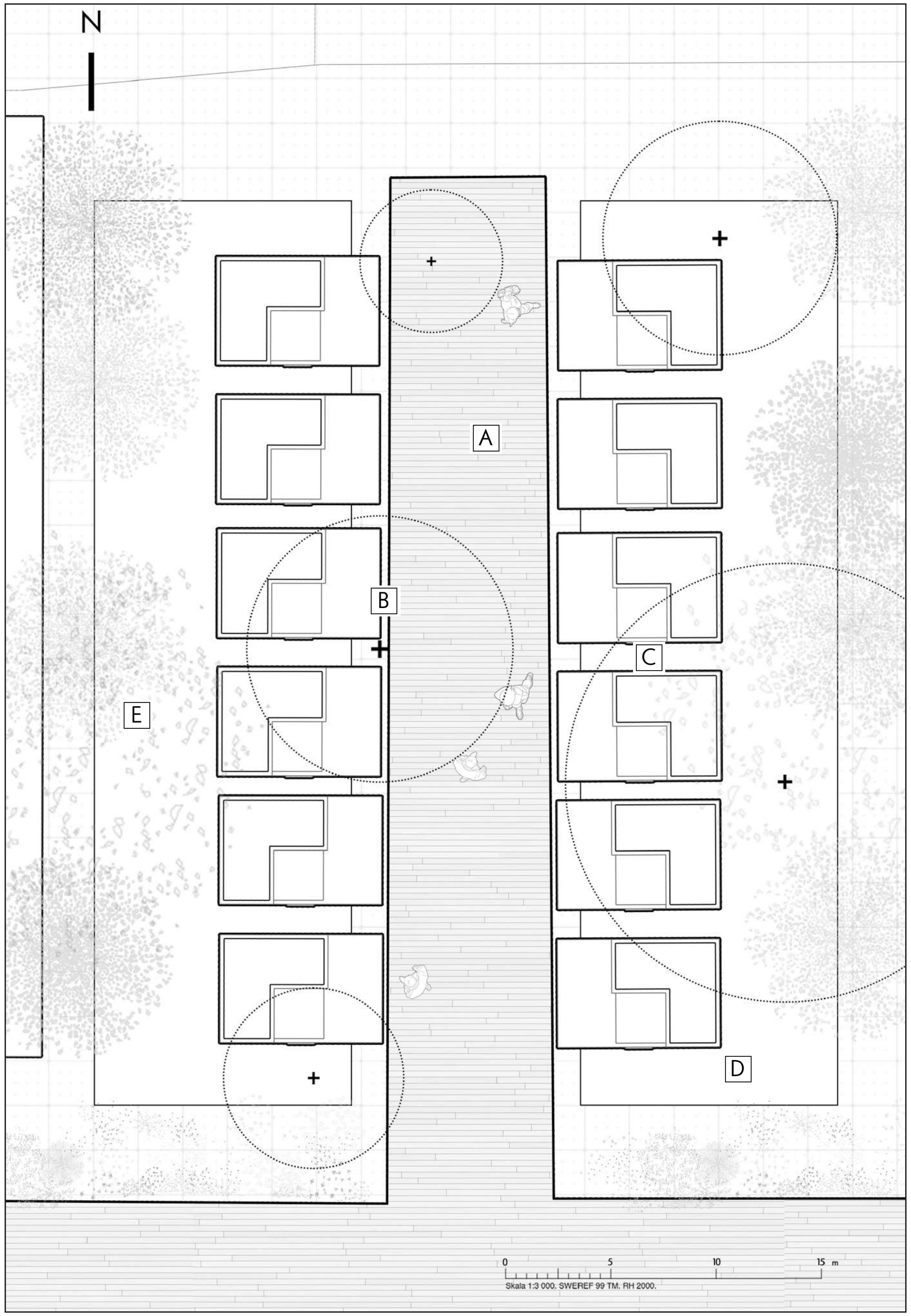


Figure 58. Detailed plan of the residential interface along the community spine. Produced by author, 2026.

A Central visual corridor - Central visual corridor for legibility and orientation.

B Repeated semi-open interfaces - Semi-open residential interfaces support observation, contact, and everyday visibility.

C Gradual transition from private to shared - A softer threshold between private units and shared space

D Low-threshold social edge - Facing edges create a daily social field rather than isolated front doors.

E Balance between openness and enclosure - Open enough for visibility, enclosed enough for shared use.

Figure 59. Residential interface strategy diagram. Produced by author, 2026.

This page shows the detailed spatial organisation of the residential interface along the community spine. The existing housing blocks are kept, while the space between them is restructured into a clearer shared corridor. The central path becomes a visual and social spine, supporting orientation, everyday movement, and informal encounter.

The repeated semi-open interfaces along both sides create a softer relationship between private homes and shared outdoor space. Instead of treating the housing edges as closed backs, the design introduces thresholds, small pockets, and visual openings that allow residents to observe, enter, and use the shared space more naturally. The aim is to balance openness and enclosure: open enough to improve visibility and connection, but enclosed enough to support comfort, safety, and local belonging.

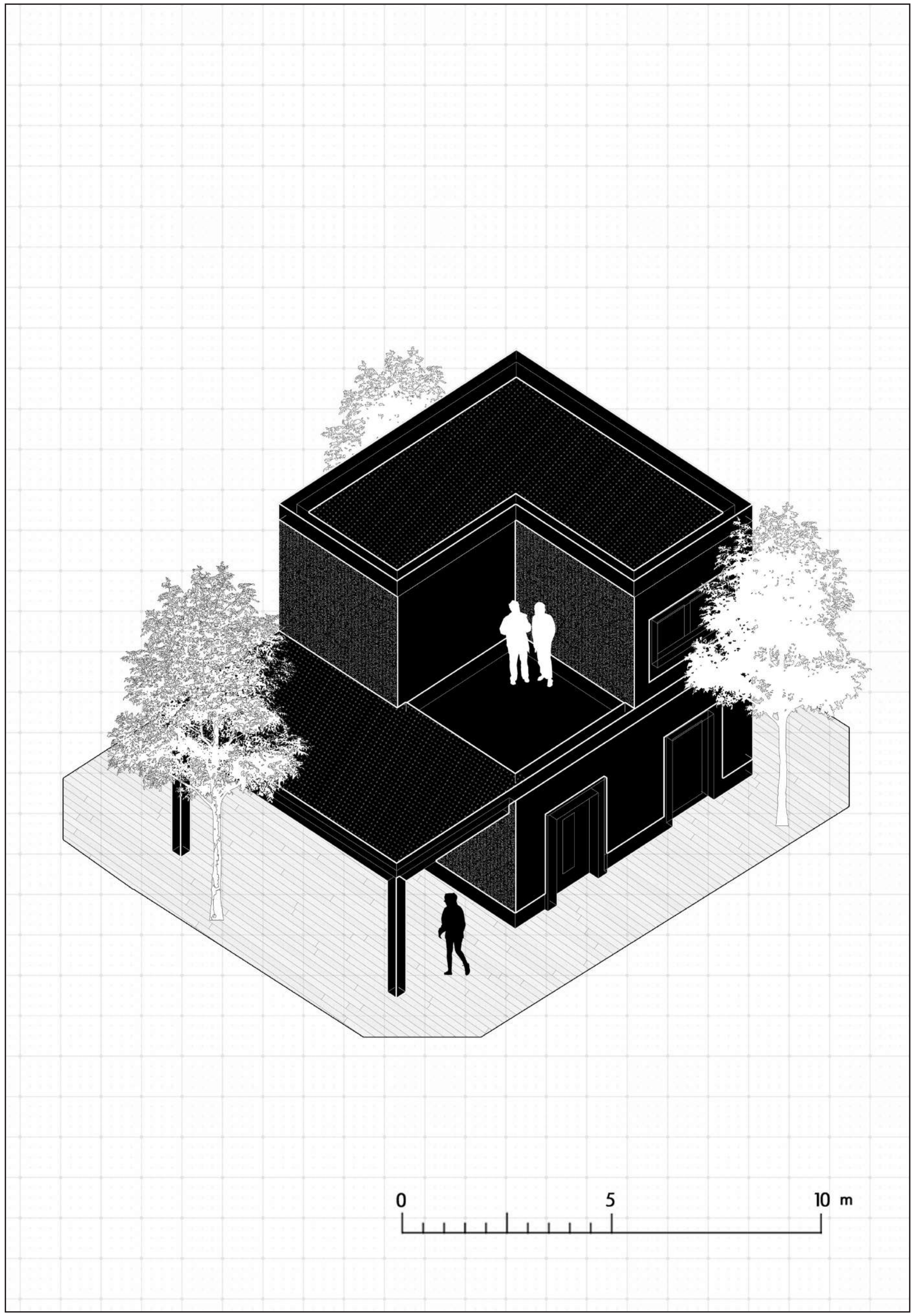


Figure 60. Building-scale axonometric drawing of the semi-open residential interface. Produced by author, 2026.

- This page develops the semi-open residential interface at the building scale. The proposal keeps the existing housing logic, but adds a small transitional layer between the private interior and the shared outdoor space. This layer works as a porch, balcony, or covered threshold, allowing residents to observe, pause, and enter the public spine more gradually.

- The aim is to avoid a direct contrast between private rooms and open public space. Instead, the semi-open interface creates a softer social edge: visible enough to support safety and everyday contact, but protected enough to maintain privacy and comfort. Through this small architectural adjustment, the housing block becomes more connected to the community spine and contributes to the social life of the site.

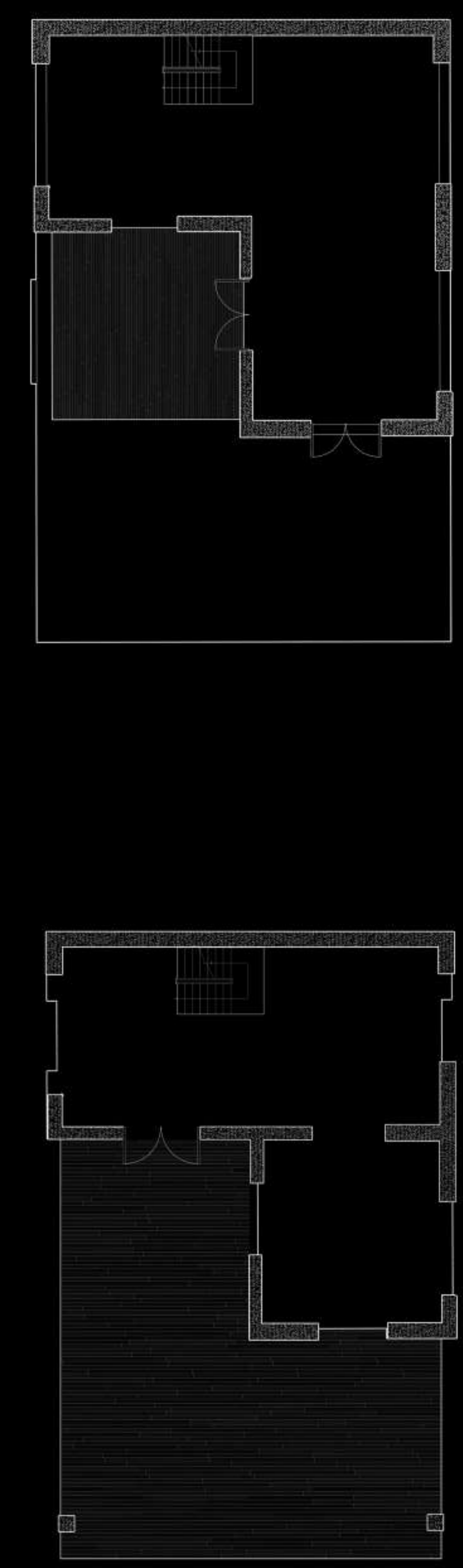


Figure 61. Plan diagrams of the semi-open residential interface strategy. Produced by author, 2026.

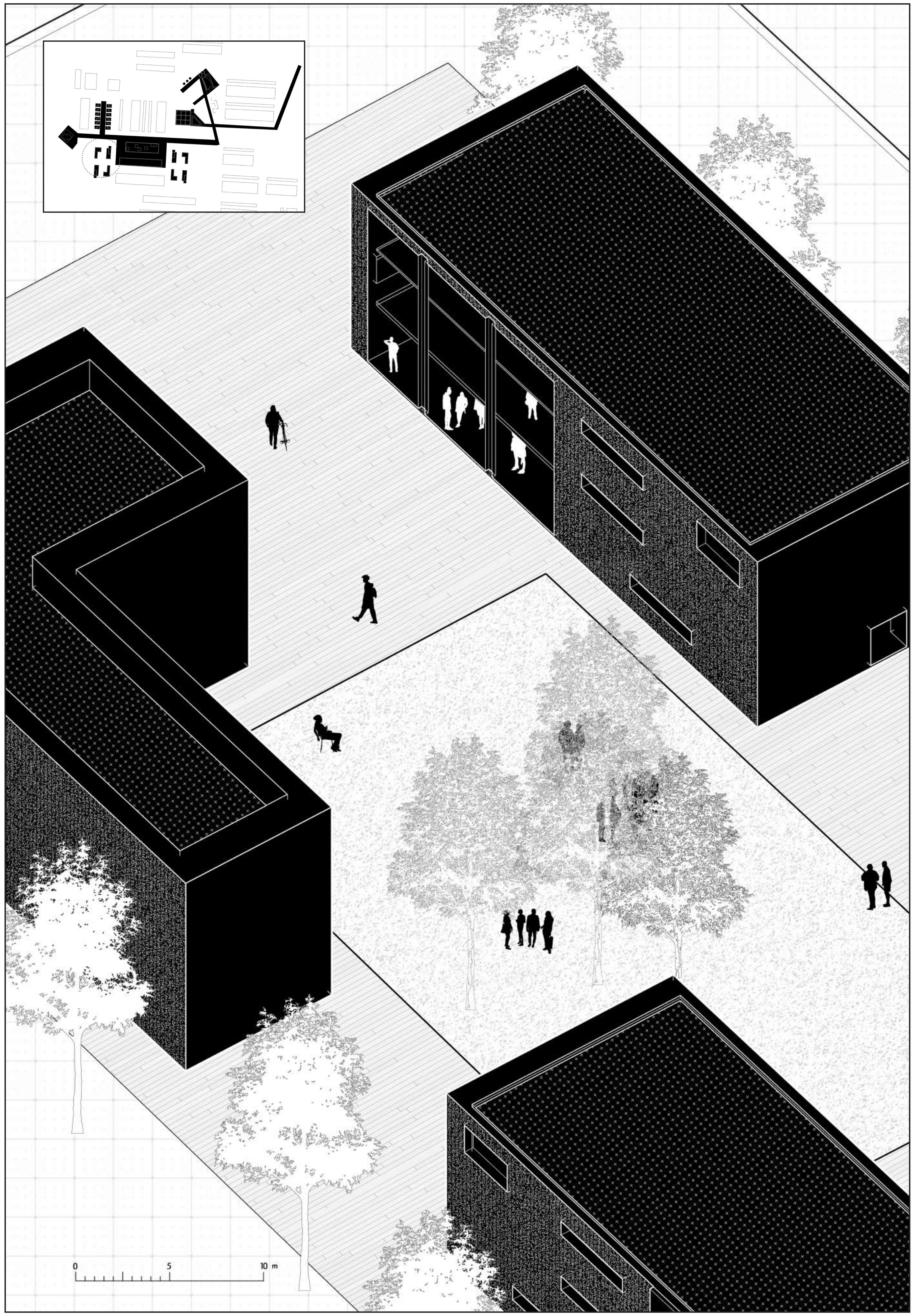


Figure 62. Axonometric drawing of the semi-enclosed residential block arrangement. Produced by author, 2026.

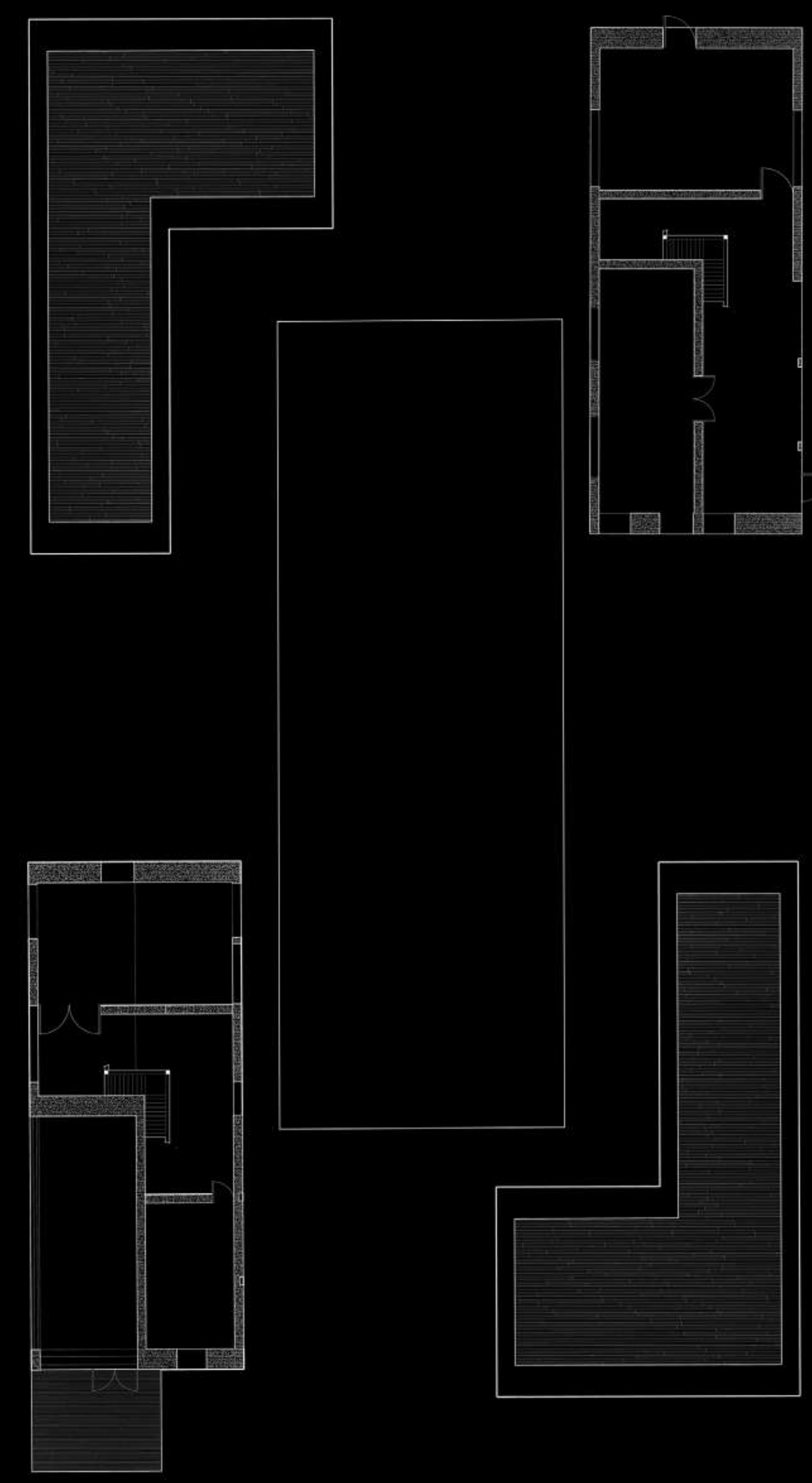


Figure 63. Plan diagram of the residential block arrangement. Produced by author, 2026.

- This block arrangement is designed to create a clearer relationship between housing, shared space, and movement. Instead of placing buildings as isolated objects, the blocks are organised around a semi-enclosed communal courtyard. This creates a central shared space that is visible from different sides and naturally connected to the community spine.

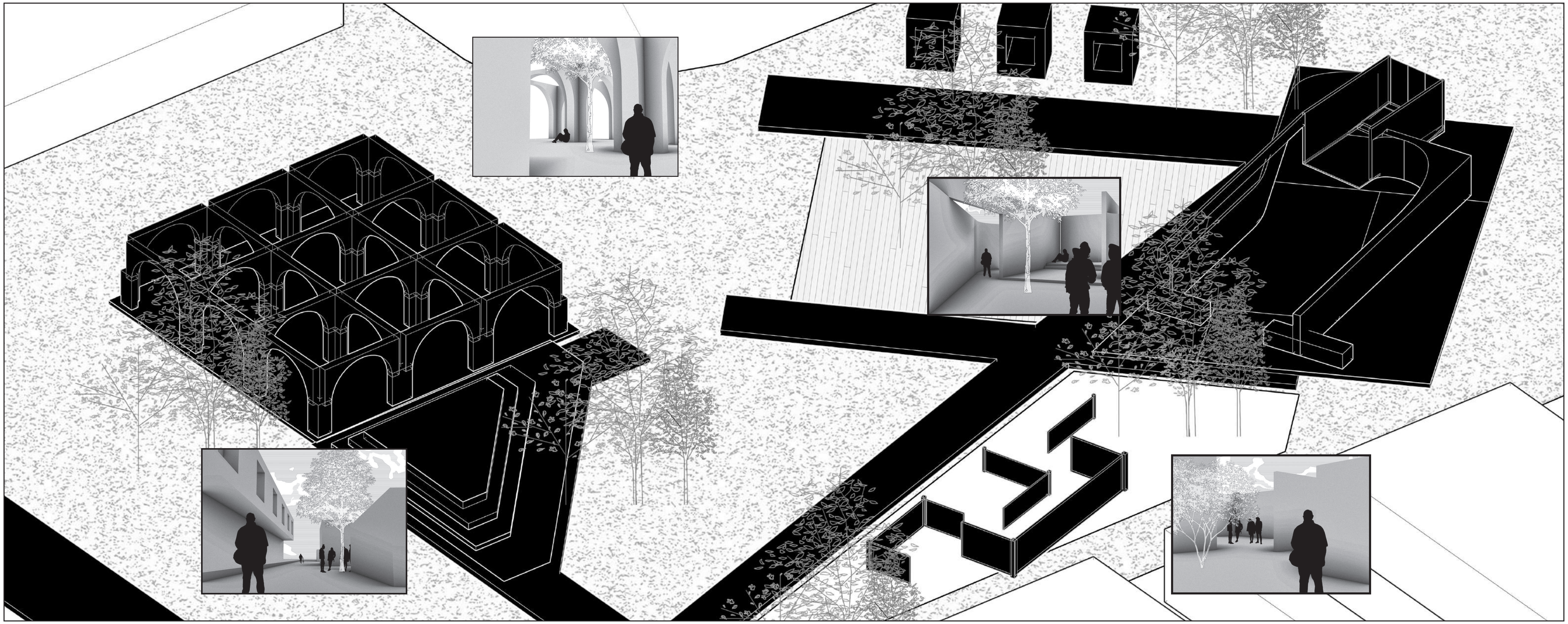
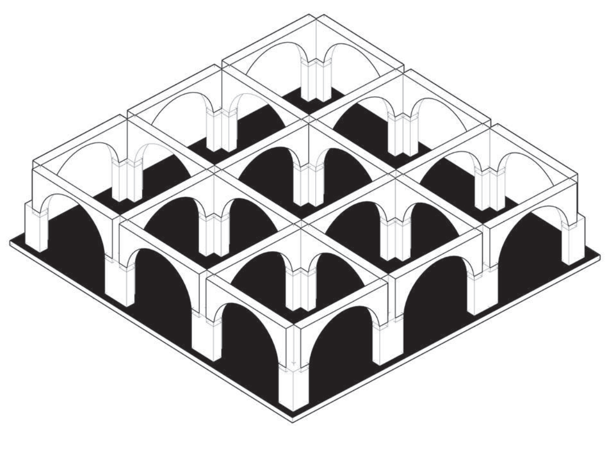
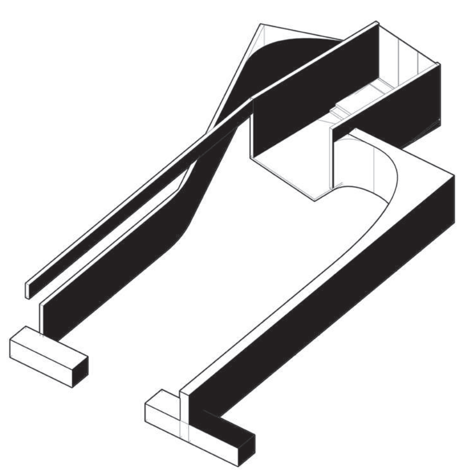


Figure 64. Axonometric drawing of spatial typologies along the community spine. Produced by author, 2026.



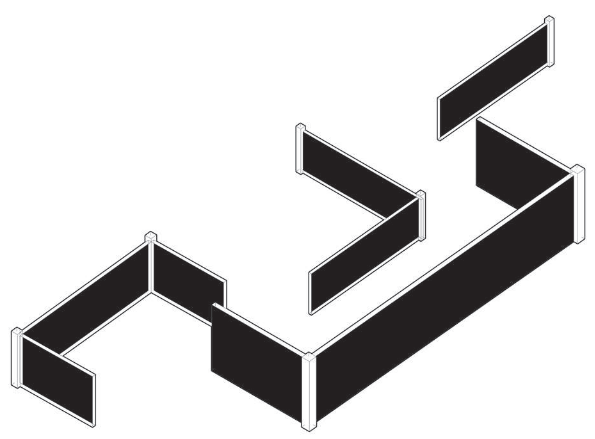
Semi-Open Pavilion

A semi-open pavilion provides a sheltered community room for informal gathering, small events, and quiet staying.



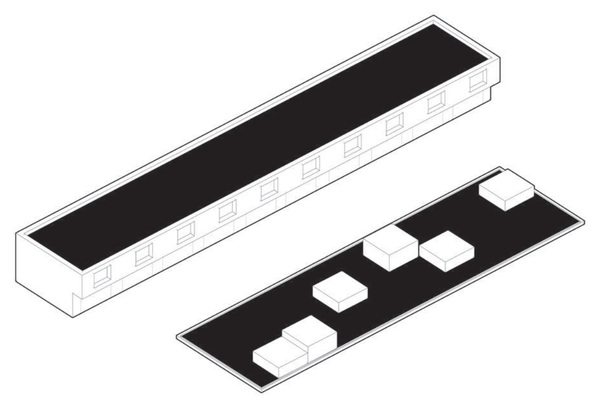
Framed Path

The framed path creates a guided transition between residential space, public spine, and landscape edge.



Micro-Courtyard

The social pocket works as a small-scale node along the spine. It offers places for sitting, meeting, and short daily encounters



Linear Interface

The linear interface reorganises the relationship between housing blocks and shared outdoor space.

Node / Interface Typology

This page presents a set of spatial typologies developed along the community spine. Each intervention responds to a different condition of visibility, threshold, and social capacity. Instead of introducing one large public facility, the proposal creates a sequence of smaller spaces that support different forms of everyday use: passing, resting, meeting, playing, observing, and entering the forest edge. Together, these typologies transform the spine into a flexible social infrastructure, where movement is gradually combined with stay, encounter, and community activity.

Before And After Design Comparison

Aspect	Before Design	After Design	Expected Change
Spatial Structure	Fragmented paths and unclear public structure	Community spine organises movement and public space	More continuous everyday structure
Resource Connection	Housing, POIs, public spaces, and forest exist but are weakly connected	Spine connects existing resources into one readable sequence	Stronger relationship between daily resources
Movement Continuity	Pedestrian routes are discontinuous and difficult to read	Main route becomes clearer, more visible, and easier to follow	Improved legibility and orientation
Social Nodes	Few clear places for staying, meeting, or shared activity	Social nodes are placed along the spine at key intersections and resource points	More opportunities for everyday encounter
Residential Edge	Housing edges are relatively closed or passive	Semi-open interfaces and threshold spaces are introduced	Softer transition between private and shared space
Forest Edge	Forest works partly as a boundary or background	Forest edge becomes connected to public route and activity spaces	Forest becomes part of daily public life
Visual Contact	Limited visibility between paths, housing, and shared spaces	Framed views, semi-open interfaces, and spatial changes support visual contact	More observation and informal social awareness

Table 7. Before And After Design Comparison. Produced by author, 2026.

The Result Of Reconnection

This page compares the existing condition with the proposed design transformation. Before the intervention, Site 4 already contains housing, paths, POIs, public spaces, and forest edges, but these elements are fragmented and weakly connected. After the intervention, the community spine reorganizes these existing resources into a clearer everyday structure. Movement becomes more legible, social nodes are placed along key routes, residential edges become more open, and the forest edge is transformed into a shared public resource. The comparison is qualitative and shows the expected spatial improvement produced by the design proposal.

CONCLUSION.

This thesis investigates how AI-supported spatial analysis can be used to identify structural social isolation risk and translate analytical findings into evidence-based urban design strategies. Rather than treating social isolation as an individual condition, the thesis focuses on its spatial and structural dimensions: accessibility, network position, facility distribution, spatial continuity, and the relationship between housing, landscape, and public space.

Through QGIS, Python, linear regression, logistic regression, K-means clustering, and City2Graph-based network analysis, the research develops a workflow from large-scale risk identification to site-scale design translation. The P_iso risk map reveals where structural isolation risk is spatially concentrated in Bergsjön, while clustering shows that high-risk areas do not share one single mechanism. Different spatial types require different design responses.

The detailed design for Site 4 demonstrates how analytical evidence can inform a community-scale proposal. The design does not rely on large-scale demolition or complete redevelopment. Instead, it works through targeted spatial adjustments: strengthening a community spine, introducing social nodes, opening residential interfaces, and transforming the forest edge into a usable community resource. These interventions aim to improve perceived connectivity, spatial readability, everyday encounter, and the relationship between residents and their surrounding environment.

The thesis concludes that AI-supported and graph-based spatial analysis can strengthen urban design by making hidden spatial risks more visible and by supporting more precise design decisions. Its value lies not in replacing design judgement, but in providing a clearer evidence base through which spatial problems can be interpreted and translated into design action.

REFLECTION.

This thesis does not claim that spatial design alone can solve social isolation. Social isolation is a complex issue shaped by social, economic, cultural, psychological, and political factors. However, the built environment can influence how people move, meet, perceive safety, and access everyday resources. For this reason, spatial design can still play an important role in reducing structural conditions that may reinforce isolation.

A key reflection from the process is that data analysis becomes most meaningful when it is connected to spatial interpretation. The models used in this thesis do not provide final answers by themselves. They identify patterns, probabilities, and relationships, but these findings need to be read through urban context, site conditions, and design judgement. In this sense, AI-supported analysis should be understood as a design-support tool rather than an automatic design generator.

The project also shows the importance of working between scales. District-scale risk mapping helped identify where intervention may be needed, while site-scale network reading helped clarify how intervention could happen. The movement from risk map to cluster interpretation, and then from graph-based reading to spine, nodes, and interfaces, became the main methodological contribution of the thesis.

The final proposal is therefore not only a design for one site in Bergsjön, but also a test of a broader workflow. It suggests that evidence-based urban design can benefit from combining computational analysis with careful spatial reading, especially when addressing complex and hidden urban issues such as structural social isolation.

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APPENDIX.

```python
import pandas as pd

# z-score standardization
df["z_dist_poi_min"] = (
    df["dist_poi_min"] - df["dist_poi_min"].mean()
) / df["dist_poi_min"].std()

df["z_poi_within_1000m"] = (
    df["poi_within_1000m"] - df["poi_within_1000m"].mean()
) / df["poi_within_1000m"].std()

# calculate Y_iso
df["Y_iso"] = df["z_dist_poi_min"] - df["z_poi_within_1000m"]
```

Appendix 1. Python code for z-score standardisation and preliminary proxy construction. Produced by author, 2026.

Preliminary Proxy Construction

This code shows how the preliminary isolation proxy was constructed from POI accessibility indicators. First, the distance to the nearest POI and the number of POIs within 1000 metres were standardised using z-score transformation, so that the two variables could be compared despite having different units and scales.

The preliminary proxy was then calculated by subtracting the standardised POI count from the standardised POI distance. In this logic, grid cells that are far from facilities and have fewer nearby POIs receive higher proxy values, indicating a higher preliminary condition of structural isolation risk.


```python
# 1. continuous isolation proxy
df["Y_iso"] = zscore(df["dist_poi_min"]) - zscore(df["poi_within_1000m"])

# 2. binary label
threshold = df["Y_iso"].quantile(0.75)
df["Y_binary"] = (df["Y_iso"] >= threshold).astype(int)

# 3. features
X = df[["ang_mean", "GFA_density", "dist_poi_min", "poi_within_1000m"]]

# 4. standardize X
X_scaled = scaler.fit_transform(X)

# 5. logistic regression
model.fit(X_scaled, df["Y_binary"])

# 6. probability
df["p_iso"] = model.predict_proba(X_scaled)[:, 1]
```

Appendix 1. Python code for binary risk labelling, logistic regression modelling, and P_iso calculation. Produced by author, 2026.

Logistic Regression and P_iso Calculation

This code shows the main modelling process used to estimate P_ iso. The continuous isolation proxy was first converted into a binary label by using the 75th percentile as the high-risk threshold. Spatial variables, including angular integration, GFA density, nearest POI distance, and POI count within 1000 metres, were then selected as model inputs.

After standardising the input variables, a logistic regression model was trained to estimate whether each grid cell belongs to the high-risk category. The model output is P_iso, a probability value between 0 and 1, representing the estimated probability of high structural isolation risk for each spatial unit.

```python
G_path = c2g.knn_graph(
    gdf=path_points,
    k=2,
    distance_metric="euclidean",
    as_nx=True
)

print("number of nodes:", G_path.number_of_nodes())
print("number of edges:", G_path.number_of_edges())
```
[69]

```
number of nodes: 1172
number of edges: 1557
```

```python
components = list(nx.connected_components(G_path))
print("number of connected components:", len(components))
print("largest 20 component sizes:", sorted([len(c) for c in components], reverse=True)[:20])
```
[70]

```
number of connected components: 10
largest 20 component sizes: [1059, 30, 26, 21, 11, 8, 7, 4, 3, 3]
```

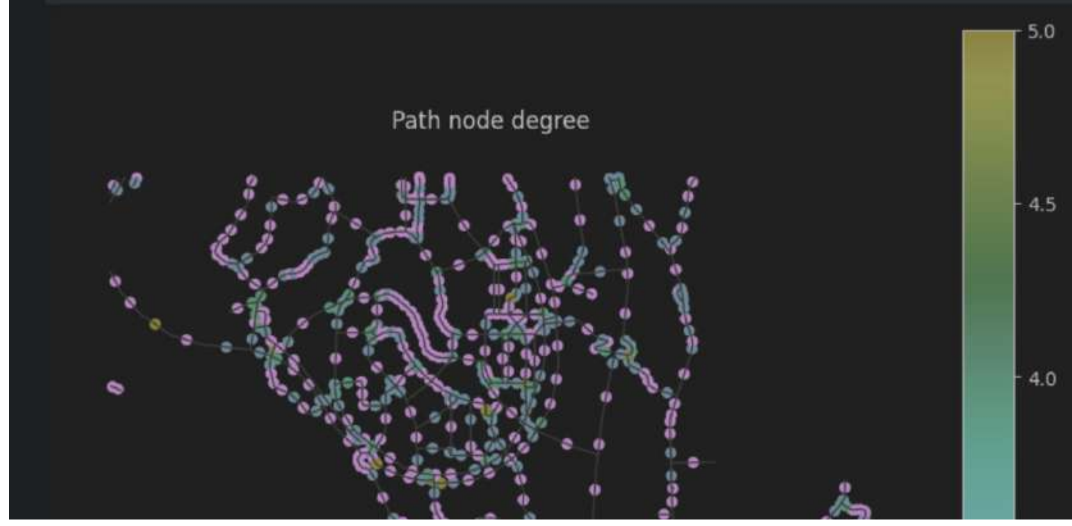
```python
degree_dict = dict(G_path.degree())
path_nodes["degree"] = path_nodes.index.map(degree_dict)

print(path_nodes[["degree"]].head())
```
[71]

```python
fig, ax = plt.subplots(figsize=(10, 10))

paths.plot(ax=ax, color="lightgray", linewidth=1)
path_nodes.plot(ax=ax, column="degree", legend=True, markersize=25)

ax.set_title("Path node degree")
ax.set_axis_off()
plt.show()
```
[73]



Appendix 3. Excerpt of Python code used to calculate path node degree in the site-scale graph-based analysis. Produced by author, 2026.

Path Node Degree Calculation

This code calculates path node degree from the non-motorised path graph. In the graph, path intersections and endpoints are treated as nodes, while path segments are treated as edges. Degree measures how many direct path connections are linked to each node. Higher-degree nodes indicate local intersections or access points where several routes meet. The result was visualised to identify potential locations for social nodes and small-scale encounters along the community spine.

id	left	top	right	bottom	row_index	col_index	unit_id	fid_2	is_core	geometry	centroid	dist_poi_m	poi_within	poi_within	Y_iso_cont	y_iso_bin	ang_mean	B_GFA_der	p_iso	risk_level
124	322168	6402641	322368	6402441	24	3	g_000124	1	1	MULTIPOL	POINT (32:	50.1645	40	60	-2.12045	0	2808.255	3.498368	6.46E-05	low
159	322368	6402241	322568	6402041	26	4	g_000159	1	1	MULTIPOL	POINT (32:	393.0034	9	92	-2.16874	0	1515.378	0.667956	0.10265	low
158	322368	6402441	322568	6402241	25	4	g_000158	1	1	MULTIPOL	POINT (32:	254.3437	33	70	-1.73748	0	2111.062	1.930973	0.003977	low
157	322368	6402641	322568	6402441	24	4	g_000157	1	1	MULTIPOL	POINT (32:	88.80808	37	67	-2.28013	0	2962.382	2.131487	0.001151	low
156	322368	6402841	322568	6402641	23	4	g_000156	1	1	MULTIPOL	POINT (32:	176.3038	37	67	-1.92123	0	1981.896	0.03543	0.230517	medium
155	322368	6403041	322568	6402841	22	4	g_000155	1	1	MULTIPOL	POINT (32:	43.23383	21	61	-2.19434	0	2247.14	0.558123	0.068407	low
145	322368	6405041	322568	6404841	12	4	g_000145	1	1	MULTIPOL	POINT (32:	413.6073	1	25	0.961307	1	0	0	0.675299	high
144	322368	6405241	322568	6405041	11	4	g_000144	1	1	MULTIPOL	POINT (32:	345.0322	2	22	0.816386	1	0	0.00035	0.675129	high
192	322568	6402241	322768	6402041	26	5	g_000192	1	1	MULTIPOL	POINT (32:	333.1003	6	83	-2.00536	0	1495.788	0.263803	0.22184	medium
191	322568	6402441	322768	6402241	25	5	g_000191	1	1	MULTIPOL	POINT (32:	260.457	9	71	-1.75786	0	1682.201	0.085364	0.262154	medium
190	322568	6402641	322768	6402441	24	5	g_000190	1	1	MULTIPOL	POINT (32:	91.95036	13	65	-2.17633	0	2193.751	2.426472	0.001232	low
189	322568	6402841	322768	6402641	23	5	g_000189	1	1	MULTIPOL	POINT (32:	13.54108	12	63	-2.40705	0	2412.285	0.453871	0.073404	low
188	322568	6403041	322768	6402841	22	5	g_000188	1	1	MULTIPOL	POINT (32:	204.6795	12	63	-1.62301	0	2290.298	0.867302	0.034343	low
187	322568	6403241	322768	6403041	21	5	g_000187	1	1	MULTIPOL	POINT (32:	321.6144	9	62	-1.0979	0	1393.839	0.082099	0.319284	medium
186	322568	6403441	322768	6403241	20	5	g_000186	1	1	MULTIPOL	POINT (32:	394.9008	7	51	-0.29727	0	2094.566	0.049819	0.207026	low
185	322568	6403641	322768	6403441	19	5	g_000185	1	1	MULTIPOL	POINT (32:	356.8036	2	37	0.182835	1	2508.966	0	0.165013	low
184	322568	6403841	322768	6403641	18	5	g_000184	1	1	MULTIPOL	POINT (32:	394.4861	1	28	0.746507	1	1431.339	0	0.35195	medium
182	322568	6404241	322768	6404041	16	5	g_000182	1	1	MULTIPOL	POINT (32:	392.2679	2	20	1.101054	1	1260.939	0	0.389211	high
181	322568	6404441	322768	6404241	15	5	g_000181	1	1	MULTIPOL	POINT (32:	337.7396	4	24	0.69556	1	853.7418	0.008231	0.478298	high
180	322568	6404641	322768	6404441	14	5	g_000180	1	1	MULTIPOL	POINT (32:	280.0185	3	28	0.276971	1	660.398	0.029472	0.511869	high
179	322568	6404841	322768	6404641	13	5	g_000179	1	1	MULTIPOL	POINT (32:	348.8973	3	26	0.650417	1	829.2857	0.308656	0.325406	medium
178	322568	6405041	322768	6404841	12	5	g_000178	1	1	MULTIPOL	POINT (32:	445.9644	5	25	1.094034	1	503.3359	0.426164	0.335498	medium
177	322568	6405241	322768	6405041	11	5	g_000177	1	1	MULTIPOL	POINT (32:	277.2987	3	24	0.447637	1	623.6951	0.174236	0.440636	high
176	322568	6405441	322768	6405241	10	5	g_000176	1	1	MULTIPOL	POINT (32:	136.7373	3	24	-0.12893	0	710.3853	0.002735	0.514942	high
225	322768	6402241	322968	6402041	26	6	g_000225	1	1	MULTIPOL	POINT (32:	337.0142	8	76	-1.67111	0	977.7463	0.116207	0.391207	high
224	322768	6402441	322968	6402241	25	6	g_000224	1	1	MULTIPOL	POINT (32:	227.9853	7	68	-1.75469	0	1417.605	0.926671	0.06604	low
223	322768	6402641	322968	6402441	24	6	g_000223	1	1	MULTIPOL	POINT (32:	63.53033	9	68	-2.42927	0	1491.575	0.310259	0.205237	low
222	322768	6402841	322968	6402641	23	6	g_000222	1	1	MULTIPOL	POINT (32:	102.0899	13	65	-2.13474	0	1943.839	0.390208	0.123994	low
221	322768	6403041	322968	6402841	22	6	g_000221	1	1	MULTIPOL	POINT (32:	130.6993	14	60	-1.79011	0	1704.677	0.597049	0.100768	low
220	322768	6403241	322968	6403041	21	6	g_000220	1	1	MULTIPOL	POINT (32:	153.0626	14	50	-1.24382	0	2239.539	0.086355	0.173671	low
219	322768	6403441	322968	6403241	20	6	g_000219	1	1	MULTIPOL	POINT (32:	235.0912	11	36	-0.27096	0	1721.861	0.269653	0.185426	low
218	322768	6403641	322968	6403441	19	6	g_000218	1	1	MULTIPOL	POINT (32:	158.3253	8	34	-0.49494	0	1636.368	0.025609	0.297441	medium
217	322768	6403841	322968	6403641	18	6	g_000217	1	1	MULTIPOL	POINT (32:	231.0354	5	31	-0.06032	0	1738.232	0.06011	0.262802	medium
216	322768	6404041	322968	6403841	17	6	g_000216	1	1	MULTIPOL	POINT (32:	287.2468	2	28	0.306621	1	1476.284	0.038134	0.323646	medium
215	322768	6404241	322968	6404041	16	6	g_000215	1	1	MULTIPOL	POINT (32:	192.5139	2	31	-0.21833	0	0	0.070257	0.64031	high
214	322768	6404441	322968	6404241	15	6	g_000214	1	1	MULTIPOL	POINT (32:	205.292	6	28	-0.02955	0	995.2753	0.57335	0.186826	low
213	322768	6404641	322968	6404441	14	6	g_000213	1	1	MULTIPOL	POINT (32:	80.54292	6	28	-0.54126	0	1469.742	0.650054	0.110497	low
212	322768	6404841	322968	6404641	13	6	g_000212	1	1	MULTIPOL	POINT (32:	164.9461	6	29	-0.2405	0	1887.277	0.73722	0.064746	low

Appendix 4. Excerpt of the spatial feature database used for linear regression, logistic regression, and K-means clustering. Produced by author using QGIS and Python, 2026.

Path Node Degree Calculation

This appendix shows an excerpt of the spatial feature database used for the linear regression, logistic regression, and K-means clustering analysis. The database was produced by extracting and calculating spatial variables from QGIS and Python, and then joining them to the grid-based spatial units.

Each row represents one spatial unit in the study area. The columns include geometric information, core-area identification, local angular integration, GFA density, POI distance, POI count, the preliminary proxy, binary risk labels, predicted P_iso values, and classified risk levels. These variables form the main input dataset for the AI-based spatial modelling process.

The database was used in three steps: first, to test relationships between spatial variables and the preliminary proxy through linear regression; second, to estimate high-risk probability through logistic regression; and third, to classify high-risk spatial units into cluster types using K-means. This table therefore documents the computational dataset behind the risk map and cluster-based interpretation.