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Spatial configurations in rehabilitated social housing: a relational analysis of design patterns in Brazil

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Abstract
The rehabilitation of vacant buildings in central urban areas constitutes a promising – yet still underexplored in Brazil – alternative for delivering social housing (SH) in a more sustainable and spatially integrated manner. This article aims to characterize rehabilitated buildings through design patterns, based on the theory of Christopher Alexander, which proposes solutions oriented toward enhancing architectural and urban qualities. Initially, patterns potentially applicable to this context were identified, forming a relational analytical framework: rather than being examined in isolation, they are analyzed in terms of co-occurrence, considering their combined effects and topological performance within the design structure of buildings. Subsequently, this framework is applied to a sample of ten rehabilitated buildings in Brazil, using architectural documentation and on-site visits. Data analysis was conducted through the construction of networks in VOSviewer, complemented by centrality metrics (Degree and Betweenness Centrality) to interpret their relational structure. The results indicate the presence of strongly connected design cores and patterns that perform articulating roles across different spatial scales, suggesting the existence of a recurring spatial grammar in the context of rehabilitation. Additionally, they show that the configuration of SH produced through rehabilitation tends to result from the articulation between constructive attributes, functional organization, collective spaces, and urban insertion. This analytical reading provides support for the formulation of design guidelines and the improvement of evidence-based public policies aimed at housing provision in central urban areas.

Keywords: Rehabilitation. Social housing. Urban areas. Christopher Alexander.

1. Introduction

In Brazil, the implementation of large-scale social housing developments in peripheral urban areas – driven by budget constraints, the search for low-cost land, and the feasibility of large-scale construction – has historically resulted in projects disconnected from essential urban infrastructure, thereby compromising housing quality and exacerbating urban inequalities (Maricato, 2015; Libertun de Duren, 2018; Gallo et al., 2022). This model of housing provision not only limits access to the city but also dissociates housing policy from consolidated urban dynamics. In this context, housing provision should be understood not merely as a quantitative response to the housing deficit, but as a component that shapes how the built environment is organized and appropriated, with direct effects on access to services, mobility, and urban opportunities (Murray & Clapham, 2015; Mouratidis, 2021; Muianga & Kowaltowski, 2024).

Conversely, the rehabilitation of vacant buildings for residential purposes has emerged as a strategy to address not only the housing deficit, but also urban degradation and the growing demand for more sustainable and socially inclusive housing solutions. This approach combines environmental, economic, and social benefits, while also improving access to services, infrastructure, and established mobility networks (Pomponi & Moncaster, 2017; Martins & Salcedo, 2018; Kern & Zuliani da Silva, 2024). In this sense, the

reintegration of social housing into central areas contributes to this debate by enabling the articulation between housing and existing infrastructure, fostering more integrated forms of occupation within the consolidated urban fabric (Savoie et al., 2025).

In contrast to the logic of standardization and economies of scale commonly observed in peripheral housing production in Brazil, the rehabilitation of buildings requires approaches that are more sensitive to context and to the pre-existing built environment (Savoie et al., 2025). It is within this perspective that Christopher Alexander's Pattern Language (Alexander et al., 1977) can be situated, advocating the use of recurrent and interrelated design solutions based on universal human needs and adaptable to different cultural and situational contexts. These patterns articulate spatial and social dimensions, proposing guidelines that can inform the creation of more inclusive and meaningful environments, and can be applied adaptively across diverse contexts (Barros & Pina, 2010; Postle & Salingaros, 2025; Wu et al., 2025).

Although building rehabilitation has gained increasing attention in academic and institutional debates, approaches that investigate how specific design solutions contribute to the configuration of the housing environment in rehabilitated buildings remain limited – particularly with regard to the relationship between private and collective spaces and their integration within the immediate urban context. In this regard, the theory proposed by Alexander et al. (1977) is not employed as an end in itself, but as an analytical framework capable of revealing how spatial solutions are combined and structured relationally in housing rehabilitation cases. This study is therefore grounded in the assumption that analyzing the presence and configuration of such patterns can provide insights into the design strategies underlying housing production through rehabilitation in the Brazilian context.

Based on these premises, the objective of this article is to investigate the occurrence, connections, and interrelations among design patterns, grounded in the theory of Alexander et al. (1977), identified in a sample of ten rehabilitated buildings in Brazil. In doing so, the study aims to contribute to this field by examining, from a relational perspective, how design patterns are articulated in the spatial organization of rehabilitated social housing, highlighting implications for use, appropriation, and socio-spatial integration within the housing environment.

2. Building rehabilitation in urban areas

The social housing sector in Brazil faces a significant housing deficit alongside constraints in the availability of resources. This scenario has often been used to justify the adoption of solutions that prioritize low-cost land, resulting in the implementation of large-scale housing developments – frequently exceeding 500 units – in peripheral urban areas, far from essential infrastructure (Libertun de Duren, 2018; Gallo et al., 2022). This approach, historically embedded in Brazilian housing policy and also observed in other Latin

American countries, exacerbates the challenges faced by residents by disregarding the broader urban context (Maricato, 2015) and limiting access to the benefits offered by central urban areas (Anitelli, 2017).

Within this framework, housing tends to be treated as a commodity produced on inexpensive land, rather than as an integrated component of the right to the city. The implementation of subsidized housing programs imposes cost-reduction and efficiency demands on developers, which are typically achieved through economies of scale, the adoption of standardized architectural models, and the reduction of built area. As a result, housing units often provide only minimal habitability conditions. The absence of essential urban infrastructure – such as public transport networks, commerce, and services – further intensifies the difficulties experienced by residents, undermining the potential of these developments as sustainable and inclusive housing solutions (Libertun de Duren, 2018; Marguti, 2018; Santos & Vale, 2020; Gallo et al., 2022). Consequently, the critique of peripheral social housing production extends beyond the housing unit itself to its disconnection from urban facilities, networks, employment opportunities, and public spaces within the consolidated city. In this context, its performance is associated with processes of socio-spatial exclusion, as it fails to articulate design strategies with insertion in infrastructure-rich areas, contradicting the understanding that the quality of the built environment results from the integration of different spatial components (Spink et al., 2020).

Despite the significant demand for adequate housing, hundreds of vacant and deteriorated buildings remain part of the urban landscape of major Brazilian cities, largely due to functional obsolescence and a lack of investment. This situation is complex and challenges the capacity of the State to address it effectively. Among the factors that support the provision of social housing in central areas are zones not yet fully contested by the real estate market, the presence of built heritage with architectural or historical value, demands from housing movements – such as tenement residents and the homeless – vertical occupations, and vacant buildings suitable for rehabilitation (Rossetto Netto, 2017; Savoie et al., 2025).

Building rehabilitation has been identified as a strategy with significant environmental, social, and economic advantages (Kern & Zuliani da Silva, 2024). These buildings benefit from existing infrastructure and offer improved access to healthcare, education, and commercial services compared to peripheral areas. From this perspective, rehabilitation represents not only the reuse of the existing building stock, but also an opportunity to restore the social function of property and to reintegrate social housing into more urbanized areas (Murray & Clapham, 2015; Mouratidis, 2021). Despite this potential, the practice remains underdeveloped in the Brazilian context, occurring in a fragmented and discontinuous manner with limited outcomes (Rossetto Netto, 2017). In a country where many large cities have reached a stage in which rehabilitation is increasingly necessary – particularly considering the real estate boom of the 1950s and 1960s – this strategy still represents a largely underexplored field.

Although building rehabilitation has been part of construction policies and practices in Europe since the 1980s, this topic remains relatively underexplored and underimplemented in Latin America. However, since 2023, rehabilitation has been formally incorporated and promoted in Brazil through the *Minha Casa, Minha Vida (MCMV) Retrofit Program*. The MCMV, the country's main strategy for the provision of social housing, has traditionally focused on financing large-scale housing production to reduce the housing deficit. In doing so, the search for large, low-cost plots has contributed to the spatial segregation of millions of people to the urban periphery. By being incorporated into the country's largest housing policy, the "Retrofit" modality aligns with a vast existing building stock with significant potential for renewal. As a result, building rehabilitation emerges as a timely and relevant issue across urban, architectural, and construction scales.

The limited diffusion of this strategy can be understood in light of structural constraints, including the scarcity of dedicated financing mechanisms, the predominance of housing policies oriented toward peripheral expansion, and the inherent complexity of rehabilitation works, which still represents a challenge for the construction sector (Devecchi, 2014). In this context, a gap persists in understanding how design solutions are articulated to simultaneously respond to pre-existing conditions and contemporary housing demands.

3. A Pattern Language

The seminal work A Pattern Language (1977), developed by Christopher Alexander (1936-2022) – an Austrian-born architect, urbanist, and mathematician based in the United States – emerges as a counterpoint to the homogeneous practices and functionally disconnected policies often observed in large-scale peripheral housing developments in Brazilian and Latin American cities. In this context, the possibility of delivering social housing through building rehabilitation – thereby leveraging existing infrastructure and better addressing the needs of residents and the urban environment – can be envisaged through the adoption of specific design patterns, analyzed in light of the theoretical framework proposed by Alexander et al. (1977).

Alexander's work argues that architecture should be grounded in solutions that respond to human needs and local contexts, synthesized into "archetypes" or timeless patterns. These patterns provide practical guidance for designers and planners, suggesting that their application can help reproduce the harmonious qualities of "timeless places" and address recurring challenges in cities and buildings in a structured manner. A pattern refers to a design solution that can be applied repeatedly across different contexts without being identical in each instance (Alexander et al., 1977). This concept is further developed through the distinction between two interdependent types: patterns of events, which describe recurring human activities associated with specific spatial configurations, and patterns of space, which refer to physical arrangements that support

these activities. These two dimensions are inseparable – spaces gain life when they enable meaningful events, and events flourish when grounded in appropriate spatial forms (Alexander, 1979).

The work comprises 253 patterns, organized into three categories: Towns (Section 1), Buildings (Section 2), and Construction (Section 3). This structure enables the understanding of housing projects not merely as a building-level problem, but as a multi-scalar approach in which construction decisions, internal spatial organization, neighborhood relationships, and urban integration are interdependent. This relational dimension allows patterns to be understood beyond their mere identification, by revealing how they are associated with one another and which spatial structures emerge from their co-occurrence. Although originally rooted in architecture, pattern language has evolved into one of the most influential design methods of the twentieth century (Salingaros et al., 2017; Cozzolino, 2020; Wu et al., 2025).

Pattern language, therefore, is not limited to a collection of isolated elements; rather, it can be understood as a network of principles and relationships among patterns that connect to form an integrated solution (Postle & Salingaros, 2025; Wu et al., 2025). Such solutions have been applied across a wide range of contexts over recent decades – including urban regeneration, housing, sustainable communities, and territorial appropriation – demonstrating adaptability to diverse cultural and economic settings while maintaining their core purpose of fostering human-centered environments and more inclusive and connected cities (Mehaffy, 2007; Dawes and Ostwald, 2017; Wu et al., 2025).

This framework may thus support the articulation of design responses and enhance its use as an operational and adaptable analytical method (Salingaros et al., 2017). More recent computational approaches, including data-driven frameworks and large language models, further expand its operationalization in design and neighborhood-scale analysis (Postle & Salingaros, 2025; Zhang & Dimitrijevic, 2025). Taken together, these advances reinforce this theory as a transferable framework for both design support and the systematic evaluation of multi-family housing.

4. Methods

The approach adopted in this article understands the built environment as a reality that is simultaneously material and cultural, requiring an interpretive lens to assess how design supports or constrains the configuration of the housing environment and aspects of socio-spatial integration (Groat and Wang, 2013). The research is based on a preliminary set of design patterns identified by Schneck et al. (2025), in which, from the 253 original patterns proposed by Alexander et al. (1977), a total of 76 were selected as potentially applicable to the context of building rehabilitation for SH (Table 1).

Table 1: Set of selected patterns

Section 1 Patterns (Towns)		
P09-Scattered Work	P48-Housing In Between	P75-The Family
		P76-House for a Small Family
P10-Magic of the City	P56-Bike Paths and Racks	P77-House for a Couple
P16-Web of Public Transport	P61-Small Public Squares	P78-House for One Person
P21-Four-Story Limit	P67-Common Land	P79-Your Own Home
P35-Household Mix	P73-Adventure Playground	P89-Corner Grocery
Section 2 Patterns (Building)		
P95-Building Complex	P131-The Flow Through Rooms	P164-Street Windows
P104-Site Repair	P135-Tapestry of Light and Dark	P166-Gallery Surround
P105-South Facing Outdoors	P136-Couple´s Realm	P167-Six-Foot Balcony
P106-Positive Outdoor Space	P137-Children´s Realm	P170-Fruit Trees
P108-Connected Buildings	P138-Sleeping to the East	P172-Garden Growing Wild
P110-Main Entrance	P139-Farmhouse Kitchen	P173-Garden Wall
P114-Hierarchy of Open Space	P141-A Room of One´s Own	P174-Trellised Walk
P118-Roof Garden	P145-Bulk Storage	P176-Garden Seat
P119-Arcades	P147-Communal Eating	P177-Vegetable Garden
P122-Building Fronts	P158-Open Stairs	P182-Eating Atmosphere
P127-Intimacy Gradient	P160-Building Edge	P190-Ceiling Height Variety
P128-Indoor Sunlight	P161-Sunny Place	P192-Windows Overlooking Life
P129-Common Areas at the Heart	P162-North Face	P196-Corner Doors
P130-Entrance Room	P163-Outdoor Room	P203-Child Caves
Section 3 Patterns (Construction)		
P205-Structure Follows Social Spaces	P237-Solid Door with Glass	P245-Raised Flowers
P222-Low Sill	P238-Filtered Light	P246-Climbing Plants
P226-Column Place	P239-Small Panes	P247-Paving With Cracks Between the Stones
P229-Duct Space	P241-Seat Spots	P250-Warm Colors
P233-Floor Surface	P242-Front Door Bench	P252-Pools of Light
P236-Windows Which Open Wide	P243-Sitting Wall	P253-Things From Your Life

This prior selection aimed to establish an analytical framework aligned with the specificities of building rehabilitation, avoiding both the indiscriminate application of the full set of patterns and an overly unconstrained interpretation of the empirical cases. Based on this preliminary set, the study was conducted in two stages, as described in the following sections.

4.1. Stage 1: Identification of design patterns in rehabilitated buildings

The first stage of the study consisted of identifying the presence of this set of patterns in a multi-case study comprising two rehabilitated buildings in Porto Alegre and eight in São Paulo, both located in major Brazilian metropolitan areas. The buildings range from four to twenty-three storeys. At the time of analysis, one project was under construction, six had been completed, and three were in the design phase. Some of these cases are illustrated in Figures 1, 2, and 3.

Fig. 1, 2 and 3: Three buildings included in the case study



The cases were selected based on a survey of interventions recognized within the sector, as well as recent projects chosen through a municipal economic subsidy call issued by the São Paulo City Hall for the requalification of the city's central area. Case selection followed four operational criteria. First, location in dense urban areas, defined as buildings situated in consolidated central zones characterized by established infrastructure and service provision, where the property directly engages with the existing urban fabric. Second, building typology was defined as multi-family housing – either originally designed or later adapted for collective residential use – with shared circulation and common components typical of social housing provision in apartment buildings. Third, the type of intervention refers to adaptive rehabilitation applied to pre-existing buildings, involving reconfiguration and upgrading works required to meet residential standards while preserving substantial portions of the original structure. Fourth, the final use as subsidized housing, indicating that the buildings were not intended for the real estate market, but for housing provision through government programs. Taken together, these criteria ensure that the sample represents comparable conditions of rehabilitation, while allowing for the analysis of contextual differences in implementation and housing systems. The resulting sample can thus be characterized as exploratory, suitable for identifying recurring design patterns in housing rehabilitation experiences in the Brazilian context.

The identification of design patterns in the rehabilitated buildings followed a mixed-method approach, combining document analysis, architectural drawings, photographic records, and direct observation. On-site visits to all case studies enabled the assessment of pattern presence within the buildings and their immediate surroundings, in line with the literature. The identifiable patterns from the preliminary set were examined for evidence of their application in each case, based on structured criteria developed for this purpose. A spreadsheet was used to systematically record the occurrence of each pattern across the sample. This procedure enabled the construction of a comparable empirical dataset, encompassing both

building attributes and aspects related to their interface with collective spaces and the immediate urban context.

It is important to note that, in most cases, the identification of patterns is straightforward, as they are either present or absent. In some situations, however, a pattern may occur recurrently without being ubiquitous. In such cases, patterns were considered present when they appeared in at least two-thirds of the relevant spatial instances, ensuring consistency in application while allowing for design variation and contextual constraints (Yu et al., 2016; Lee et al., 2018). Although conducted systematically and based on explicit criteria, this identification process still relies on expert interpretation, as a fully automated protocol is not feasible. The multidimensional nature of the material – requiring analysis across urban scale, floor plans, and architectural sections, among others – poses challenges to the automated detection of patterns.

4.2. Stage 2: Data Processing

Based on the data collected in Stage 1, a co-occurrence (CO) matrix was developed to identify how frequently design patterns appeared together across the analyzed buildings. This matrix was converted into a compatible (.json) format and imported into VOSviewer, a software tool designed for network visualization and analysis. The adoption of a relational approach is grounded in the understanding that design characteristics arise less from the isolated presence of elements and more from the articulation of spatial solutions that operate in combination.

Two classical measures of topological centrality were applied to interpret the structural relationships among patterns: Degree Centrality (DC) and Betweenness Centrality (BC) (Freeman, 1978). DC measures the number of direct connections a node has with others, represented by the frequency of co-occurrence between patterns. BC, in turn, indicates how often a pattern lies on the shortest paths between other nodes, revealing its role as a mediator or bridging element within the network. This measure identifies patterns with the potential to connect different groups, acting as bridges between clusters that would otherwise remain disconnected (Netto et al., 2024). Within the scope of this study, DC enables the identification of patterns that constitute the recurrent core of the analyzed housing rehabilitation cases, while BC highlights patterns that articulate different spatial scales, domains, and complementary solutions. In addition, the two centrality measures were analyzed jointly by correlating DC and BC. For this purpose, the graph was divided into four analytical quadrants: (i) high DC/high BC, (ii) high DC/low BC, (iii) low DC/high BC, and (iv) low DC/low BC. This procedure made it possible to distinguish patterns that are highly recurrent in the system from those that perform mediating functions between different spatial domains. Therefore, the quadrant-based classification was not used as a statistical typology in itself, but as an interpretive device to support the analysis of how different patterns contribute to the spatial organization of rehabilitated social

housing. These calculations were performed using the Igraph package, a library designed for network manipulation and analysis.

In both analyses, VOSviewer employs a method based on the strength of links to group similar patterns into clusters. Each cluster consists of entities that co-occur more frequently with one another than with patterns in other groups. This clustering is generated through a variation of the tool's modularity optimization algorithm, which aims to maximize the density of connections within clusters while minimizing connections between them. The resulting organization reflects how patterns were applied in combination across the sample of buildings, as the algorithm does not consider pattern numbering or original classification, but relies solely on empirical co-occurrence data. In this way, network analysis makes it possible to reveal the spatial grammar effectively mobilized in the studied cases, offering a systemic reading of the context under investigation.

5. Results and Discussion

From the set of 76 patterns identified as potentially applicable to the rehabilitation of buildings for social housing (Schneck et al., 2025), 16 belong to the Towns section, 42 to the Buildings section, and 18 to the Construction section. However, in the analyzed sample, 16 of these patterns were absent across all ten buildings. From this point onward, the investigation focused on the remaining 60 patterns, each identified in at least one of the case study examples. This finding indicates that the analyzed buildings mobilize a substantial portion of the preliminary set, suggesting the existence of a relatively broad and contextually relevant design repertoire.

Table 2 presents part of the co-occurrence matrix, indicating how frequently each pair of patterns appears together within the same building. Each pattern is identified by the letter "P" followed by its original numbering in Alexander et al. (1977).

Table 2. Part of the co-occurrence matrix of design patterns

Pattern	P09	P10	P16	P21	P35	P48	P...
P09	0	10	10	1	9	10	X
P10	10	0	10	1	9	10	X
P16	10	10	0	1	9	10	X
P21	1	1	1	0	1	1	X
P35	9	9	9	1	0	9	X
P48	10	10	10	1	9	0	X
P...	X	X	X	X	X	X	0

The co-occurrence matrix enabled the observation of how frequently patterns appeared together across the analyzed buildings. The main diagonal of the matrix is zero, as a pattern cannot co-occur with itself. The highest co-occurrence value recorded was 59, indicating that certain patterns are directly connected to 59 distinct others. This finding suggests the existence of an articulated system of design

solutions, in which specific patterns tend to operate in consistent association. Figure 4 illustrates the identification of pattern co-occurrence in one of the analyzed buildings.

Fig. 4: Identification of design patterns in (a) a rehabilitated building; (b) its immediate surroundings; and (c) floor plan.



The clustering process performed in VOSviewer resulted in the formation of three clusters:

a) Cluster 1 (red): comprising 33 patterns, this group presents, on average, the highest Degree Centrality (DC) values, indicating high co-occurrence and strong connectivity. The low Betweenness Centrality (BC) observed for patterns in this cluster suggests that they form a relatively self-contained group,

with limited bridging functions between other regions of the network. This core concentrates widely recurring solutions and can be interpreted as the structural backbone of the analyzed housing rehabilitation projects, predominantly anchored in the scales of Buildings and Construction.

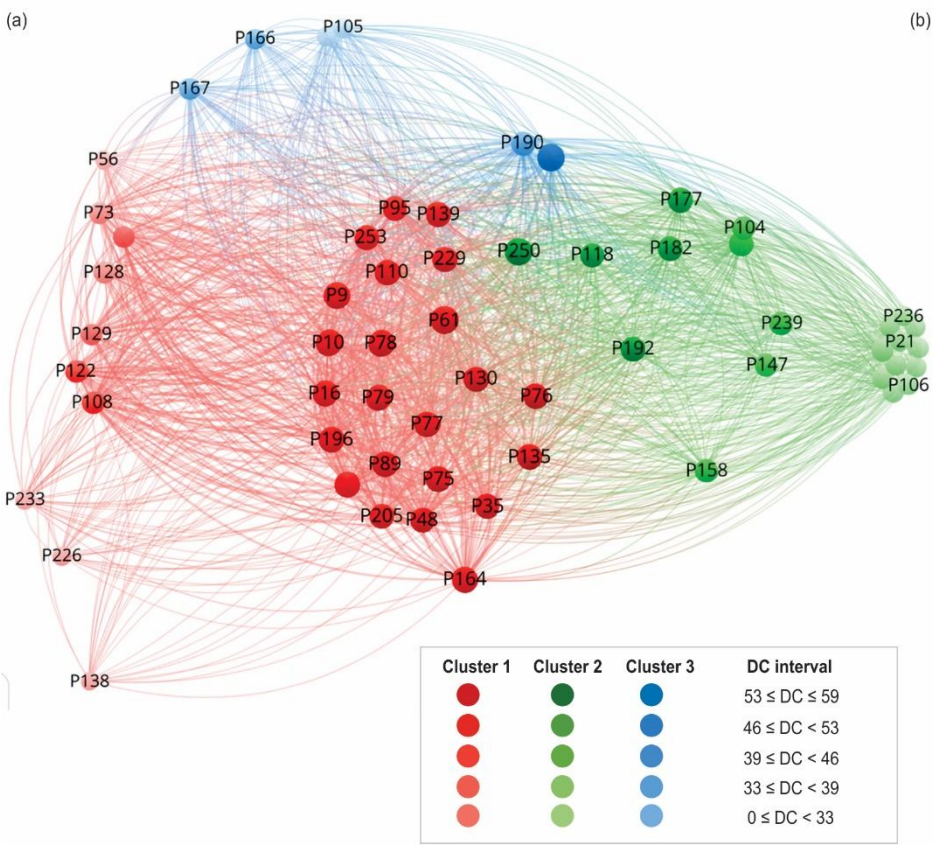
b) Cluster 2 (green): composed of 21 patterns, this group exhibits intermediate average values of both DC and BC, suggesting a role in articulating the central core with more peripheral patterns. Its topology indicates that these patterns may act as bridges between different spatial domains, connecting building-level features with their immediate surroundings and the broader urban fabric. This cluster is most clearly associated with multi-scalar mediation between interior spaces, collective areas, and the city.

c) Cluster 3 (blue): consisting of only 6 patterns, this cluster is characterized by high average BC values despite lower DC. This configuration suggests that, although these patterns are less frequent, they perform an important topological function as mediators and connectors between different parts of the network. Their presence reinforces that more specific or less recurrent solutions may play a decisive role in reconciling pre-existing conditions, functional adaptation, and spatial configuration.

Overall, these configurations indicate that the organization of the housing environment does not arise from isolated solutions, but from the recurring articulation of different spatial components, which tend to structure relationships between housing units, collective spaces, and the immediate urban context. Patterns with higher centrality values point to elements with the potential to influence multiple aspects of the housing environment, acting as mediators between different spatial domains and contributing to the coherence of the internal organization of buildings.

Based on the Degree Centrality (DC) data (Figure 5), it is possible to observe a structure concentrated around a core of highly connected patterns. In this context, the number of direct connections each pattern maintains with others serves as an indicator of its “popularity” – or relational recurrence – within the set of analyzed buildings. Patterns that reach the maximum degree value (59), such as P09-Scattered Work, P10-Magic of the City, P16-Web of Public Transport, P35-Household Mix, P48-Housing In Between, P61-Small Public Squares, and P75-The Family, emerge as highly connected central nodes, systematically associated with a wide range of other patterns. This group brings together patterns related to urban integration and the diversity of domestic arrangements, suggesting that the analyzed housing rehabilitation operates on a design basis that articulates dwelling organization with surrounding urban dynamics.

Fig. 5: (a) Design pattern network based on DC and (b) the 35 design patterns with the highest DC values



(b)

Design pattern	DC
P09-Scattered Work	59
P10-Magic of the City	59
P16-Web of Public Transport	59
P35-Household Mix	59
P48-Housing In Between	59
P61-Small Public Squares	59
P75-The Family	59
P76-House for a Small Family	59
P77-House for a Couple	59
P78-House for One Person	59
P79-Your Own Home	59
P89-Corner Grocery	59
P95-Building Complex	59
P110-Main Entrance	59
P127-Intimacy Gradient	59
P130-Entrance Room	59
P135-Tapestry of Light and Dark	59
P139-Farmhouse Kitchen	59
P196-Corner Doors	59
P205-Structure Follows Social...	59
P229-Duct Space	59
P253-Things From Your Life	59
P250-Warm Colors	58
P118-Roof Garden	57
P164-Street Windows	57
P190-Ceiling Height Variety	57
P192-Windows Overlooking Life	57
P222-Low Sill	57
P177-Vegetable Garden	56
P182-Eating Atmosphere	56
P104-Site Repair	55
P173-Garden Wall	55
P147-Communal Eating	53
P158-Open Stairs	53
P239-Small Panes	52

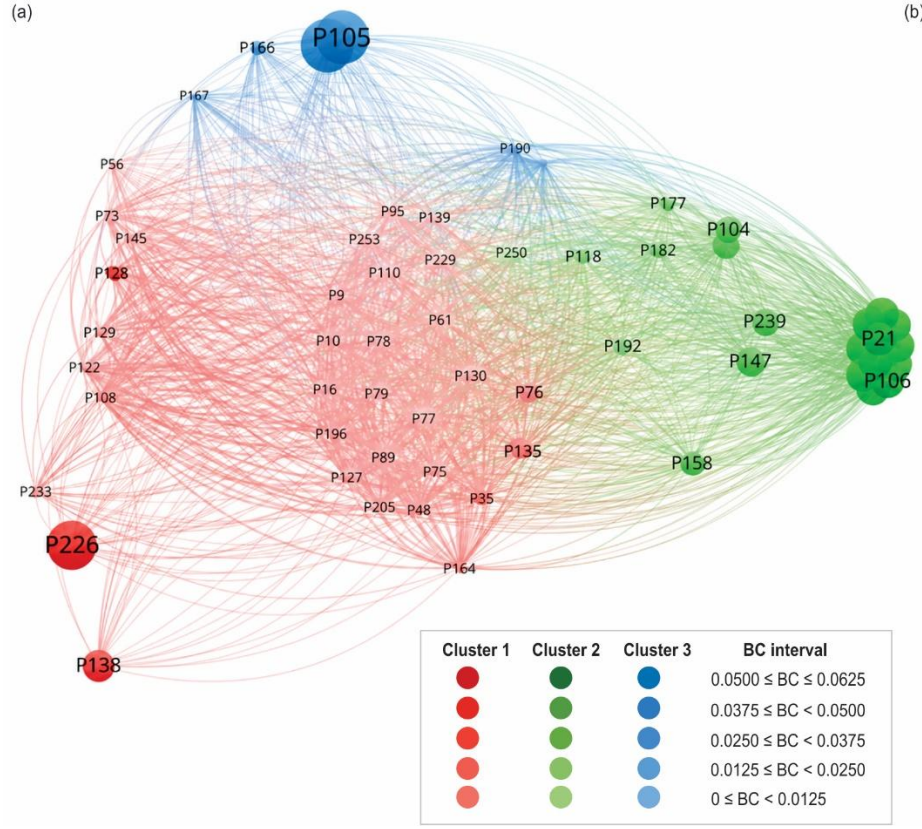
By examining the content of the patterns involved (such as P95-Building Complex, P196-Corner Doors, and P253-Things from Your Life), it can be inferred that this versatile group also articulates functional, constructive, and appropriation-related aspects of habitable spaces. The high concentration of patterns with elevated DC suggests the existence of a structuring core of design guidelines that tend to be mobilized in combination. This indicates that building rehabilitation is not limited to physical adaptation, but involves the reconfiguration of an integrated spatial system, in which solutions related to housing, collective use, and urban integration mutually reinforce one another.

The distribution of patterns with higher DC across the sections proposed by Alexander et al. (1977) reveals a predominance at the scales of Buildings and Construction. Patterns such as P205-Structure Follows Social Spaces and P229-Duct Space, for instance, reflect functional, constructive, and adaptability-related aspects that are frequently addressed in rehabilitation interventions. However, the simultaneous presence of patterns from the Towns section among the most connected ones highlights the importance of central location, proximity to transport networks, relationships with public spaces, and access to existing urban infrastructure.

Regarding the Betweenness Centrality (BC) analysis (Figure 6), a subset of patterns with a strategic topological role can be identified. Patterns with the highest BC values, such as P105-South Facing Outdoors,

P131-The Flow Through Rooms, and P226-Column Place, may function as connectors between subgroups of patterns, enabling the integration of design solutions. Unlike the most recurrent patterns, these do not necessarily define the core of the network but instead act as bridges between environmental, functional, and constructive requirements.

Fig. 6: (a) Design pattern network based on BC and (b) the 35 design patterns with the highest BC values



(b)

Design pattern	BC
P105-South Facing Outdoors	.0625
P131-The Flow Through Rooms	.0625
P226-Column Place	.0469
P21-Four-Story Limit	.0242
P67-Common Land	.0242
P106-Positive Outdoor Space	.0242
P114-Hierarchy of Open Space	.0242
P160-Building Edge	.0242
P163-Outdoor Room	.0242
P170-Fruit Trees	.0242
P172-Garden Growing Wild	.0242
P236-Windows Which Open Wide	.0242
P241-Seat Spots	.0242
P243-Sitting Wall	.0242
P138-Sleeping to the East	.0214
P147-Communal Eating	.0182
P239-Small Panes	.0165
P104-Site Repair	.0153
P173-Garden Wall	.0153
P158-Open Stairs	.0127
P192-Windows Overlooking Life	.0056
P76-House for a Small Family	.0053
P182-Eating Atmosphere	.0049
P118-Roof Garden	.0048
P166-Gallery Surround	.0043
P177-Vegetable Garden	.0042
P135-Tapestry of Light and Dark	.0038
P35-Household Mix	.0037
P128-Indoor Sunlight	.0028
P233-Floor Surface	.0023
P129-Common Areas at the Heart	.0022
P130-Entrance Room	.0021
P164-Street Windows	.0021
P190-Ceiling Height Variety	.0015
P222-Low Sill	.0015

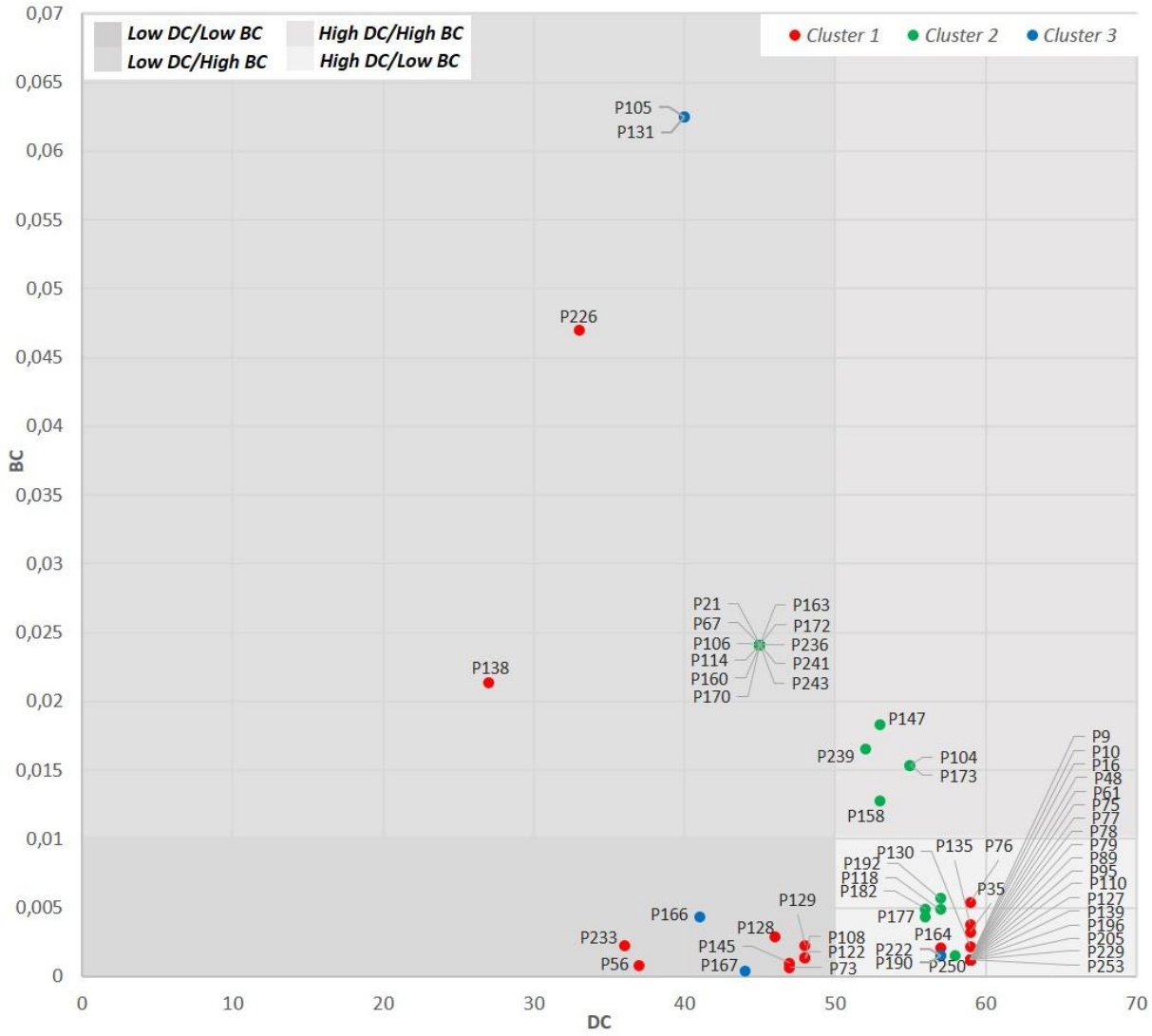
The establishment of structuring connections within the design system, particularly in relation to solutions that enable the reconciliation between existing spaces and new functional requirements, can be observed in this network. For instance, P105-South Facing Outdoors illustrates the articulation between interior and exterior spaces. Belonging to the Buildings scale, this pattern emphasizes the importance of solar exposure for environmental comfort, directly influencing the quality of spaces in rehabilitation projects. Similarly, P131-The Flow Through Rooms reflects its role as an internal spatial connector between different areas. Its topological position in the network reinforces that spatial continuity can foster more adaptable and integrated environments. In turn, P226-Column Place, although less frequent, emerges as a key articulating node between structural and spatial solutions. While associated with the Buildings scale, it has implications at the Construction scale. Its presence indicates that existing structural elements should not

be seen merely as constraints, but as design assets capable of mediating functional adaptations in rehabilitated buildings.

In addition, patterns such as P21-Four-Story Limit, P67-Common Land, P106–Positive Outdoor Space, P114-Hierarchy of Open Space, P160-Building Edge, P163-Outdoor Room, and P170-Fruit Trees also present significant BC values. All belong to the Towns or Buildings scales and function as transitional elements between built and open spaces, as well as between private and collective domains. Their high intermediary role suggests that these patterns may integrate internal architectural decisions with the environmental and urban qualities of the surrounding context, promoting cohesion through the articulation of multiple design scales. This set of patterns contributes to the urban debate by indicating that social housing through rehabilitation in central areas can benefit from conditions of urbanity that are difficult to reproduce in peripheral housing developments.

The joint distribution of DC and BC enabled the classification of design patterns into four analytical quadrants (highly recurrent patterns, mediating patterns, strategic patterns, and more peripheral patterns), defined by the mean values of both metrics (Figure 7).

Fig. 7: Relational positioning of design patterns according to DC and BC



Patterns with high DC and low BC represent recurrent core elements, frequently associated with many other patterns but with limited bridging roles; these indicate the spatial components that structure the dominant configuration of the analyzed rehabilitation projects. Patterns with low DC and high BC, in contrast, are less recurrent but perform important mediating functions, connecting otherwise more distant spatial domains and revealing critical points of articulation between pre-existing conditions and new housing requirements. Patterns with high values in both metrics can be interpreted as strategic elements, combining recurrence and mediation, while those with low DC and low BC tend to play more peripheral or context-specific roles. This quadrant-based reading strengthens the interpretation of the results by showing that the relevance of a pattern is not determined only by how often it appears or how many connections it has, but also by its capacity to connect different parts of the spatial system.

Of the 60 patterns analyzed, 50% are located in the high DC/low BC quadrant, suggesting that the network is strongly structured by a recurrent set of solutions that are highly connected to one another, but

do not necessarily perform mediating roles between groups. This reinforces the presence of a recurring design core in the analyzed rehabilitation cases. Examples include P10-Magic of the City, P79-Your Own Home, and P192-Windows Overlooking Life. In contrast, five patterns are located in the high DC/high BC quadrant. These are particularly important because they combine recurrence with an articulating role: P104-Site Repair, P147-Communal Eating, P158-Open Stairs, P173-Garden Wall, and P239-Small Panes. These patterns can therefore be interpreted as strategic solutions within the context analyzed in this study.

In summary, the results support the argument that the analyzed housing rehabilitation cases do not operate through isolated solutions, but through recurring combinations of patterns that connect the building to its surroundings and to the city. This suggests that their spatial configuration arises from the articulation between internal housing attributes, collective spaces, street interfaces, and their insertion within consolidated urban areas. From a housing perspective, these relationships indicate that the performance of the built environment is associated with how private and collective spaces are articulated, influencing possibilities for use, appropriation, and social interaction.

In this sense, these findings may support more consistent decision-making processes in rehabilitation projects, guiding interventions toward configurations that enhance usability, accommodate diverse patterns of occupation, and strengthen the integration of housing environments within the urban context. From this perspective, building rehabilitation for social housing can be understood not only as a constructive response to the housing deficit, but as an urban strategy with greater potential to promote socio-spatial integration and to address, at least in part, the historical limitations of peripheral social housing production in Brazil.

6. Conclusion

Based on the analysis of rehabilitated buildings in Brazil, this study identified the presence of approximately 80% of the patterns included in the preliminary set within the selected cases. The results also reveal the connections and interrelations among the design patterns proposed by Alexander et al. (1977) when applied to this specific context. Through network analysis and centrality metrics, it was possible to examine the co-occurrence of these patterns from a systemic perspective, moving beyond approaches that consider design elements in isolation. This strategy made it possible to demonstrate that building rehabilitation in central areas mobilizes a relatively consistent relational structure, composed of recurring clusters of solutions and mediating patterns that articulate different spatial domains.

The findings show that certain patterns assume structuring or mediating roles, as indicated by Degree and Betweenness Centrality values, suggesting that their use may be strategic in the development of more integrated architectural solutions. More importantly, the results indicate that design decisions should prioritize not only the inclusion of specific spatial elements, but their relational articulation—particularly in

the integration between circulation, collective spaces, and housing units. This highlights the importance of considering how spatial configurations support continuity, accessibility, and shared use within rehabilitated buildings.

The identification of patterns with critical topological roles, grounded in empirical evidence and supported by a replicable method, points to the existence of a recurring spatial grammar in the context of housing rehabilitation. In this sense, the relational structures identified may support the development of evaluation frameworks that move beyond checklist-based approaches, enabling the assessment of how spatial components interact to shape housing environments. From a policy perspective, the results suggest that rehabilitation strategies should not be evaluated solely based on location or housing provision, but also in terms of the spatial organization of the built environment and its capacity to support more integrated forms of living in central urban areas. By linking spatial configuration to housing outcomes, this study contributes to a more nuanced understanding of how design can support socially and spatially integrated housing provision.

As a further development, future research should expand the sample, compare different urban contexts, and systematically contrast central-area rehabilitation with peripheral housing production, in order to deepen the understanding of the relationships between urban form, housing characteristics, and policy frameworks.

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