

Article

Rethinking the Sustainable Regeneration of French Colonial Mass Housing Estates in Algiers: Insights from GIS-Space Syntax and Building Condition Assessment

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Abstract

French colonial mass housing estates built in Algiers between 1950 and 1962 constitute a substantial part of the city's housing stock and continue to shape its urban structure. As aging residential environments, they present important challenges for sustainable regeneration. Despite their significance, the relationship between urban configuration and long-term physical deterioration remains poorly understood. This study establishes a georeferenced inventory of these estates by combining archival documentation and field surveys with Geographic Information Systems (GIS) and space syntax analysis. Configurational properties were quantified using Normalized Angular Integration (NAIN) in DepthmapX, while the physical state of each estate was evaluated through a systematic assessment of structural elements, façades, and public spaces. The results reveal considerable variation in integration and a statistically significant relationship between its levels and physical quality. Estates occupying more privileged positions within the street network generally exhibited better maintenance and higher-quality public spaces, whereas more isolated estates experienced greater deterioration. The findings suggest that street integration is associated with estate performance, providing quantitative evidence to support sustainable regeneration planning by proposing a practical decision-support framework for identifying evidence-based resilience planning and governance priorities.

Keywords: space syntax; Normalized Angular Integration (NAIN); French colonial urbanism; mass housing estates; building condition assessment; regeneration; governance; resilience



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1. Introduction

Post-war and colonial mass housing estates across many cities worldwide are approaching the end of their design lifecycle. Rather than large-scale demolition, current research advocates sustainable regeneration based on building diagnosis, spatial analysis and evidence-based retrofit [1]. This approach aligns with the principles of a circular economy and Sustainable Development Goal 11 [2], and initiatives like Making Cities Resilient 2030 (MCR2030) [3].

Consequently, reliable digital methods for diagnosing building condition and prioritizing interventions have become essential components of resilient urban planning.

French colonial mass housing estates, constructed in Algiers between 1950 and 1962, continue to shape the city's spatial structure more than six decades after their completion [4]. These estates represent a persistent component of the city's housing stock, making their understanding essential for contemporary urban planning [5]. Scholarly inventories and analyses of mass housing estates in Algiers have taken multiple forms, yet their emphases and methodologies differ significantly.

Zeynep Çelik's foundational work situates mass housing grands ensembles within the framework of French colonial urban strategies, emphasizing socio-spatial control and segregation [6]. Jean-Jacques Deluz's *Aperçu critique* (1988) [7] and *Le tout et le fragment* (2010) [8] combine professional experience with detailed critique of colonial and post-independence urbanism, including inventories of social housing.

In the architectural domain, Rym Merzelkad focused on the documentation of Fernand Pouillon's mass housing projects; this work provides a structured catalog of specific built ensembles in Algeria [9]. Comparative historiographical work on grands ensembles in the French context, such as that of Dufaux et al., establishes analytical frameworks for understanding mass housing estates socially and politically [10].

However, existing studies have not yet provided a systematic spatial assessment of Algiers' mass housing estates, and rarely integrate configurational analysis, GIS-based inventory, and building condition assessment within a unified decision-support framework for prioritizing sustainable interventions.

This study develops an integrated methodology combining GIS inventory, Space Syntax analysis, and on-site building condition assessment to identify spatially informed priorities for sustainable urban regeneration.

Space syntax provides such an analytical framework. Developed by Hillier and Hanson (1984), it describes and analyzes the spatial configuration of built environments by examining the relationship between urban form, movement, and social activity [11,12].

When integrated with Geographic Information Systems (GIS), space syntax gains significant analytical power, enabling the precise georeferencing of street networks, the overlay of morphological and physical datasets, and the spatial analysis of large urban areas at the scale of entire cities or housing districts [13]. Its primary indicators, including Normalized Angular Integration (NAIN), measure the degree to which urban spaces are embedded within the wider network [14].

Low integration values, reflecting topological isolation, have been associated with reduced pedestrian movement, weaker urban vitality, and limited investment, conditions that may contribute to the progressive deterioration of buildings and public spaces [15].

This approach also provides a basis for identifying targeted urban interventions aimed at improving the integration of the most disconnected estates [16]. Therefore, three research questions structure this inquiry:

1. How does normalized angular integration (NAIN) vary across inventoried mass housing estates, and what do these configurational differences reveal about each estate's position within the broader urban fabric?
2. What is the relationship between configurational integration (NAIN) and building deterioration across the 19 French colonial mass housing estates?
3. What regeneration recommendations can improve both the built form and spatial integration of French colonial mass housing estates within the broader urban fabric?

The main scientific contributions of this study can be summarized as follows:

- To the best of our knowledge, this is the first study to integrate GIS-based inventory, space syntax analysis, and systematic building-condition assessment within a unified framework for the case of Algiers.
- It investigates the relationship between building deterioration and spatial configuration indicators, demonstrating how characteristics of the urban street network are associated with variations in building conditions.
- It proposes a resilience-oriented decision-support framework that combines building diagnosis with urban spatial analysis, enabling more evidence-based prioritization of regeneration interventions.
- Beyond the case study of Algiers, the proposed methodology offers a transferable approach for municipalities and planning authorities managing aging mass housing estates facing physical deterioration, resource constraints, and increasing sustainability challenges.

The overall structure of the study, including its research objectives, methodology, and expected outputs, is summarized in Figure 1.

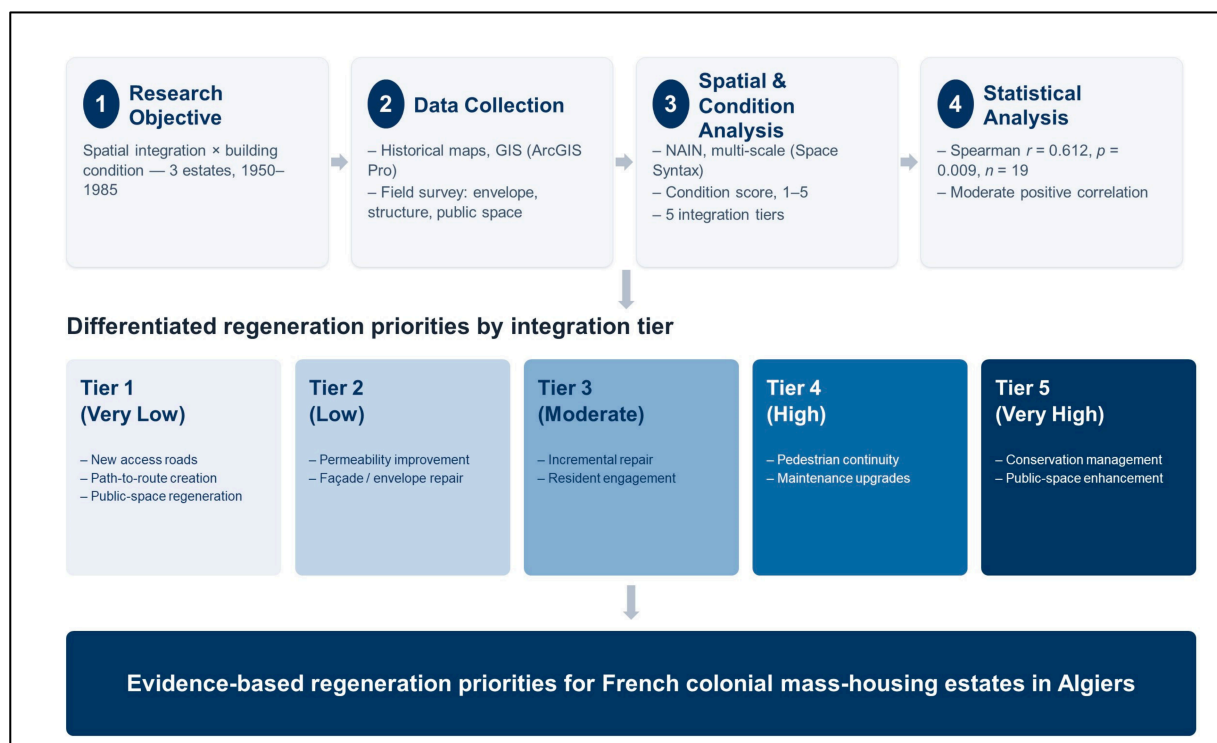


Figure 1. Structure of the study: research objectives, methodology, and expected outputs for the space syntax analysis of French colonial mass housing estates in Algiers.

2. Theoretical Framework

2.1. Building Techniques, Materials, and Industrialization in Algiers' Colonial Mass Housing Estates

The first period of mass housing construction in Algiers, represented by the projects of l'Agence du Plan and the works of architects Roland Simounet and Fernand Pouillon, relied on traditional yet highly durable construction methods. Similar techniques were employed in the housing estates of Diar Es-Saâda, Diar El-Mahçoul, and Djenan el-Hassan, emphasizing the use of local materials and load-bearing masonry systems. The structures in Pouillon's projects were built with white cut stone from Fontvieille, while concrete was mainly used for foundations and horizontal structural elements. Floors incorporated cross-reinforced slabs and chainages, with only a limited number of prefabricated components.

Acoustic insulation was achieved through cork panels covered with plaster, forming the ceiling finishes. Internal load-bearing partitions were constructed with vertically laid brickwork, and roofs consisted of pozzolana concrete terraces with recycled terracotta debris used as the base layer. These methods reflected a preference for craftsmanship, material durability, and climatic adaptation rather than industrialized production [17,18].

The second period, corresponding to the Constantine Plan (1958–1962), was characterized by the adoption of industrialized and prefabricated building techniques due to the urgent requirement of producing housing on a large scale. Projects such as Carrière Jaubert employed load-bearing walls of reconstructed stone blocks, with foundations suitable to complex topography (piles, wells, and spread footings, according to soil conditions). Some of these terraces were designed for communal use, for example, as schools or day care centers, and their roofs were made waterproof [19,20].

Figure 2 illustrates the construction systems in Carrière Jaubert estate.

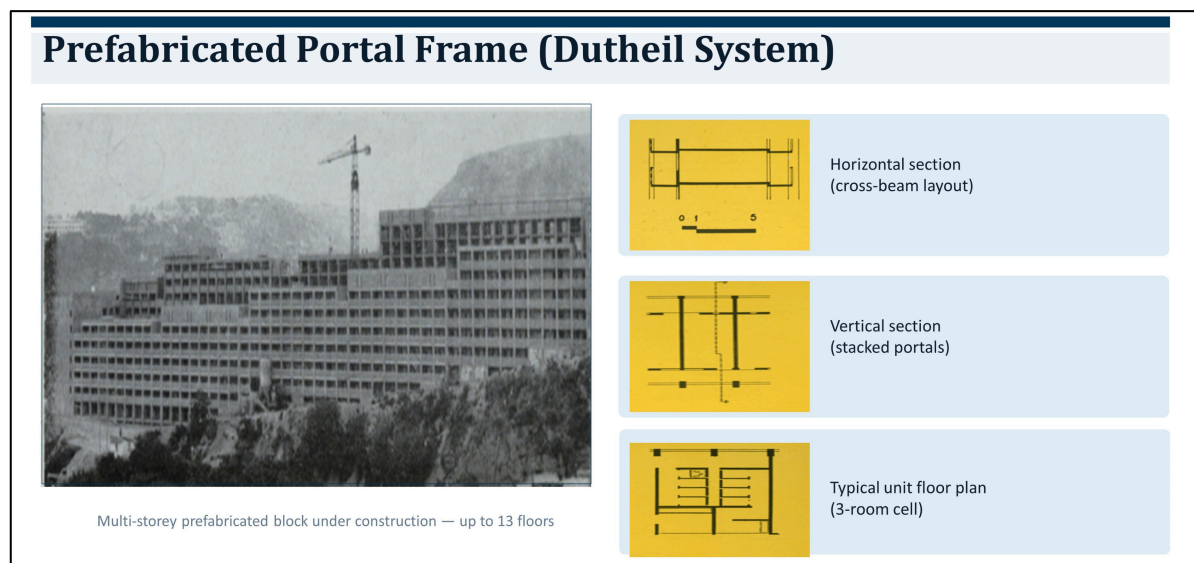


Figure 2. Carrière Jaubert Housing Complex Perfected system.

2.2. Normalized Angular Integration (NAIN): Definition and Computation

Within the space syntax framework, urban street networks are represented as interconnected street segments linked through angular relationships. Connections between segments are weighted according to angular deviation, with straight continuations assigned lower costs than sharp turns, reflecting the tendency of pedestrians to favor routes that minimize directional change.

Normalized Angular Integration (NAIN) measures the relative accessibility of each segment by evaluating the cumulative angular distance required to reach all other segments within the network [21]. Raw integration values are influenced by network size and therefore cannot be directly compared across different urban systems. To overcome this limitation, integration is normalized using the harmonic mean depth (HH) formulation, which accounts for variations in network scale. The resulting values are then standardized through min–max normalization to facilitate comparison across the study sample [22].

2.3. The Role of Angular Integration in Urban Spatial Systems

Spatial integration influences how movement and activities are distributed throughout urban areas. Streets with higher NAIN values are generally more accessible within the network and tend to support greater levels of pedestrian movement, economic activity,

and social interaction [23,24]. Conversely, poorly integrated areas often experience reduced accessibility and lower levels of natural movement [25,26].

Lower levels of integration may also contribute to urban decline by limiting everyday activity and informal surveillance, factors commonly associated with vibrant and well-maintained urban environments. As a result, NAIN provides a useful framework for examining the relationship between street-network configuration and broader urban outcomes [27–29]. Figure 3 Schematic illustration of the Normalized Angular Integration (NAIN) measure used in space syntax analysis. The figure presents the conceptual progression from street-network configuration to the assessment of urban accessibility using Normalized Angular Integration (NAIN). (a) Schematic representation of street-network configuration and axial depth, illustrating angular relationships between connected street segments; (b) normalization of integration values to account for differences in network size and enable comparison between urban systems; (c) interpretation of NAIN as an indicator of relative street-network accessibility, with higher values representing greater spatial integration.

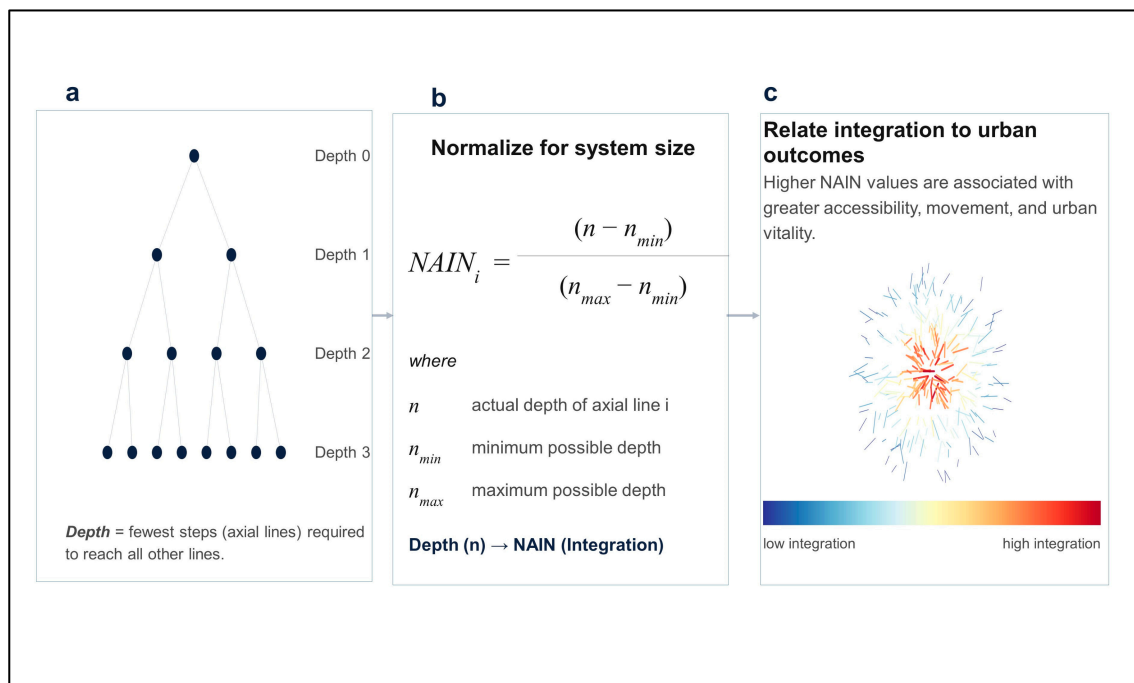


Figure 3. From Street-Network Configuration to Urban Accessibility: The NAIN Framework. (a) Calculation of axial depth, showing the number of steps required to reach each axial line from the starting line; (b) normalization of integration values according to system size using the NAIN formulation; (c) interpretation of NAIN in relation to urban accessibility, movement, and vitality, from low to high integration.

3. Materials and Methods

3.1. Data Preparation and Representation

3.1.1. Scope and Definition of the Corpus

The study focuses on large-scale mass housing developments from the French colonial period in Greater Algiers, built between 1950 and 1962. The corpus includes developments selected based on three cumulative criteria. Similar multi-source documentation strategies have recently been applied in Algerian architectural heritage research to establish systematic inventories supporting conservation and management [30].

The first is chronological, requiring a construction start date of 1950 or later and substantial completion by 1962. The second is typological, encompassing repetitive collective

vertical residential blocks consisting of approximately 500 flats or more, commissioned under public ownership (HLM, CIA, etc.) [31].

The third is spatial, requiring the development to constitute a physically coherent entity, a defined residential neighborhood with shared exterior spaces and a traceable internal circulation system.

Applying these criteria to the archival corpus produced an initial list of 21 developments, of which two were excluded because of insufficient documentation for the space syntax analysis.

3.1.2. Multi-Source Archival Compilation

The identification of candidate developments rests on the systematic consultation of five categories of sources (Table 1) [32].

Table 1. Source matrix used for the identification and documentation of the 19 developments.

Source Type	Repository/Platform	Role in Identification
Historical cartography (1950–1962)	ANOM; BNF Gallica, Revue Les Chantiers Nord-africains [6,17–19,33–44]	Primary geometric reference for boundaries
Cadastral plans	Wilaya of Algiers [45]	Boundary confirmation and post-independence modifications
Architects' archives (Deluz)	Glycine Library [46]	Designed project vs. built form
Satellite imagery (2023)	Esri Basemap [47]	Verification of current condition
Field surveys (2023–2026)	On-site documentation	Physical existence and boundary verification

3.1.3. Identification Procedure and Boundary Delineation

Each estate was identified through cross-verification of archival plans, cadastral documents, aerial imagery, and field observations. Boundaries were digitized and georeferenced in ArcGIS Pro 3.3 (WGS 84/UTM Zone 31N, EPSG:32631) using stable urban reference points visible in both historical and contemporary imagery [48].

Three types of boundary conditions were encountered, each requiring a specific detection strategy: hard physical boundaries (wall, fence, or road). Each polygon is subject to three quality criteria: geometric closure, topological consistency (no overlaps), and thematic consistency (all attribute fields populated and verified) [49].

3.1.4. Output: The Georeferenced Development Layer

The identification phase produces a single spatial output, comprising 19 features with complete attribute tables. This layer forms the spatial foundation for all subsequent phases: street network extraction for DepthmapX 0.5, localization of NAIN results within the Algiers urban context, and differentiated interpretation according to the conservation status of each development. Figure 4 displays the final georeferenced estate boundary layer.



Figure 4. Georeferenced estate boundary layer (estate_perimeters_WGS84_31N.shp) comprising the inventoried developments, overlaid on the Algiers urban fabric.

3.2. Conversion of Road Networks to Representations in DepthmapX

The production of space syntax NAIN values begins not with computation but with a careful translation of geographic data into a topological structure, or segment map, that DepthmapX can process. This conversion from GIS road centerlines to a segment map is the foundational operation on which all subsequent space syntax analysis depends [36,50].

The surrounding context window was defined consistently across all 19 estates as a 1500 m buffer around each estate boundary, clipped to the continuous road network [51,52]. A radius of 10,000 m was used to capture citywide accessibility, since larger radii generally reflect strategic movement patterns while smaller radii capture neighborhood-scale relationships [51–53]. A sensitivity analysis using R1500, R3000, R5000, and R10000 showed unchanged NAIN values, rankings, and tier classifications across all radii, confirming the robustness of the configurational analysis to this parameter [54–56].

Figure 5 presents the segment computation integration map of the Algiers urban network produced in DepthmapX, from which estate-level NAIN values were extracted.

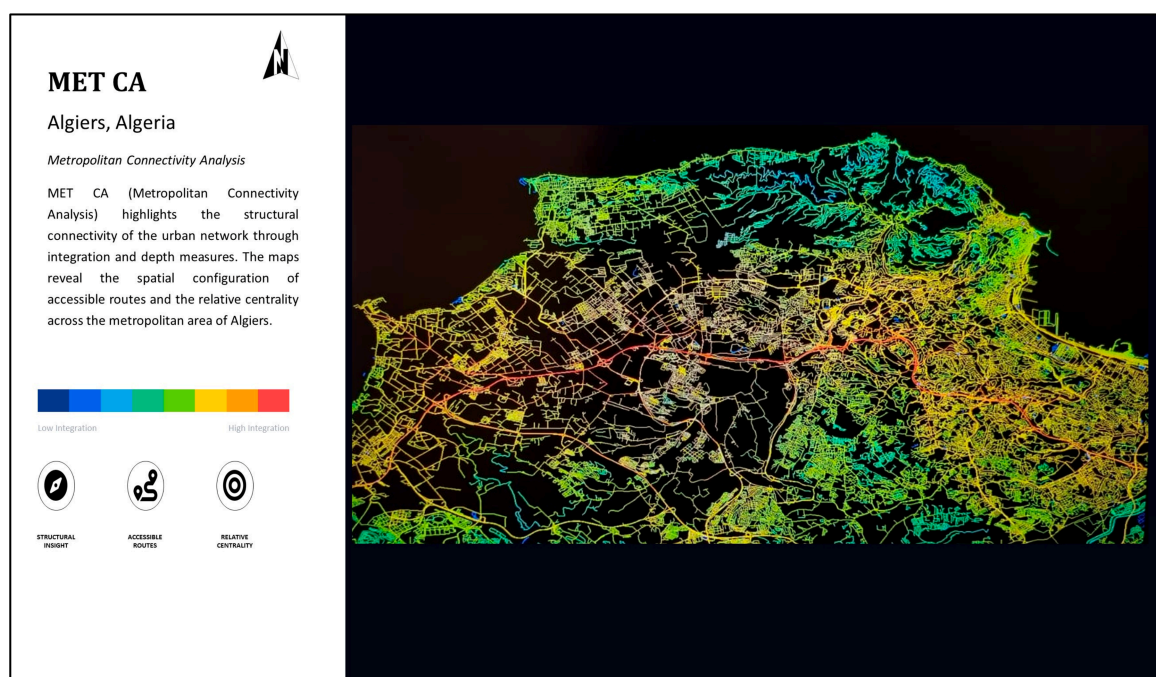


Figure 5. Segment integration map of the Algiers urban street network showing Normalized Angular Integration (NAIN) values.

Before analysis, the network was checked for topological consistency and corrected for three main errors: disconnected islands (isolated clusters caused by digitizing inaccuracies, resolved by snapping endpoints), duplicate edges (overlapping road segments that could bias local measures, removed as redundant geometry), and false dead ends (apparent breaks in connectivity verified in the field as continuous links, corrected by extending segment endpoints) [57].

3.3. Extraction of Estate-Level Integration Values

The integration value assigned to each estate is not the value of a single segment but the mean NAIN value of all segments falling within the estate boundary polygon. This spatial averaging was performed by exporting the DepthmapX representation to ArcGIS, performing a spatial join between the segment layer and the estate polygon layer, and computing the mean per estate using the field calculator.

3.4. Building Condition Assessment

Surveys were conducted across all nineteen estates during two field campaigns between 2023 and 2026, with each estate visited at least twice to ensure completeness and resolve scoring ambiguities. Data were recorded on a structured field sheet developed for this study, capturing observation time, weather and lighting conditions, number of blocks assessed, condition scores across the three evaluated dimensions, key defects, and a photographic log.

The field surveys were conducted by a team comprising two urban-planning experts and one architect, who independently assessed every housing estate using the standardized assessment form and the predefined evaluation criteria. Independent scoring was completed before any discussion among the evaluators. Inter-rater agreement was assessed using Fleiss' kappa coefficient because three raters independently classified each assessment item into the ordinal categories Good, Moderate, and Bad.

The assessment was conducted according to a standard protocol used across all estates to allow for comparison and to avoid bias due to differences in typology or size. Fieldwork was carried out prior to the final interpretation of NAIN results to avoid interpretive bias. This consistent methodology allowed measurement of three externally observable physical dimensions for each estate, permitting evaluation without internal units or structural testing.

The field observations were systematically supported by photographic and video documentation, establishing a visual archive for cross-checking and verification of condition ratings. All records were filled out in the field and checked for internal consistency and accuracy immediately after each visit [58]. It included an overall summary of the survey, a description of the surveyed area, a description of the construction characteristics, an overview of identified emergency failures and building pathologies, and regeneration recommendations for conservation and preservation interventions [59].

The building condition assessment was conducted using a set of Algerian technical regulations (DTRs), guidebooks, and urban planning documents to evaluate the structural, material, environmental, and urban conditions of the existing site. Structural conditions were assessed using DTR BE 2.1 on reinforced concrete construction and the relevant structural calculation codes, with the corresponding evaluation criteria summarized in Appendix A, Table A3.

The assessment of façades relied on DTR C 6.1 concerning curtain walls [60], DTR E 5.1, E 5.2, and E 5.3 for wooden, metallic, and PVC joinery [61–63], DTR E 6.1 and E 6.6 for renders and paint finishes [64,65], and DTR E 7.1 for glazing systems [66]. These documents provided criteria for assessing material deterioration, waterproofing, thermal and acoustic performance, construction quality, maintenance requirements, and conformity with national building standards. In addition, the 2016 Algiers Master Plan [67], its regulatory report, and the Public Space Charter were used to evaluate the architectural integration of façades within the urban landscape, including visual coherence, heritage value, skyline composition, streetscape quality, and compliance with metropolitan planning guidelines. The façade assessment framework is presented in Appendix A, Table A2.

Public spaces were evaluated using the VRD regulations, the Guide for Urban Improvement Works (Guide 07), the Guide for Graphic Representation in Urban Planning (Guide 08), the Recommendations for Construction on Sloping Sites (Guide 12), as well as the Public Space Charter and the PDAU 2016 regulatory framework [45]. These references provided criteria for assessing accessibility, functionality, landscape integration, public amenities, mobility, and the overall quality and regulatory conformity of public spaces within the study area. The public-space assessment dashboard is presented in Appendix A, Table A1.

Envelope condition encompasses the external fabric of the residential blocks: the integrity of rendered or exposed concrete façade surfaces; the condition of window frames and glazing units; the state of balcony elements, including parapets, balustrades, and slab edges; and the presence or absence of water staining, efflorescence, or biological growth on external walls. Envelope condition is the most immediately visible indicator of ongoing maintenance investment; its deterioration typically precedes and accelerates structural decline.

Structural condition encompasses the visible indicators of load-bearing or frame degradation: cracking patterns in columns, beams, and shear walls; spalling of concrete cover exposing reinforcement; deformation or settlement of structural elements; and any signs of foundation movement visible at ground level. Structural indicators were assessed conservatively: in the absence of clearly visible structural distress, this dimension was scored Good or Moderate. A Bad rating required evidence of active rather than historic structural compromise.

Common area condition encompasses the shared non-residential fabric: stairwells and entrance lobbies; shared circulation corridors and landings; open ground-floor areas, including *pilotis* zones and bin stores; and the immediate paved or unpaved surrounds within the estate boundary. Common areas function as the interface between private dwellings and public streets; their condition reflects not only maintenance investment but also the degree to which residents collectively inhabit and care for shared space, itself a function of spatial integration and syntactic position.

Each dimension was evaluated using a three-point ordinal scale: Good, Moderate, and Bad, corresponding respectively to (i) conditions consistent with routine maintenance and absence of observable deterioration, (ii) visible but non-critical deterioration with partial or uneven maintenance, and (iii) extensive deterioration affecting multiple building elements and indicating a systemic lack of maintenance investment.

This simplified ordinal classification was adopted in line with recent approaches in built-environment condition assessment literature [68], which emphasize that limited-category scales improve inter-observer reliability in field-based surveys while maintaining sufficient sensitivity to capture meaningful variation in building pathology.

For analytical purposes, a numerical code was assigned to each category (Bad = 1, Moderate = 2, Good = 3), and the scores for the three assessment dimensions (Structure, Façade, and Public Space) were summed to obtain an overall condition score ranging from 3 to 9. The numerical BCA scores were grouped into qualitative condition classes: Good (7–9), Moderate (5–6), Moderate–Bad (4), and Bad (1–3). The dominant rating corresponds to the category assigned to at least two of the three assessed dimensions (majority rule). If all three dimensions received different ratings, the numerical total score was used to assign the final qualitative condition class.

3.5. Correlation Analysis

To evaluate the relationship between NAIN and building condition, Spearman's rank correlation coefficient (ρ) was calculated. Spearman's correlation was selected because building condition is based on ordinal categories (Bad, Moderate, Good) rather than continuous measurements.

$$\rho = 1 - \frac{6\sum d_e^2}{n(n^2 - 1)}$$

where ρ is Spearman's correlation coefficient, d_e is the difference between the ranks of the two variables for estate i , and n is the number of estates. A positive coefficient indicates that higher levels of spatial integration are associated with better building conditions [69,70].

Figure 6 presents the four-step methodology applied in this study, from data preparation and georeferencing through to cross-validation with field observations.

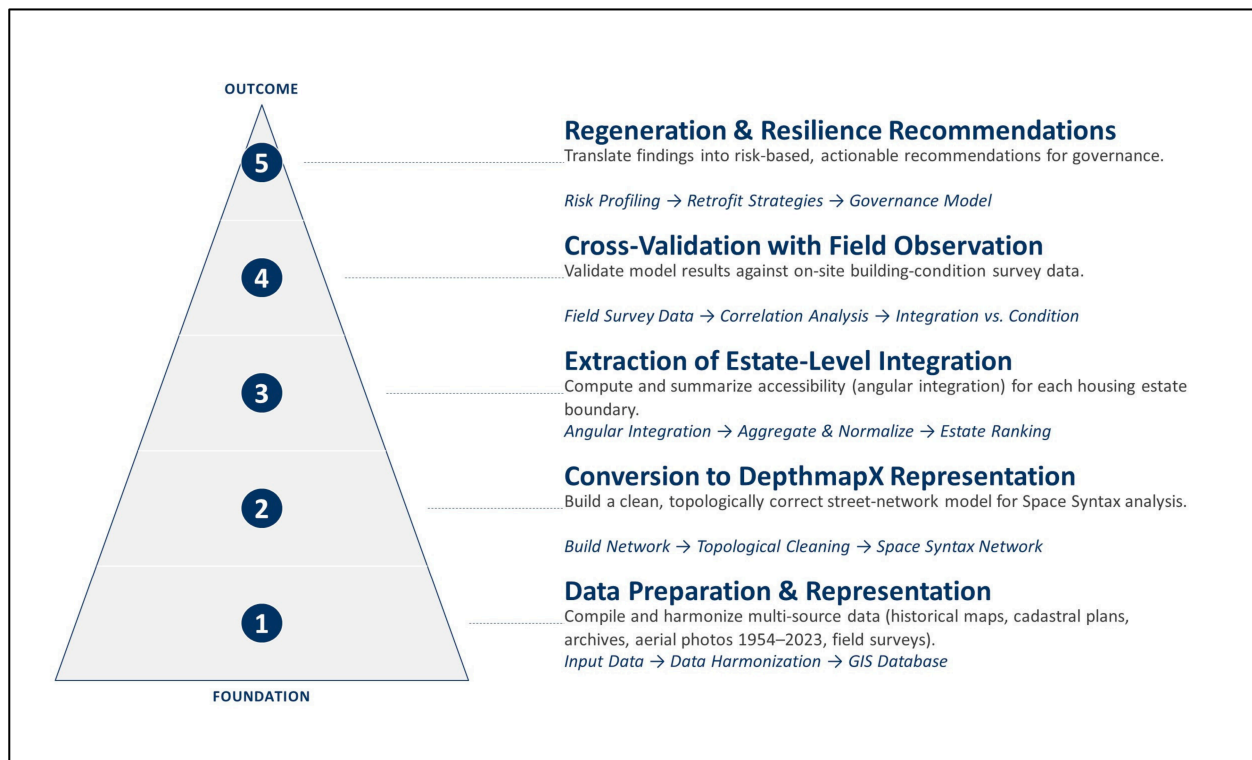


Figure 6. Overview of the four-step methodology: (1) data preparation and georeferencing, (2) conversion of road networks to DepthmapX representation, (3) extraction of estate-level NAIN values, and (4) cross-validation with field observations and (5) translation of the validated findings into risk-based regeneration and resilience recommendations.

3.6. Exploratory Control Analysis

An exploratory sensitivity analysis was performed to assess the stability of the observed association between NAIN and building condition. Contextual variables available in the supplementary estate inventory were used for this purpose, including construction date, developer/institutional type, density (units per bloc), and construction system (structural material, foundation type, and prefabrication technology). Each variable was examined individually to determine whether the direction and magnitude of the NAIN–building condition association remained consistent across contextual conditions.

Given the exploratory scope of this analysis ($n = 19$), the approach prioritized a qualitative consistency check over a formal adjusted model. Construction-system entries are coded in Supplementary Table S2.

4. Results

4.1. Overview of Integration Performance

Table 2 presents the NAIN value assessments for the 19 estates for which complete syntactic data were obtained. Figure 7 illustrates the spatial distribution and integration levels of the selected colonial mass housing estates in Greater Algiers; Figure 8 presents the ranked NAIN values for all 19 estates.

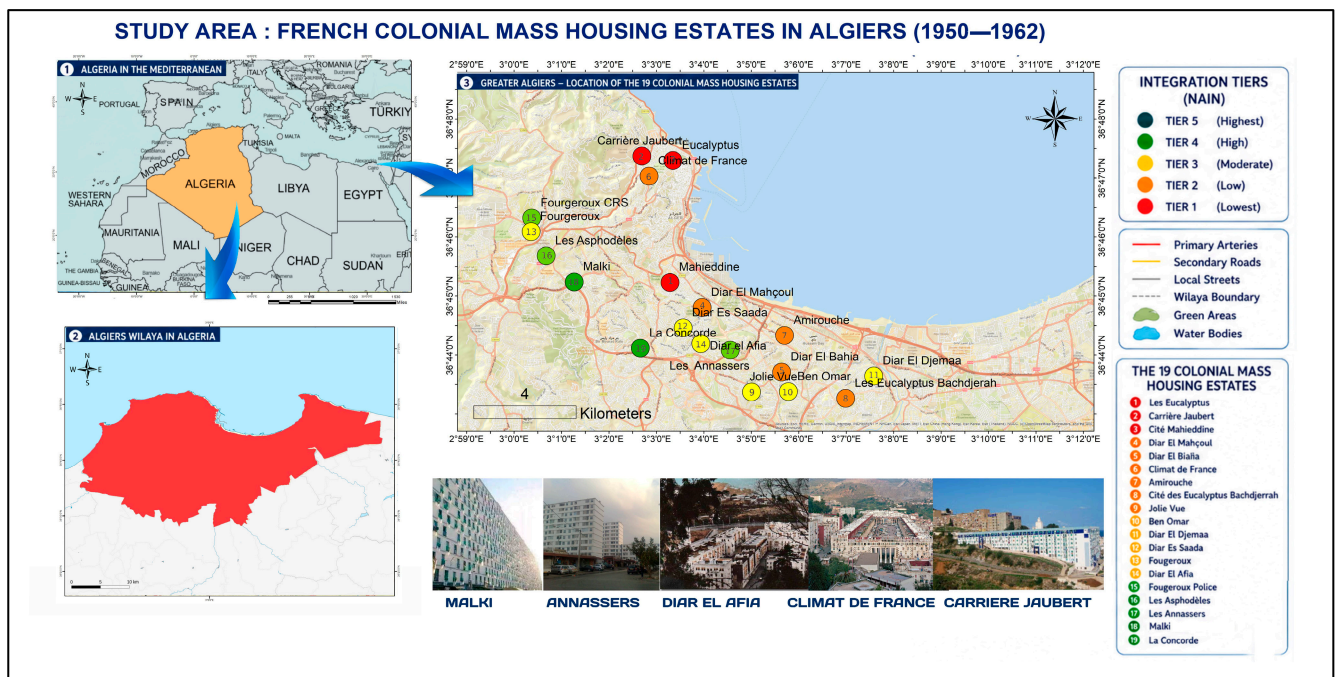


Figure 7. Map of the spatial distribution and integration levels of French colonial mass housing estates in Greater Algiers (1950–1962).

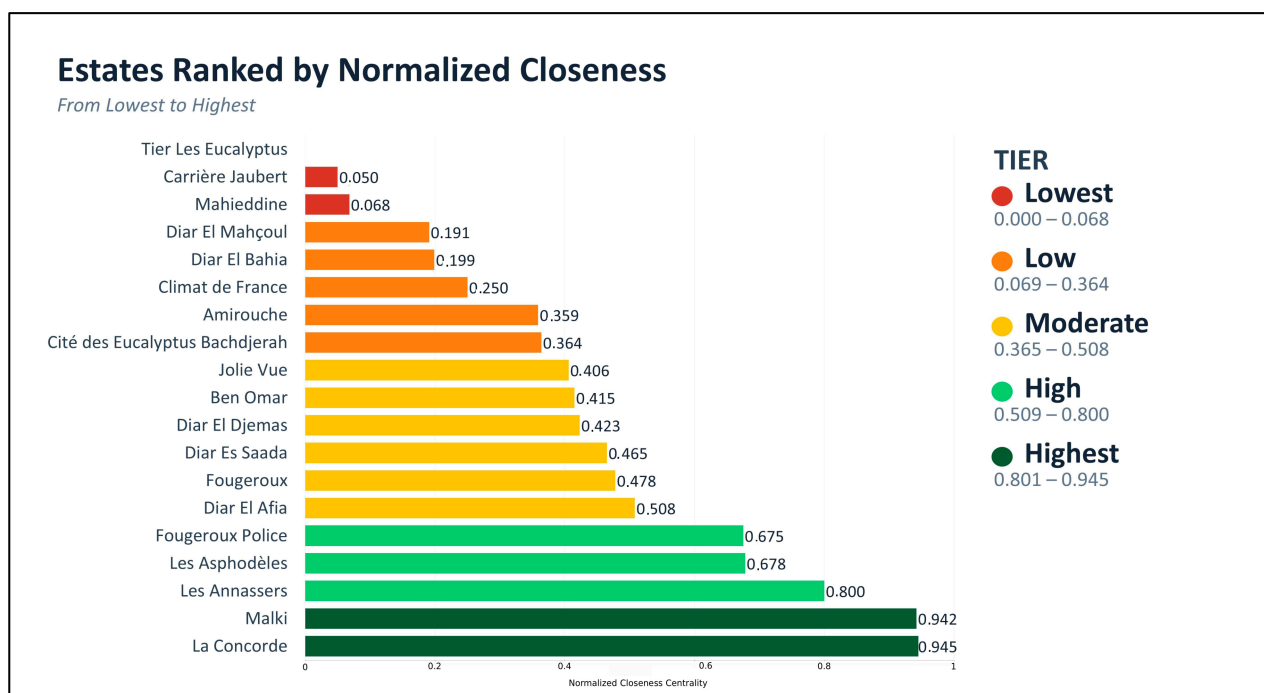


Figure 8. Bar chart of NAIN values for the 19 French colonial mass housing estates, ranked from least to most integrated.

Table 2. NAIN values for French Colonial mass housing estates in Algiers (1950–1962).

N	Name of the Estate	NAIN	Tier
1	Les Eucalyptus	0.00	1
2	Carrière Jaubert	0.05	1
3	Mahieddine	0.068	1
4	Diar El Mahçoul	0.191	2

Table 2. *Cont.*

N	Name of the Estate	NAIN	Tier
5	Diar El Bahia	0.199	2
6	Climat de France	0.25	2
7	Amirouche	0.359	2
8	Cité des Eucalyptus Bachdjerah	0.364	2
9	Jolie Vue	0.406	3
10	Ben Omar	0.415	3
11	Diar El Djemaa	0.423	3
12	Diar Es Saada	0.465	3
13	Fourgeroux	0.478	3
14	Diar El Afia	0.508	3
15	Fourgeroux CRS	0.675	4
16	Les Asphodèles	0.678	4
17	Les Annassers	0.8	4
18	Malki	0.942	5
19	La Concorde	0.945	5

4.2. Interpretation of Integration Results

Tier 5: 2 estates, La Concorde (0.945) and Malki (0.942), occupy the top positions, indicating near-maximum embeddedness within the street network. Their road layouts maintain exceptionally strong global topological centrality within the wider urban fabric.

High NAIN values are produced by a different topological condition: their internal routes function as through-routes rather than dead ends, meaning they contribute to the shortest angular paths between segments on either side of the estate. An estate whose internal streets are traversable in this way does not add depth to the network; it reduces it, pulling surrounding segments closer together and elevating its own integration value in the process.

Tier 4: 3 estates, Les Annassers (0.800), Les Asphodèles (0.678), and Fourgeroux CRS (0.675), form the second tier. Their spatial configurations allow strong movement flows and reasonable closeness centrality relative to the broader network. These estates, located in peripheral localities such as Kouba and Bouzareah, retain mild topological centrality despite their suburban positions.

Tier 3: 6 estates, Diar El Afia (0.508), Fourgeroux (0.478), Diar Es Saâda (0.465), Diar El Djemaa (0.423), Ben Omar (0.415), and Jolie Vue (0.406) form the middle tier. Their spatial configurations allow reasonable movement flows but are neither highly centralized nor deeply isolated. These estates tend to occupy inner suburban locations with partial connectivity to arterial routes.

Tier 2: 5 estates, Cité des Eucalyptus Bachdjerah (0.364), Amirouche (0.359), Climat de France (0.250), Diar El Bahia (0.199), and Diar El Mahçoul (0.191), fall into this tier. Their layouts exhibit limited topological integration to the surrounding network. Notably, Climat de France, despite its large scale, registers a low value (0.250), suggesting its internal grid remains poorly accessible to surrounding arteries.

Tier 1: 3 estates, Mahieddine (0.068), Carrière Jaubert (0.050), and Les Eucalyptus (0.000), share the lowest values in the sample, consistent with enclosed or cul-de-sac-heavy layouts that result in near-complete spatial segregation from the broader network. A cul-de-sac-dominated layout produces near-zero NAIN values through a specific topological mechanism: each dead-end segment can only be reached by reversing the path used to enter it, which means its angular depth from all other segments in the network is approximately double what a through-route of equivalent length would produce.

The sensitivity analysis performed using multiple angular radii (R1500–R10000) produced identical NAIN rankings and tier classifications across all 19 housing estates, confirming the stability of the reported configurational patterns.

4.3. Building Condition Assessment Results

4.3.1. Overview of Condition Performance Across the Sample

Table 3 shows building-condition scores for all estates across three physical dimensions: envelope condition, structural condition, and common-area condition.

Each estate is also assigned a tier. A composite overall condition score is calculated as the sum of the numerical scores assigned to the three assessment dimensions (range: 3–9). Figure 9 presents photographic documentation from field surveys, illustrating the range of building conditions observed across the French colonial mass housing estates in Algiers.

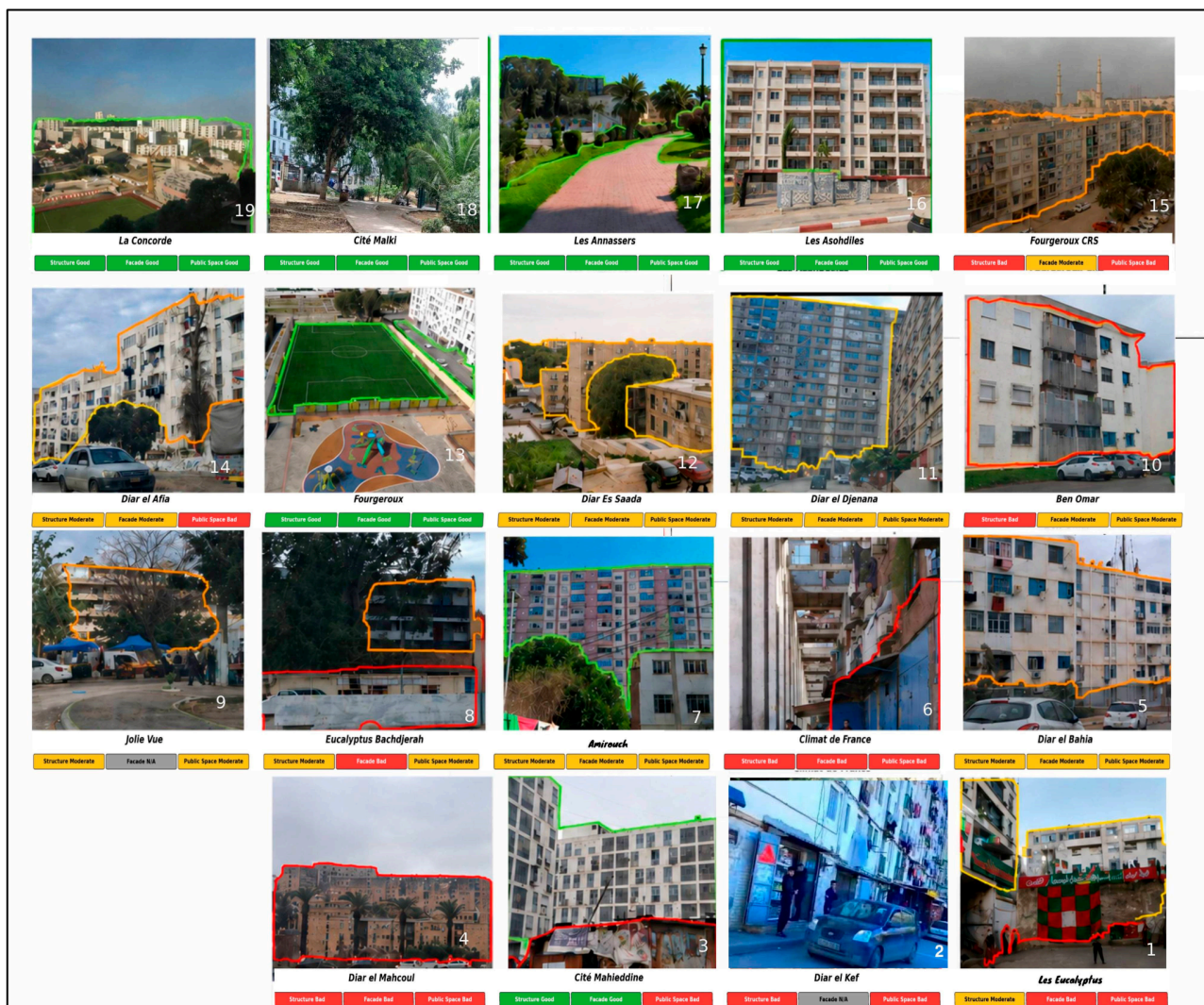


Figure 9. Field photographic documentation of the French colonial mass housing estates in Algiers, captured during field surveys.

Table 3. Building condition assessment results cross-tabulated with NAIN tier.

N	Estate Name	Structure	Facade	Public Space	Overall State	Score
1	Les Eucalyptus	Moderate	Bad	Bad	Bad	3
2	Carrière Jaubert	Bad	Bad	Bad	Bad	3

Table 3. *Cont.*

N	Estate Name	Structure	Facade	Public Space	Overall State	Score
3	Mahieddine	Good	Good	Bad	Moderate	7
4	Diar El Mahçoul	Bad	Bad	Bad	Bad	3
5	Diar El Bahia	Moderate	Moderate	Moderate	Moderate	6
6	Climat de France	Bad	Bad	Bad	Bad	3
7	Amirouche	Moderate	Moderate	Moderate	Moderate	6
8	Les Eucalyptus Bachdjera	Moderate	Bad	Moderate	Moderate–Bad	4
9	Jolie Vue	Moderate	Moderate	Moderate	Moderate	6
10	Ben Omar	Moderate	Moderate	Moderate	Moderate	6
11	Diar El Djemaa	Moderate	Moderate	Moderate	Moderate	6
12	Diar Es Saada	Moderate	Moderate	Moderate	Moderate	6
13	Fourgeroux	Good	Good	Good	Good	9
14	Diar El Afia	Moderate	Moderate	Bad	Moderate–Bad	4
15	Fourgeroux CRS	Bad	Moderate	Bad	Bad	4
16	Les Asphodèles	Good	Good	Good	Good	9
17	Les Annassers	Good	Good	Good	Good	9
18	Malki	Good	Good	Good	Good	9
19	La Concorde	Good	Good	Good	Good	9

4.3.2. Relationship Between Spatial Integration and Building Condition

A comparison between NAIN values and field-condition assessments reveals a clear tendency for Tier 4 and Tier 5 estates generally obtained good overall condition ratings. For example, La Concorde (NAIN = 0.945), Malki (0.942), Les Annassers (0.800), and Les Asphodèles (0.678) all display good structural condition, well-maintained façades, and high-quality public spaces.

In contrast, estates located within tiers 1 and 2 tend to present the poorest physical conditions. Diar El Mahçoul (0.191) and Climat de France (0.250) are characterized by deteriorated structures, degraded façades, and bad public-space quality. Similarly, Les Eucalyptus (0.000) and Mahieddine (0.068) occupy the lowest integration category and show significant deficiencies in at least one physical dimension.

Tier 3 presents a more heterogeneous pattern. Estates such as Ben Omar, Diar Es Saada, Diar El Djemaa, and Jolie Vue generally achieve moderate ratings across all dimensions, suggesting that intermediate accessibility is associated with average levels of maintenance. However, some exceptions are evident. Fourgeroux CRS exhibits a relatively high NAIN value (0.675) while remaining in bad physical condition, indicating that spatial accessibility alone does not guarantee building maintenance. Likewise, Cité Mahieddine shows good structural and façade conditions despite belonging to the lowest integration tier, although its public space remains very degraded.

Field observations also revealed the presence of informal transformations in several estates, including balcony enclosures, façade alterations, extensions of ground-floor units, and modifications of collective open spaces. These interventions appear to reflect residents' efforts to adapt aging housing stock to evolving social and functional requirements. Although informal transformations were not systematically quantified in the present study, their recurrence across multiple estates suggests that they constitute an important dimension of the long-term evolution of colonial mass housing environments and deserve further investigation. Figure 10 presents highlighted examples of resident-led modifications, including balcony enclosures, window alterations, and façade extensions.



Figure 10. Visual evidence of informal residential transformations in Fourgeroux (Tier 3), Les Asphodèles (Tier 4), and Diar El Bahia (Tier 2).

Importantly, the distribution of these transformations did not appear to follow the NAIN hierarchy. Similar forms of modification were observed in estates belonging to different integration tiers, indicating that the propensity for resident adaptation is not necessarily linked to the degree of spatial integration. Rather, these interventions appear across both highly integrated and poorly integrated estates, suggesting that they are driven by household needs and socio-economic factors rather than configurational accessibility alone. The resulting alterations contribute to increasing façade heterogeneity and illustrate the ongoing appropriation and adaptation of housing environments over time.

A moderate-to-strong positive correlation was observed between normalized angular integration (NAIN) and the condition score of the housing estates in Algiers ($\rho = 0.678$, $p = 0.0014$, $n = 19$). This indicates that estates with higher levels of spatial integration tend to exhibit better physical conditions. Linear regression yielded an $R^2 = 0.472$, indicating that approximately 47.2% of the variance in condition scores is explained by spatial integration. As shown in Figure 11, the scatter plot confirms a clear positive relationship between NAIN values and the normalized physical condition of the estates. The Sankey diagram further illustrates this relationship by showing that estates located within the higher integration tiers (Tiers 4–5) are predominantly associated with Good physical condition, whereas estates characterized by lower spatial integration (Tiers 1–2) are more frequently associated with Moderate–Bad or Bad conditions. The Sankey diagram Figure 11 further illustrates that estates classified under high integration tiers (Tier 4–5) are predominantly in Good physical condition, while those in lower integration tiers (Tier 1–2) are more likely to fall into Moderate–Bad or Bad categories.

From a resilience perspective, the results indicate that integration and building condition should be considered complementary dimensions of long-term residential performance. Estates combining high accessibility with good physical condition exhibit greater capacity to sustain everyday urban functions, whereas isolated estates affected by deterioration are likely to require more comprehensive regeneration strategies.

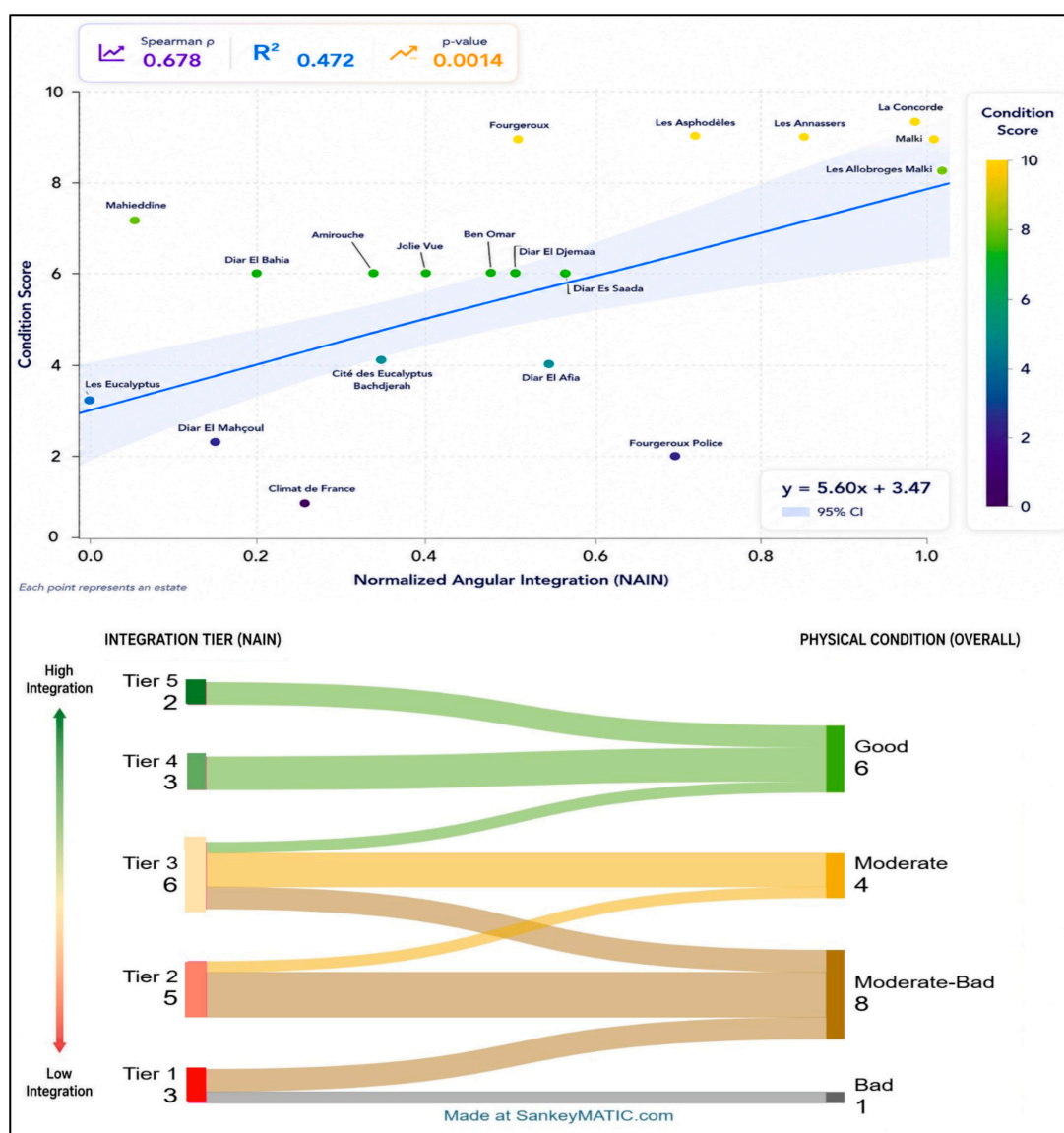


Figure 11. Relationship Between Spatial Integration and Physical Condition of Residential Estates in Algiers: A Scatter Plot and Sankey Diagram Analysis.

4.4. Exploratory Sensitivity Analysis

The exploratory sensitivity analysis indicated that the positive association between NAIN and building condition remained broadly consistent across the available contextual conditions, including construction period, developer/institutional type, housing density, target population, and construction system. While these contextual factors may contribute to the long-term evolution of individual estates, none of them provided a more consistent explanation of building condition than spatial integration within this dataset. Table 4 summarizes the observations for each dimension of the sensitivity analysis.

Table 4. Summary of exploratory observations for contextual variables included in the sensitivity analysis.

Contextual Variable	Observation from the Estate Inventory
Construction period	Estates constructed during similar periods were distributed across different NAIN tiers and building-condition classes.

Table 4. *Cont.*

Contextual Variable	Observation from the Estate Inventory
Developer/institutional type	Estates developed by HLM, CIA, Planning Agency and other institutions exhibited varying levels of integration and condition.
Housing density	Both higher- and lower-density estates displayed a wide range of physical conditions.
Target population (SES proxy)	Estates intended for different population groups occurred across both high- and low-performing categories.
Construction system	The documented Pouillon construction system was observed in estates with different integration levels and condition outcomes.

5. Discussion

5.1. Integration Patterns and the Spatial Logic of Colonial Housing

The integration analysis reveals substantial variation between colonial mass housing estates and the Algiers street network. Since location, size, and construction period are comparable across the sample, social function best explains these differences.

This pattern refines the arguments of Zeynep Çelik [6] and Samia Henni [71] regarding colonial urbanism as a system of socio-spatial control. If segregation had been applied uniformly, integration values would be consistently low across the sample. Instead, the results show strong polarization.

Estates built to rehouse displaced populations, including Climat de France, Diar El Mahçoul, and Carrière Jaubert, occupy the lowest positions [72], whereas estates in European residential districts such as Kouba and Birmandreïs record the highest values. Spatial segregation was therefore selective, achieved through morphological means: low-ranked estates function as gated enclaves, with reduced access points, severed through-routes, and harsh perimeter boundaries that isolate them from the surrounding network [26,73].

Similar morphological patterns have been documented in French grands ensembles such as Sarcelles, La Courneuve, and Les Minguettes [74,75], where they emerged as a general consequence of modernist planning [76,77]. García-Pérez et al., in a work analyzing Spanish mass housing estates over fifty years, found that spatial accessibility was largely determined by original layout decisions and proved resistant to change through incremental densification and infill [78].

In Algiers, however, the same spatial mechanisms were concentrated in estates for displaced and colonized populations. The results therefore indicate that modernist spatial forms operated not only as a planning doctrine but also as a selective instrument of colonial population management. Space syntax makes this distinction measurable, revealing both the spatial mechanism and the degree of segregation embedded within the urban network [11,79,80].

The physical condition gradient observed across the estates is consistent with differences in street-network configuration. Lower levels of spatial integration may contribute to reduced pedestrian activity, lower investment attractiveness, and weaker natural surveillance, but building deterioration is also shaped by maintenance practices, governance, socioeconomic conditions, historical investment, and resident adaptations.

Contemporary urban research consistently demonstrates that pedestrian movement is strongly structured by spatial integration and network connectivity, which together shape urban accessibility and flow intensity. Highly integrated street systems tend to concentrate

movement flows, whereas poorly connected and segregated networks suppress pedestrian activity and reduce the functional performance of adjacent urban space [79,81,82].

The exploratory sensitivity analysis supports this interpretation. Although the estates differ in construction technology, development period, housing density, institutional origin, and tenure-related proxies, the overall association between NAIN and building condition remained broadly consistent. These observations suggest that spatial integration contributes additional explanatory information beyond the descriptive characteristics of the estates.

Spatial integration may be considered an important dimension of urban resilience because it is associated with the long-term capacity of residential neighborhoods to maintain functionality despite physical aging [83]. It is therefore not only a morphological indicator but also a sustainability dimension that can inform urban regeneration strategies aligned with the objectives of United Nations Sustainable Development Goal 11.

5.2. From Deterioration to Retrofit: Implications for Sustainable Regeneration

Retrofit-oriented regeneration is a promising strategy for many of the surveyed estates [84], consistent with previous studies in Algeria showing that upgrading building envelopes can improve environmental performance while preserving architectural value [85]. The estates retain substantial embodied resources, and replacement would carry significant material and social costs; retrofit strategies such as structural repair, services upgrading, and façade rehabilitation offer a more resource-efficient alternative, in line with circular economy principles in regeneration policy [86].

Renovation also avoids the large upfront carbon cost of demolition and rebuilding [87], is generally cheaper over a building's lifespan [88], and is structurally justified except where damage is severe [89], consistent with most estates here scoring Moderate–Good in Table 3. It avoids the resident displacement seen in demolition-led regeneration elsewhere [90,91], allowing informal adaptations observed here (Figures 10 and 12) to be built on rather than erased. A dedicated cost, carbon, and social impact comparison for these estates is left for future research.

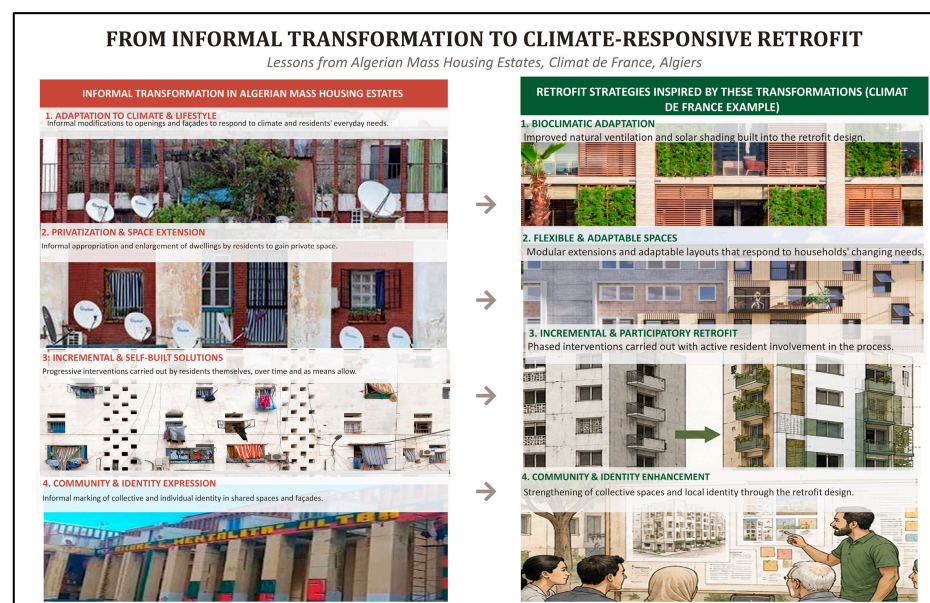


Figure 12. From Informal Transformation to Climate-Responsive Retrofit: Lessons from the Climat de France Estate, Algiers.

Beyond accessibility and physical performance, regeneration should preserve the heritage of these colonial mass housing estates [92], particularly those by Fernand Pouillon,

whose spatial composition, local materials, and architectural quality constitute important twentieth-century heritage [93]. Interventions improving spatial integration should adopt a conservation-led approach, favoring reversible, minimally invasive modifications that enhance connectivity while respecting original morphology and character [94].

Informal transformations should be read not only as evidence of neglect but as evidence of residents' adaptive capacity [95]. Regeneration frameworks incorporating compatible resident-led modifications within coherent technical guidelines are more likely to achieve durable outcomes than systematic removal. Figure 12 illustrates how such adaptations can inform socially grounded retrofit interventions.

5.3. Energy Retrofit in Mass Housing Estates

Beyond physical repair, regeneration strategies should integrate energy-efficiency improvements and climate-responsive measures. In mass housing estates, façade insulation, window upgrading, passive environmental strategies, and renewable energy systems have been identified as effective approaches for improving building performance while extending the lifespan of existing residential stock [96]. Comparable retrofit-based regeneration approaches have been documented in Mediterranean mass housing contexts such as the brutalist housing estates of Marseille (France), the Ciutat Meridiana and Torre Baró districts in Barcelona (Spain), and the Vale da Amoreira estate in Portugal, where thermal refurbishment, façade rehabilitation, and public-space upgrading were implemented as alternatives to demolition [97,98]. These cases demonstrate a shift toward energy-led regeneration strategies in Southern European social housing environments exposed to similar climatic conditions.

Figure 13 Conceptual framework illustrating how spatial integration in colonial housing estates in Algiers drives a sequential process of either urban decline or vitality, leading to two parallel regeneration strategies, framed within the SDG 11 agenda for sustainable, inclusive, and resilient cities.

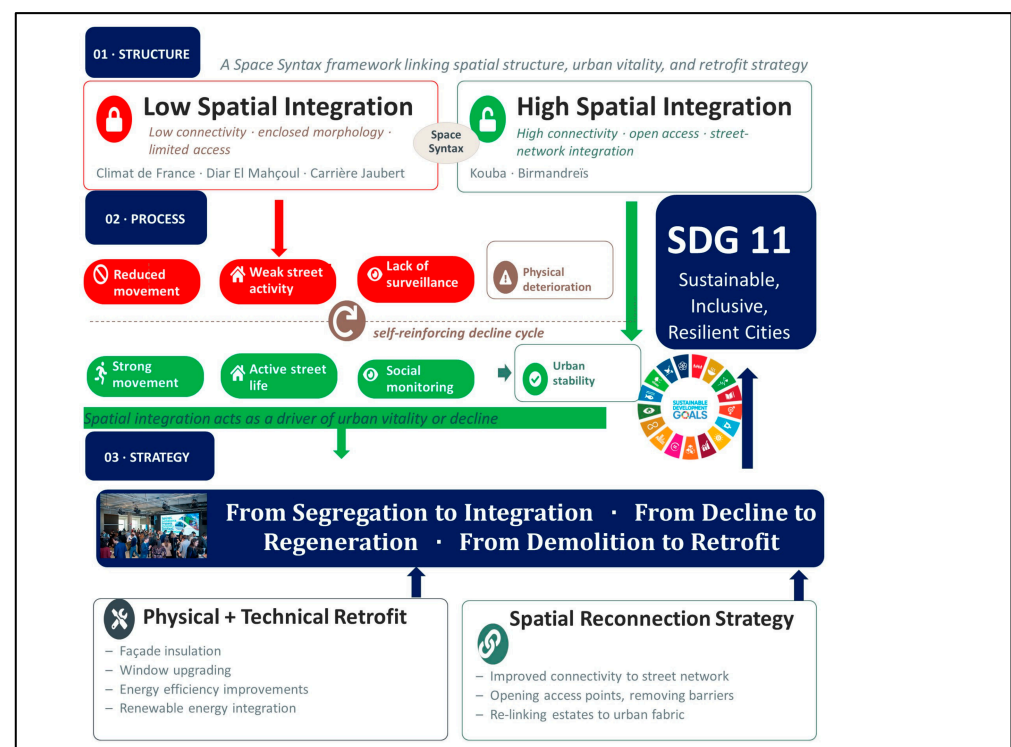


Figure 13. From Spatial Structure to Regeneration Strategy.

5.4. Regeneration by Integration Tier

The following regeneration recommendations are organized by tier, drawing on the morphological findings of the preceding sections and the NAIN assessments. Tiers 1–2. Estates belonging to Tiers 1 and 2 represent the most critical cases. Their near-zero integration values indicate severe configurational isolation, while the condition assessment reveals consistently poor performance across building structures, façades, and public spaces. This combination of spatial segregation and physical deterioration creates a cycle of decline characterized by limited accessibility, weak pedestrian movement, and reduced urban vitality. Consequently, regeneration efforts should prioritize spatial reconnection.

At least one strategic link between the internal street network and surrounding urban arteries should be established to reduce topological isolation. Selective through-routes inspired by the more integrated configurations observed in Tiers 4 and 5 may improve accessibility and movement potential. These spatial interventions should be accompanied by façade rehabilitation, repair of building envelopes, and upgrading of shared residential components. At the public-space level, pedestrian areas, communal spaces, and collective facilities should be renewed to restore activity, social interaction, and natural surveillance. The overall objective is to reverse the combined effects of spatial isolation and physical deterioration through integrated physical and spatial regeneration measures.

Tier 3. Occupies an intermediate position within the integration hierarchy and is characterized by moderate accessibility levels associated with generally stable but heterogeneous physical conditions. Although these estates benefit from a reasonable degree of spatial integration, variations in maintenance and environmental quality indicate uneven performance among estates with similar configurational characteristics. Regeneration strategies should therefore focus on consolidation rather than transformation. Spatial interventions should aim to improve permeability and legibility through the upgrading of pedestrian connections and the removal of minor physical barriers. Building-level actions should emphasize routine maintenance, localized façade and envelope repairs, and the gradual improvement of collective facilities.

Public-space interventions should remain relatively light, focusing on lighting, shading, seating, and landscape enhancement to improve usability and comfort. Given the variability observed within this tier, intervention priorities should be determined at the estate level rather than through a uniform regeneration program. For example, the good envelope condition recorded in Diar El Afia contrasts with the poorer common-area performance observed in Diar El Djemaa, highlighting the need for targeted maintenance strategies. The primary objective is to consolidate existing spatial performance, maintain acceptable physical conditions, and prevent future deterioration.

Tiers 4–5. Estates classified in Tiers 4 and 5 exhibit the highest levels of configurational integration and generally better physical conditions. Their urban structure already functions as a well-connected system, reducing the need for major spatial restructuring.

In these cases, the principal challenge is not to create connectivity but to preserve and enhance the benefits associated with existing spatial integration. Interventions should therefore focus on improving pedestrian continuity, crossing safety, and the legibility of internal routes while maintaining the overall network structure. At the building scale, preventive maintenance, façade upkeep, and conservation of architectural quality should be prioritized, with localized refurbishment limited to deteriorated sections.

Public-space improvements should concentrate on design quality through enhanced paving, lighting, seating, shading, landscaping, and clearer spatial hierarchy. Long-term performance also depends on effective urban management, including regular maintenance programs, waste management systems, and appropriate governance of shared spaces. The objective is to enhance environmental quality, everyday usability, and residential satisfac-

tion while preserving the spatial advantages associated with high levels of integration and supporting long-term community stewardship [99–101].

Beyond guiding physical interventions, the proposed framework supports evidence-based urban governance by combining spatial integration with building-condition assessment to prioritize regeneration investments objectively. Its implementation requires coordination among planning authorities, housing agencies, infrastructure providers, heritage organizations, and local communities. Moreover, the informal transformations observed across several estates highlight residents' adaptive responses to changing needs. Integrating participatory governance with technical assessment can therefore improve the effectiveness, long-term resilience, and sustainability of regeneration strategies. Figure 14 Conceptual framework illustrating the hierarchical relationship among seven dimensions. The model proposes that improvements in spatial integration, accessibility, maintenance, and building condition support effective urban regeneration and governance, which in turn contributes to sustainable development and ultimately strengthens urban resilience.

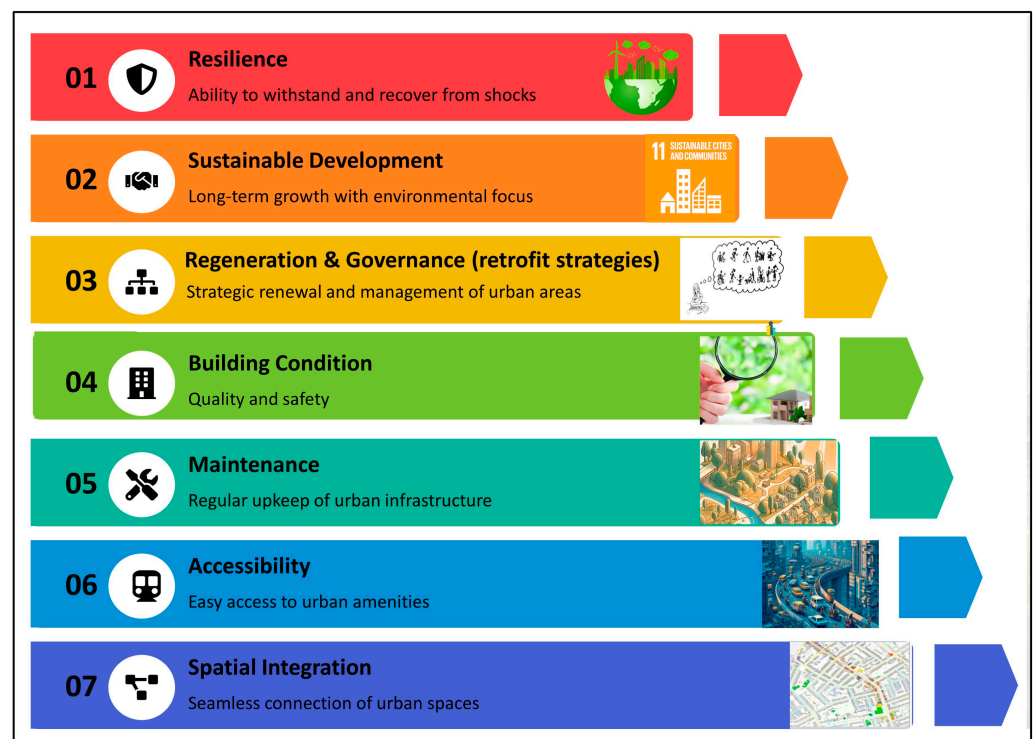


Figure 14. Conceptual urban hierarchy leading to urban resilience.

Table 5 provides a concise summary of the recommended regeneration priorities across the identified integration tiers, highlighting the main challenges, key interventions, and corresponding governance approaches.

Table 5. Regeneration priorities according to integration tier.

Tier	Main Challenge	Priority Intervention	Governance Approach
Tiers 1–2	Spatial isolation and advanced physical deterioration	Urban connectivity, Façade rehabilitation, Public-space regeneration	Strategic regeneration governance through coordinated action among key stakeholders
Tier 3	Uneven maintenance and localized deterioration	Pedestrian permeability, Routine maintenance, Public-space upgrades	Adaptive maintenance governance
Tiers 4–5	Preservation of existing spatial and environmental quality	Pedestrian continuity, Preventive conservation, Public-space quality and management	Preventive asset-management governance.

6. Conclusions

This study investigated the relationship between spatial configuration and long-term building condition in French colonial mass housing estates in Algiers (1950–1962) through an integrated methodology combining GIS-based inventory, space syntax analysis using Normalized Angular Integration (NAIN), and systematic field-based condition assessment.

The results reveal a clear spatial gradient across the housing estates. Highly integrated estates (Tiers 4 and 5) occupy central positions within the street network and systematically exhibit better building conditions and higher-quality public spaces. In contrast, low-integration estates (Tiers 1 and 2) are characterized by spatial isolation and higher levels of physical degradation. This pattern suggests that spatial configuration is associated with maintenance intensity and everyday use patterns of residential districts, with direct implications for the social and economic sustainability of these neighborhoods, as isolated estates are more prone to disinvestment, reduced walkability, and the gradual erosion of community life.

The statistical analysis indicates a moderate positive correlation between NAIN and overall building condition score ($\rho = 0.678$, $p = 0.0014$, $n = 19$), suggesting that more integrated street networks tend to be associated with more sustainable physical outcomes. While the relationship is not strictly deterministic, it suggests that configurational integration may play a role in shaping more favorable physical conditions in urban housing.

From a sustainability and urban policy perspective, the findings underline the importance of integrating spatial network analysis into regeneration strategies for large housing estates. The proposed tier-based framework demonstrates that intervention priorities should be differentiated according to both spatial integration and physical condition.

Low-integration estates demand structural reconnection and targeted physical rehabilitation. Field-observed informal transformations indicate that future regeneration should prioritize retrofit-oriented interventions. Moderately integrated estates benefit from incremental improvements in permeability, maintenance systems, and public-space usability. High-integration estates, by contrast, should be managed through conservation-oriented approaches, focusing on preventive maintenance and governance rather than structural transformation.

This approach can support regeneration processes by assisting authorities in allocating spatial and governance recommendations more efficiently. Although developed for the colonial mass housing estates of Algiers, the methodological approach may provide a useful analytical framework for investigating other aging mass housing estates. However, its application should be adapted to local planning histories, governance systems, architectural characteristics, and socioeconomic contexts before being generalized.

Some limitations should be considered. First, the analysis was conducted on a relatively small sample, reflecting the complete population that met the selection criteria within Algiers rather than a statistically large dataset. Consequently, the study relied on non-parametric correlation analysis and an exploratory sensitivity analysis.

Second, several contextual variables were examined only through an exploratory sensitivity analysis rather than a formal multivariate statistical framework, and the condition assessment was limited to external visual inspections. Therefore, it could not capture concealed structural or internal environmental defects.

Third, some potentially relevant contextual factors could not be included because reliable and comparable estate-level data were unavailable. In particular, long-term maintenance investment, detailed socioeconomic and demographic indicators, and property ownership and rental structures could not be systematically incorporated into the quantitative analyses because reliable and comparable estate-level data were unavailable.

Finally, the study identifies statistical associations rather than causal relationships. While the results demonstrate a positive relationship between street-network integration and the physical condition of the surveyed estates, building deterioration remains a multi-dimensional process operating over time.

Future research should extend the database to include a larger number of housing estates and additional contextual indicators, allowing the application of multivariate statistical models and longitudinal analyses to better quantify the relative contribution of configurational, socioeconomic, governance, and construction-related factors to the long-term performance of mass housing estates.

In addition, future research should include larger samples and contextual variables to enable multivariate analyses and complementary approaches such as Qualitative Comparative Analysis (QCA), thereby improving the robustness and generalizability of the findings. It should also quantify resident-led spatial modifications using standardized indicators to assess their contribution alongside spatial integration.

Overall, the findings suggest that spatial configuration is an important, though often overlooked, dimension of urban sustainability. It shows that street-network structure is not only a morphological feature but also a spatial characteristic that may contribute to patterns of urban resilience. Integrating configurational analysis with building-condition assessment provides a potential transferable framework for evidence-based regeneration, supporting resilient governance, sustainable investment decisions, and the long-term preservation of aging mass housing estates.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/buildings16163309/s1>. Supplementary Table S1 provides the complete inventory of the 19 housing estates and their historical, architectural, and urban characteristics. Supplementary Table S2 presents the contextual variables used in the exploratory sensitivity analysis. Supplementary Table S3 summarizes the representative estates supporting the proposed tier-based regeneration framework.

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Abbreviations

The following abbreviations are used in this manuscript:

NAIN	Normalized Angular Integration
GIS	Geographic Information Systems
PDAU	Plan Directeur d'Aménagement et d'Urbanisme
DTR	Regulatory Technical Documents (Document Technique Réglementaire)

Appendix A

Table A1. Public Space Condition Assessment Criteria.

Domain	Assessment Criterion	Field-Observable Indicators
Accessibility and Mobility	Continuity of pedestrian paths	Breaks in continuity, obstacles, sidewalk width, accessibility for people with reduced mobility (PRM)
	Condition of stairs and ramps	Deterioration, slope/grade, handrails, safety
	Urban connection	Linkage with main streets, permeability, isolation/enclosure
Surfaces and Pavement	Physical condition of the ground surface	Cracks, potholes, subsidence, wear
	Quality of materials	Durability, homogeneity, slip resistance
	Stormwater drainage	Water stagnation, runoff, dampness
Vegetation and Landscape	Presence of vegetation	Number of trees, vegetation cover, shading
	Health of plantings	Dead trees, maintenance, protection
	Ecological compatibility	Species suited to the local climate
Public Lighting	Lighting performance	Dark zones, uniformity of lighting
	Nighttime safety	Sense of insecurity, hidden/concealed spaces
	Aesthetic integration	Consistency of fixtures with the urban landscape
Street Furniture	Availability and condition	Benches, bins, bollards, equipment
	Ergonomics	Comfort, accessibility, actual use
	Resistance to vandalism	Deterioration, fixing/anchoring, maintenance
Cleanliness and Waste	Waste management	Illegal dumping, overflowing containers
	Integration of waste facilities	Position, accessibility, visual impact
	Character of the place	Heritage value, local identity
Identity and Urban Quality	Spatial legibility	Orientation, signage, comprehension of space
	Landscape coherence	Harmony between built form and open space

Table A2. Building Façade Condition Assessment Criteria.

Domain	Assessment Criterion	Field-Observable Indicators
Visible Structure Exterior Cladding	Visual stability	Cracks, deformation, detached or loose elements
	Condition of the cladding/finish	Detachment, dampness, staining, color loss
	Chromatic uniformity	Consistency of colors and materials
Openings	Condition of windows and doors	Deterioration, unauthorized or inconsistent replacement
	Architectural homogeneity	Dimensions, rhythm, alignment
	Safety	Corrosion, cracking, fragility
Balconies and Railings	Aesthetic quality	Uncontrolled or unauthorized modification
	Quality of the urban threshold	Doors, lobbies, legibility, accessibility
	Presence of discordant elements	Air-conditioning units, satellite dishes, cables, clotheslines
Parasitic Equipment	Condition of downpipes	Leaks, damp staining, integration
	Architectural integration	Visible networks, cables, ducts, conduits
	Conservation	Loss, deterioration, removal

Table A3. Structural Elements Visible on the Façade Assessment Criteria.

Domain	Assessment Criterion	Field-Observable Indicators
Visible Columns and Pilasters	Integrity of vertical load-bearing elements	Vertical or diagonal cracking, spalling, exposed reinforcement, loss of section, buckling, visible deformation
Beams and Lintels	Condition of horizontal structural members	Cracking at mid-span or supports, deflection, spalling, corrosion staining, lintel failure
Façade Wall/Bearing Walls	General wall stability and material integrity	Diagonal or stepped cracking, bulging, hollow-sounding masonry, open joints, loss of mortar
Floor Slabs and Cantilevered Elements	Visible edge condition of slabs and overhangs	Spalling, exposed reinforcement, excessive deflection, cracking, fascia detachment
Structural Joints and Connections	Condition of expansion joints and connections	Failed seals, displacement, open joints, water infiltration
Crack Pattern Analysis	Severity and nature of cracking across the façade	Hairline or structural cracks, active or dormant cracks, diagonal, vertical, horizontal, or map cracking
Deformation and Settlement	Observable signs of differential movement	Tilting, stair-step cracking, distorted openings, misaligned floors
Structural Material Degradation	Visible deterioration of structural materials	Carbonation, corrosion, stone weathering, masonry erosion, timber rot, insect damage
Roof and Roofing	Condition of roof covering	Damaged or missing tiles, leaks, sagging, deformation
	Drainage and rainwater outlets	Damaged gutters, downpipes, overflow staining
Foundations and Plinth	Visual condition of the plinth and base	Cracking, rising damp, settlement, erosion, exposed materials
	Ground–structure interface	Subsidence, vegetation intrusion, water pooling, biological growth
Exterior Staircases and Fire Escapes	Structural condition	Corrosion, cracking, missing steps, instability
	Safety and compliance	Handrails, slip resistance, lighting, signage, obstruction of escape routes

Table A4. BCA Score Rating Scale (0–9).

Overall BCA Score	Overall Condition Class	Interpretation
7–9	Good	Generally good physical condition, with only routine maintenance or localized interventions required.
5–6	Moderate	Noticeable but non-critical deterioration requiring maintenance and/or localized rehabilitation.
3	Bad	Extensive deterioration across the assessed dimensions, requiring substantial rehabilitation and priority intervention.

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