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RESEARCH

A Justified Plan Graph Analysis of Social Housing in Mexico (1974–2019): Spatial Transformations and Social Implications

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Abstract

Space Syntax researchers have asserted that the spatial configuration of the planning of a work of architecture, such as a house, reflects how social properties are inscribed in its design. In social housing, the social inscriptions through space, which promote a particular way of dwelling, are not initially determined by the inhabitants. However, through appropriation, inhabitants mold the space to their liking, challenging preconceived ways of dwelling. Therefore, this research aims to determine what kinds of social structures the spatial configuration of social housing are promoting and how the inhabitants' transformations have altered the spatial experience. Mexico's housing sector developed from a "welfare approach" in the nineteen seventies and eighties to a "market rationale" since the nineties. During this time, different dwelling perspectives were inscribed in the spatial configuration of the homes. Using the justified plan graph (JPG) method, six social housing dwellings from these two time periods, Welfare State and market rationale, are spatially analyzed, both in their original design and in the resulting design from their inhabitant's modifications. Graph analysis is used in this paper for providing spatial insights into social housing design and its users' transformations, while pointing to further research needs.

Keywords Social housing · Justified plan graph · Spatial configuration · Community relationships · Spatial appropriation

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Introduction

A common claim is that architecture and its inhabitants are mutually constitutive (Yaneva 2016); this means that we design spaces that later invite us to inhabit them in a certain way. At the same time, the built environment is not only a stage for social interaction, but in itself, is a social behavior that reflects in its patterns the origin of the conduct which created it in the first place (Hillier and Hanson 1988; Hillier 2007). Housing provides one of the most relevant scenarios for analyzing this relationship, because dwelling happens within in its most pristine form. However, most of the time, we inhabit homes conceived by others, and we are socially conditioned by these conceptions, as is the case of state social housing. In Mexico, the Institute of the National Housing Fund for Workers (Infonavit) has been in charge of promoting social housing since 1972, both as a designer and developer, and since 1992, only as a credit facilitator, on the recommendation of the World Bank (Puebla 2002). To ease the production processes for these homes, Infonavit and later, market housing developers, developed housing prototypes that standardize and spatially inscribe supposed ways of living (Boils 1995). Therefore, inhabitants must negotiate between their real needs and various presumptions about their needs. These transactions are reflected in the spatial appropriations made to their living spaces over time, thus making evident that the relationship between architecture and its inhabitants is an incessant unending dynamic of shaping and being shaped, and shaping again.

Many researchers have focused their attention on domestic appropriations in state social housing, but few have done so in spatial terms. Studying space allows us to reveal the social ideas inscribed in it, as established by Hillier and Hanson (1988), given that the spatial configuration is the mediator of form and function in architecture, as well as an example of how space is embedded in the information it receives from society. The internal spatial organization of a home is an ideological space container of social categories and roles that is continuously reaffirmed through its use, becoming the site of the reproduction of society. Furthermore, studying the house's spatial configuration reveals the conditioning design guidelines that are imposed in daily living. Likewise, its study is imperative in the situation where others have determined particular designs and ways of life for future inhabitants, such as dwellings promoted by government housing institutions. Following this line of social and spatial analysis other authors have studied vernacular living spaces in Normandy (Hillier et al. 1987) and Arroyo Hondo Pueblo (Ferguson 2007), and suburban houses in London (Hanson 2003). Other lines of investigation have focused on analyzing architects' design strategies, such as looking for a genotypical pattern in Mies' early residential plans in Germany (Bafna 1999), the early homes of the Australian architect Glenn Murcutt (Ostwald 2011a), and an analysis of the consistency of the social and spatial structure in ten of his rural domestic type (Ostwald and Dawes 2018), Frank Lloyd Wright's Prairie Houses (Lee et al. 2017), and more recently, an analysis of Palladio's arguments about connection, centrality, and control in his villa plans (Dawes et al. 2021).

Domestic appropriations have been studied from a social and formal point of view in the Latin-American context (Bamba Vicente and Costa Sepúlveda 2017; Sanín Santamaría, 2018; Zamorano 2013). However, previous studies have not analyzed the differences between spatial configurations of standardized dwellings and the resulting configurations after their users transform them. This is significant, because it is common in Mexico for people to improve their homes by adding more spaces due to their small initial size. Moreover, because an extended family can occupy a single dwelling, the growth of the house follows the family lifecycle (García-Huidobro et al. 2010). For that reason, these changes happen gradually in the inhabitants' homes, when need and money converge.

To complement existing formal and social analysis, and to take advantage of the research oversight along with the particular Mexican context, this paper investigates social housing of the city of Monterrey, Mexico. Monterrey is the industrial hub in the north of the country, and its housing market has experienced a boom in the last 20 years, becoming the supply leader nationwide. Simultaneously, along with the city's exponential expansion and its housing stock, social problems have arisen due to unconstrained and unsupervised growth. In an environment such as this, where development is being governed by market trends, we have to ask ourselves two questions. What kind of social structure is the spatial configuration of social housing promoting? How have the inhabitants' adjustments to the spatial structure altered the social and psychological properties of their spatial experience? Therefore, the present investigation aims to contrast the spatial configurations of the initial houses with the transformed ones, within a historical framework of two stages of the housing institute Infonavit: that of the welfare state (1972–1992) and that of the market (1992–2019).

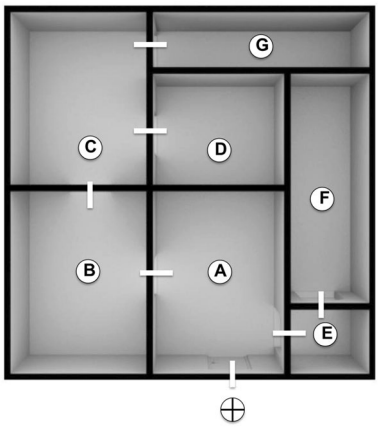
This research's innovation lies in differentiating the dwelling conceptions of the designer, and of the inhabitant. The transformations of the spatial configuration show the desires, needs, and problems that the inhabitants face. To take an in-depth dive into the inhabitants' house-cycle history and its transformations, semi-structured interviews with the inhabitants were conducted during fieldwork. The interviews asked questions regarding changes, their execution, and their motives. This approach provides the reasons that guided such appropriations.

In the following section, the JPG method, part of the space syntax methodology, is described as well as the methodological approach. Afterward, each of the six houses will be characterized, visually and mathematically analyzed, and reviewed chronologically. Subsequently, the results will be integrated, analyzed, interpreted, and discussed together. Finally, we will draw some conclusions and considerations for further research.

Methodology

This section will describe the method used for the justified graph (JPG) of the space syntax methodology, followed by the criteria used to select the sample and its characteristics.

Fig. 1 Annotated floor plan



Space syntax is a set of theories, methods, and techniques developed in the eighties by Bill Hillier and Julienne Hanson (1988) to establish relationships between spatial configuration and its social effects. It has been used both in architectural works and in urban spaces. According to Ostwald, it consists of "translating architectural plans into topological graphs that are mathematically and graphically analyzed and which are subsequently interpreted in terms of their spatial and social characteristics" (2011b: 445). The present research focuses on using one of its tools, the JPG, which helps uncover the social logic of space, to develop a graphical and mathematical analysis of the spatial configuration of a small sample of social housing in Monterrey and subsequently interpret its results. The JPG was chosen because it develops measures for topological properties such as control, permeability, and integration that describe how the house is spatially experienced in a rigorous and repeatable format.

Ostwald (2011b) describes the steps of this method and its mathematics in detail. He declares that the first step in building a JPG is to translate a plan into a map of visually defined spaces, a schematic containing the spaces within a plan and the connections between them. This map is later translated into a graphical diagram that only includes nodes (spaces) and lines (connections between spaces) arranged through a number of levels starting from 0, the root space (Figs. 1 and 2).

Ostwald states that we can visually analyze the graph to reveal a series of qualitative spatial configuration properties such as depth, asymmetry/symmetry, and spatial hierarchy or permeability. For example, when a graph has few levels, we define it as shallow; this means that from the level designated as 0, it is easy to access the rest of the spaces. When the graph is asymmetric, it means that there is less spatial consistency in the graph, or more deliberation. Finally, when its shape is arborescent (Fig. 3), we determine that there is a spatial hierarchy; on the other hand, when it features loops, it is called ring-shaped (Fig. 4), to describe the permeability of the configuration.

In turn, these graphs can be mathematically analyzed to determine the values of the variables Total Depth (*TD*), Mean Depth (*MD*), Relative Asymmetry (*RA*),

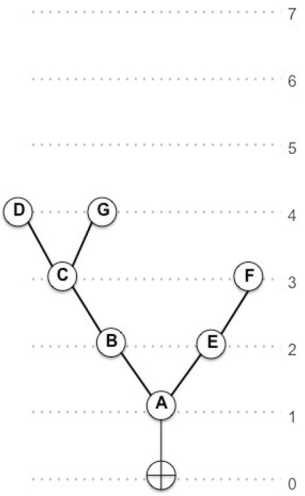


Fig. 2 Justified plan graph (exterior carrier)

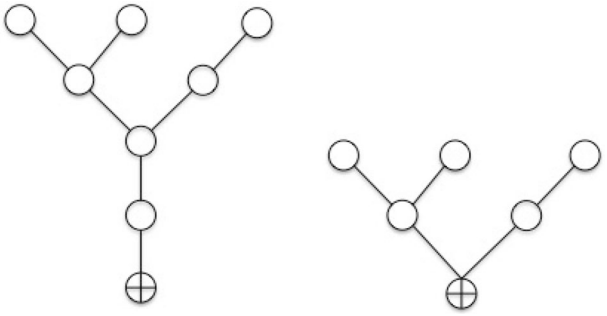


Fig. 3 Arborescent: Tree (left) and bush (right)

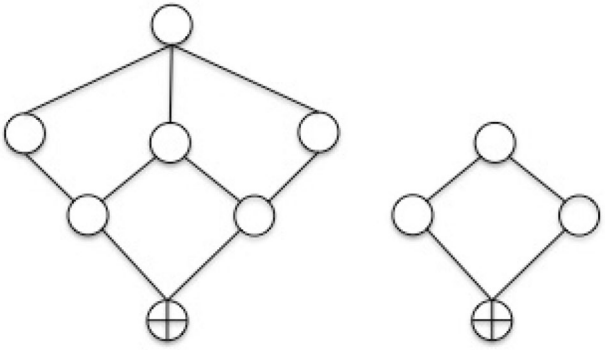


Fig. 4 Ring: Double Triple ring (left) and single ring (right)

integration (*i*, relative centrality of the spaces), and control value (*CV*, degree of influence that each node has on the system). The inscription of these values in space and subsequent translation into numbers help us compare the spaces within the configuration and establish, according to their degree of depth, integration, and control, the social patterns that their disposition reveals within the configuration (for a detailed explication of the mathematics refer to Ostwald 2011b).

Following Ostwald's approach, we chose three Monterrey neighborhoods promoted by Infonavit within two historical stages of the housing Institute. When Infonavit designed and developed houses (1972–1992) was the first stage. The second one was when Infonavit only provided the credit, and houses were handed to market housing developers who developed and designed them (1992–2019). Subsequently, two detached and privately owned dwellings of each neighborhood were selected to analyze and contrast their spatial configurations, giving a total of six cases. This selection of houses, analyzed before and after their inhabitants' transformations, highlights the dynamic aspect of the logic of space in line with Bafna's (2003) assertion that the relationship between society and space is not one of overlapping one into the other, but rather how they restructure each other.

The data collection was carried out during fieldwork including a semi-structured interview, which allowed us to understand the transformations carried out in the house and a survey of the house to draw each one's architectural plan, all with prior authorization from the interviewees. One of the study's limitations is that the inhabitants only allowed entry to the first floor and public areas of the house, limiting the analysis to only this level.

Even though most studies that employ the JPG method focus on architectural interiors, it was considered relevant to analyze attached exterior spaces as well in this research. Many activities of the inhabitants are performed in these spaces daily, as stated in the interviews. Yet, the convex partitioning of the exterior was a challenge because exterior areas are not as functionally demarcated as interior spaces are. To maintain consistency throughout all the plans, we decided to use functional space analysis for interior and exterior spaces. In this type of analysis, the abstraction procedure is guided by room functions (Dawes and Ostwald 2013), and its use has become increasingly common in recent applications of graph theory (Ostwald and Dawes 2018). By focusing on functional space analysis, we could analyze the relationship between design and social structure. This decision counters the criticism of subjectivity involved in convex partitioning (Peponis et al. 1997), and the difficulty of developing a perfect convex map and an unrealistic abstraction of spaces (Ostwald and Dawes 2018).

Single-purpose rooms were classified as nodes according to their function. Where several functions were performed in a clearly rectangular room, they were treated as a single node, such as a living-dining room or living-dining-kitchen room. Where a room contained a threshold that prevented circulation, it was divided into two nodes. Without considering their morphology, exterior spaces on the front of the house were defined as "porch" and "patio" for those on the back. In all these houses, there is no yard either in the front or the back. Watering a yard is expensive for the inhabitants, so they put concrete flooring in all outdoor spaces. For that reason, what would usually be labeled as a "front yard" was labeled as a porch and "back yard" as

Table 1 General abbreviations used for rooms in the JPG

⊕	Exterior	BT	Bathroom	BD	Bedroom
K	Kitchen	L	Laundry	LV	Living room
Cl	Closet	LD	Living-Dining	LDK	Living-Dining-Kitchen
DN	Dining	ST	Store	Po	Porch
D	Distributor	C	Corridor	Pa	Patio

a patio—these terms reflect the way they are used. Tables 1 and 2 record the labels for spaces and their graphic representations.

Social Housing Spatial Configuration Evolution: Three Neighborhoods, Six Homes

This section will describe the results obtained from the syntactical analysis of the spatial and social structure. A brief characterization of each neighborhood will be made first to frame the research results contextually. Afterward, a description of the case studies' results will be established, accompanied by an annotated floor plan and JPG for the original and transformed design of each case, along with a table summary of the mathematical results of each space ordered according to their integration values., separated by a blank row representing the mean integration. This ordering allows us to view the inequality genotype, "the ranking of programmatic labeled spaces according to their mean depth described in terms of integration values" (Bafna 2001: 20.1), as a basis to contrast the houses' differences before and after being altered. Finally, all of the results will be integrated and interpreted together. The general characteristics of each neighborhood, where a case is located, are in Table 3.

Constituyentes de Querétaro

Constituyentes de Querétaro is the second neighborhood Infonavit built in the city of Monterrey in 1974. It was designed in accordance with the urban design manuals that the Institute provided, with various typologies within the complex, and open public spaces and public infrastructures such as schools, parks, and churches. Young families, who have since purchased the homes, are now senior citizens, and they are the largest population of the neighborhood. In the seventies, Infonavit offered larger lots than what they are offering now, so these houses have ample outer areas.

The CQ2[1] house (Fig. 5) welcomes the visitor with a large porch on the front of the lot. It is a two-floor house with a living-dining area, kitchen, bathroom, patio

[1] Cases are part of a larger housing and appropriation investigation. Their original names have been retained for this study.

Table 2 Graphic representations of types of spaces in the JPG

a-space: dead-end	*b-space:* on the way to the dead-end	*c-space:* positioned in one ring of movement	*d-space:* positioned in two rings of movement

Table 3 Neighborhood characteristics

Neighborhood	*Year*	*Municipality*	*Area (hectare)/#dwellings*	*Density (inhabitant/hectare)*	*Lot area (m^2)*	*Construction area (m^2)*
Constituyentes de Querétaro	1974	San Nicolás	40 ha/2280 dwellings	193	90–160	65–104
Colinas del Río	2000	García	12.1 ha/494 dwellings	211.4	112	56
Los Encinos	2015	García	28 ha / 1800 dwellings	257	90	52

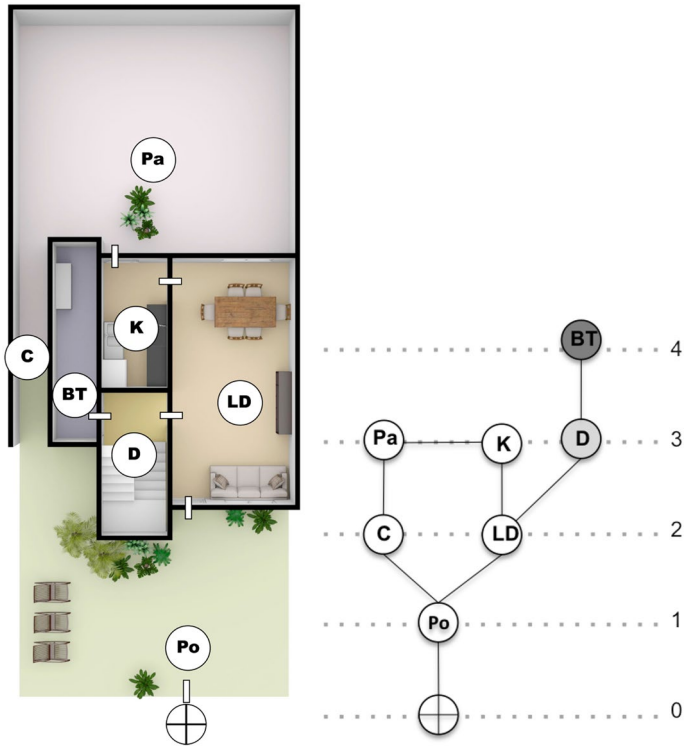


Fig. 5 Original CQ2 annotated floor plan and JPG, with the exterior as the carrier

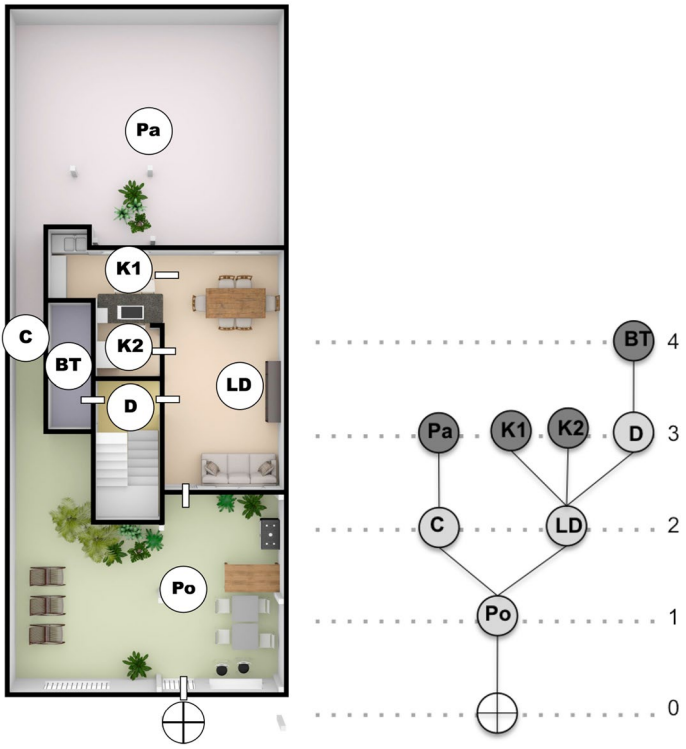


Fig. 6 Transformed CQ2 annotated floor plan and JPG, with the exterior as the carrier

on the first floor, and a private area with three bedrooms located on the second. A visual review of the JPG of the original CQ2 house reveals a "ring-like" entry configuration that allows continuous flow from the outside to the inside either through the main door or the patio door, encompassing all the spaces except the distributor and the bathroom. The latter extends beyond the living-dining area linearly, making it asymmetrical. The resulting layout can be considered a deep plan of 4 levels. The mathematical analysis (Table 4) exposes that the average total depth of the house is 15.25. We can also see that the most integrated space is the living-dining room (5.25), the room with the most connections. Yet interestingly, the space that exerts the highest control value is the porch (1.83), 37% more control than its closest rivals, the distributor and the living-dining room.

After 45 years of being inhabited, the owner Sabina transformed her porch into a small restaurant and therefore expanded her kitchen because she spent much of the day preparing stews and removed the door leading to the patio (Fig. 6). Starting from the porch, the ring-like configuration was transformed into an arborescent configuration on one side and a linear one on the other. These changes maintained the house's depth in 4 levels, but increased the mean total depth by

Table 4 Summary of JPG results for original CQ2 and transformed CQ2

#	CQ2 original	TD	MD	RA	i	CV
0	Living-dining	11.00	1.57	0.19	5.25	1.33
1	Porch	12.00	1.71	0.24	4.20	1.83
2	Kitchen	14.00	2.00	0.33	3.00	1.00
3	Corridor	15.00	2.14	0.38	2.63	0.88
4	Distributor	15.00	2.14	0.38	2.63	1.33
5	Patio	16.00	2.29	0.43	2.33	1.00
6	X	18.00	2.57	0.52	1.91	0.33
7	Bathroom	21.00	3.00	0.67	1.50	0.50
$K=8$	Mean	15.25	2.18	0.39	2.93	
#	CQ2 transformed	TD	MD	RA	i	CV
0	Living-dining	15.00	1.88	0.25	4.00	2.83
1	Porch	18.00	2.25	0.36	2.80	1.75
2	Corridor	19.00	2.38	0.39	2.55	1.33
3	Kitchen 1	20.00	2.50	0.43	2.33	0.25
4	Kitchen 2	20.00	2.50	0.43	2.33	0.25
5	Distributor	20.00	2.50	0.43	2.33	1.25
6	X	23.00	2.88	0.54	1.87	0.33
7	Bathroom	25.00	3.13	0.61	1.65	0.50
8	Patio	26.00	3.25	0.64	1.56	0.50
$K=9$	Mean	20.67	2.58	0.45	2.38	

35%. In turn, the living-dining area maintains the highest integration (4.00), yet reduced by 24%, and becomes the space with the highest CV (2.83). The space that suffered the most from these changes was the patio, which became the least integrated space of all, the position that was held by the bathroom beforehand. Overall, the mean integration of the house was reduced by 18.7%, from 2.93 to 2.38.

Smaller in scale than CQ2, the CQ5 house (Fig. 7) also welcomes visitors with a porch, but in this case, the two-story house has an open space plan with the living, dining, and kitchen areas and a bedroom on the first floor. The other two bedrooms and bathroom are on the second. The spatial configuration is arborescent and asymmetrical, departing from the porch. Even though it has fewer spaces than CQ2, it presents a deep structure of 5 levels from the carrier, yet its mean depth is lower, with a value of 13.86 (Table 5). The mathematical analysis shows that the living-dining-kitchen area is the most integrated space with an integration value of 7.50, 100% more than its closest competitor, the distributor. Yet interestingly, this latter space exerts a higher control value by more than 140% over the social area.

When the owner Imelda became older, she built a bathroom on the ground floor and made an independent kitchen (Fig. 8). Additionally, she added access to the patio through the new kitchen, separating the service functions from the social ones. The spatial configuration changes in very interestingly ways, because it introduces a

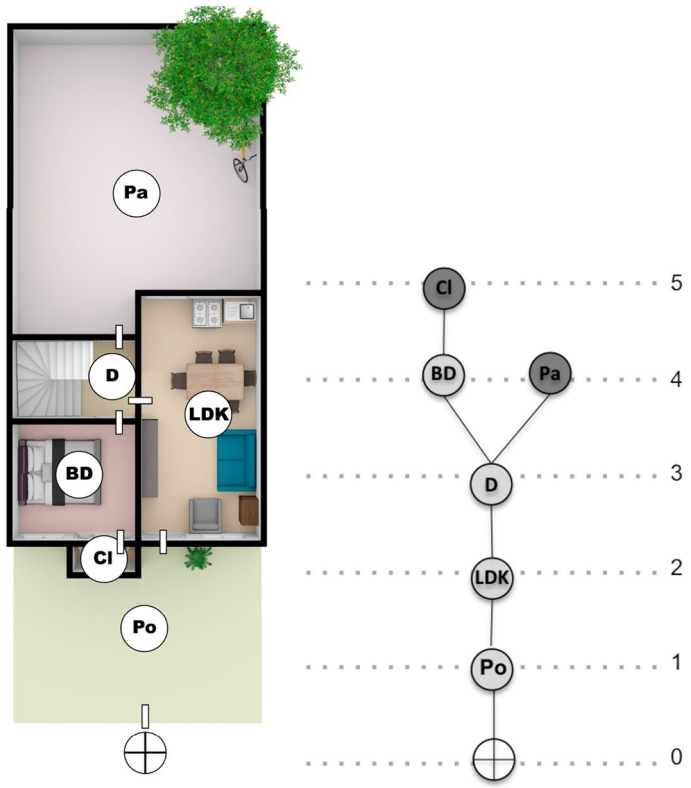


Fig. 7 Original CQ5 annotated floor plan and JPG, with the exterior as the carrier

ring in the second level extending from the living-dining area and encompassing the kitchen, the patio, the corridor, and the distributor, making the route more flexible and the spaces more permeable. With these changes, the living-dining room went from first in integration value to second to last, losing 77% of its original value. The distributor lost its place as the space with the highest control value, a position given away to a new exterior corridor between the bathroom and the kitchen, yet in a decreased way. With these changes, Doña Imelda increased her home's average integration value slightly by 7.6%, from 2.76 to 2.97, and with the construction of the new spaces, the average total depth was increased as well from 13.86 to 22.80, a 65% difference.

Colinas del Río

Housing developers produced Colinas del Río in 2000, on the fringes of the city in a municipality called García. By then, Infonavit only provided loan credit

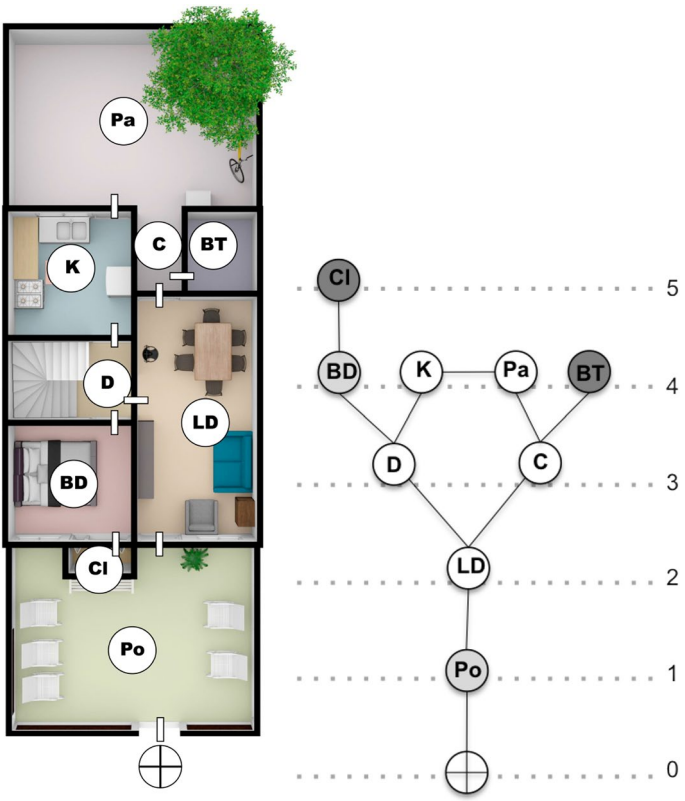


Fig. 8 Transformed CQ5 annotated floor plan and JPG, with exterior as carrier

for the purchase of houses, without supervising the design and construction. The local municipality authorities enforced the urban guidelines, yet they were insufficiently specific. For example, they only referred to percentages of communal use area, yet didn't specify how that area should be dealt with. Consequently, the neighborhood has no proper public space, with leftover and unused terrain at the end of each block that complied with the percentage demanded. The neighborhood design only contains two models of one-story houses in a linear and monotonous urban layout. Both houses analyzed have an open front space that could be used as a garage or a porch, a patio on the back, a living and dining area, two bedrooms, a bathroom, and a kitchen.

A visual review of the original spatial configuration of CR1 (Fig. 9) reveals a ring-like entry configuration that encompasses the porch, the living room, kitchen, patio, and corridor. Stemming from the living room, we find a bush-like arrangement with the private spaces and the dining room, making it asymmetrical. The JPG comprises an intermediate plan of 4 levels, with an overall average depth of 24.09 (Table 6). The mathematical analysis reveals that the living room is the most integrated space, with a very high integration value of 9. This result

Table 5 Summary of JPG results for original CQ5 and transformed CQ5

#	CQ5 original	TD	MD	RA	i	CV
0	LDK	8.00	1.33	0.13	7.50	0.83
1	Distributor	10.00	1.67	0.27	3.75	2.00
2	Bedroom	13.00	2.17	0.47	2.14	1.33
3	Porch	14.00	2.33	0.53	1.88	1.50
4	Patio	15.00	2.50	0.60	1.67	0.33
5	Closet	18.00	3.00	0.80	1.25	0.50
6	X	19.00	3.17	0.87	1.15	0.50
$K=7$	Mean	13.86	2.31	0.52	2.76	
#	CQ5 transformed	TD	MD	RA	i	CV
0	Corridor	16.00	1.78	0.19	5.14	1.83
1	Porch	17.00	1.89	0.22	4.50	1.33
2	Kitchen	19.00	2.11	0.28	3.60	0.83
3	Bathroom	21.00	2.33	0.33	3.00	0.50
4	Distributor	22.00	2.44	0.36	2.77	1.33
5	X	22.00	2.44	0.36	2.77	0.50
6	Patio	23.00	2.56	0.39	2.57	0.83
7	Closet	27.00	3.00	0.50	2.00	0.50
8	Living dining	30.00	3.33	0.58	1.71	1.16
9	Bedroom	31.00	3.44	0.61	1.64	1.33
$K=10$	Mean	22.80	2.53	0.38	2.97	

is 80% higher than the porch, its closest rival. And given that all the spaces are configured around it, it also exerts the highest control value (3.16).

Over time, the owner Leticia decided to remove the passage to the patio from the exterior corridor with a staircase that accesses the second level of bedrooms under construction (Fig. 10). She additionally closed the dining room, changing it to a bedroom for her father, whom she now takes care of. These changes eliminated the ring-link spatial configuration and transformed it into an asymmetric, arborescent one with an even deeper five-level plan. As such, these transformations increased the mean total depth by 8% to 26.09, and overall integration was decreased by 12%. The living room was affected by these changes, although still in the first place, increasing its control value from 3.16 to 3.30 but decreasing its integration value by 16% to 7.5.

House CR3 (Fig. 11) is the other model of Colinas del Río. Its simple plan comprises a social area with the living and dining room where people may access the two bedrooms, bathroom, and kitchen. It has an intermediate depth of 3 and a double ring-like spatial configuration because the exterior can be accessed in three ways: from the living-dining room to the porch and patio and through the kitchen to the corridor. Outside of the permeable ring-like configuration, the bedrooms and the bathroom are located in a bush-like configuration that extends from the living room, giving them more privacy. Its total depth is 15.56 (Table 7).

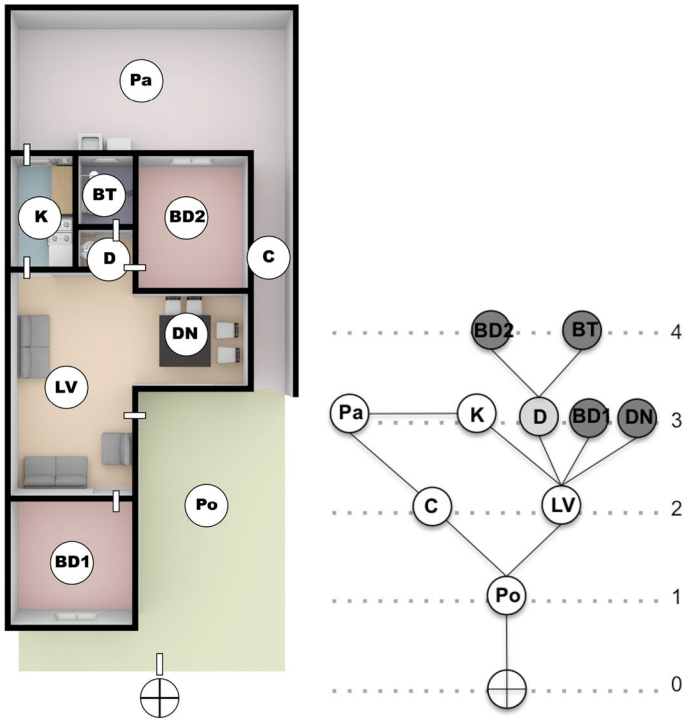


Fig. 9 Original CR1 annotated floor plan and JPG, with the exterior as the carrier

The space with the highest integration (14.0) and control value (4.33) is the living room. The living-dining room integration result is 150% higher than the porch, its closest rival, and has the highest value overall in the investigation by more than 55% than the living area of CR1 that holds the second place.

After her father died, the owner Luisa and her mother decided to completely transform the house and reconfigure the spaces, integrating the kitchen into the living area to socialize while doing their daily chores (Fig. 12). At the same time, they transformed the space that previously was the kitchen to a laundry room and removed the exit to the patio from both the living room and the new laundry area, modifying the configuration of the double ring that it previously had. Extending from the porch, on the one side, is a bush-like configuration with the inner areas, and on the other, a linear one with the exterior spaces, separating the interior from the exterior. The house's mean total depth increased by 17.1% after these changes, yet maintained 3 JPG levels. These changes reduced overall integration by more than 30%. With these transformations, the living-dining-kitchen area maintains the highest integration with half its original value (from 14 to 7) and the same CV (4.33). In fact, all spaces but the porch had a decrease in integration. As in CQ2, the patio became the least integrated space of the whole house, reducing its integration by more than 58%. It's not by chance their patio is only used by their dogs, but not by them.

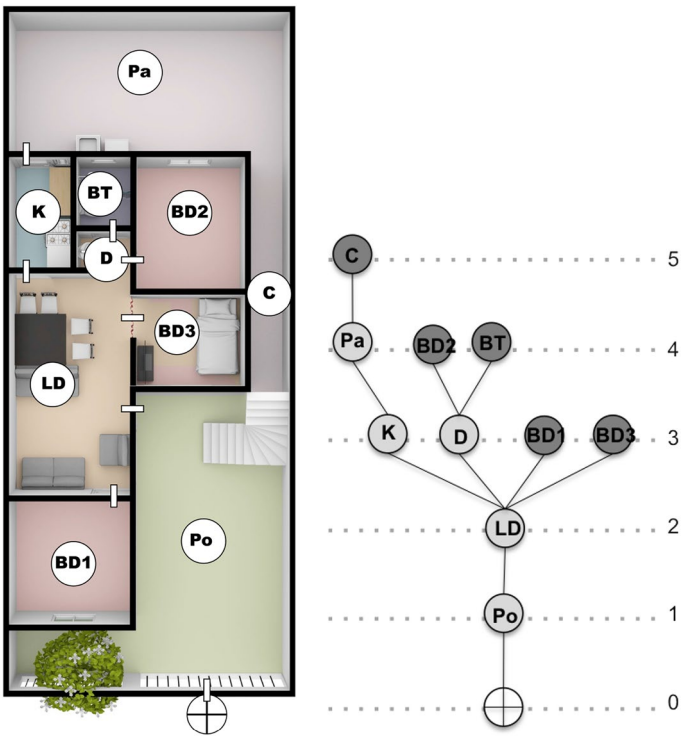


Fig. 10 Transformed CR1 annotated floor plan and JPG, with the exterior as the carrier

Los Encinos

Los Encinos was built by a housing developer in 2015 on the outskirts of García. By this time the competition was fierce, and developers had to offer more while maintaining accessible housing prices. That is one of the reasons for its liminal location, but also its wide commercial avenue on the center with the innovative "casa-tienda," a home designed to have retail space on the bottom and the living quarters on the second floor, and its park, community center and soccer fields on the southern side. Los Encinos has five different housing models under an orthogonal urban design, with rows of houses in the north–south direction and a commercial driveway in the center. Many young families populate it, and their main concern is the difficulty in communicating with the rest of the city due to their location. Both houses analyzed in Los Encinos are the same model. They have "T" plans where all services are located on the short side, and the kitchen and bathroom, two bedrooms, and the living-dining area on the long one. Like the houses from Colinas del Rio, they have a front open space used as a porch or a garage and a patio on the back.

The original design of EN3 (Fig. 13) has a ring-like entry configuration that encompasses the porch, the living room, the laundry room, and the kitchen.

Table 6 Summary of JPG results for original CR1 and transformed CR1

#	CR1 original	TD	MD	RA	i	CV
0	Living	15.00	1.50	0.11	9.00	3.16
1	Porch	19.00	1.90	0.20	5.00	1.70
2	Distributor	20.00	2.00	0.22	4.50	2.20
3	Bedroom 1	24.00	2.40	0.31	3.21	0.20
4	Kitchen	24.00	2.40	0.31	3.21	0.70
5	Dining	24.00	2.40	0.31	3.21	0.20
6	Corridor	25.00	2.50	0.33	3.00	0.83
7	X	28.00	2.80	0.40	2.50	0.33
8	Patio	28.00	2.80	0.40	2.50	1.00
9	Bathroom	29.00	2.90	0.42	2.37	0.33
10	Bedroom 2	29.00	2.90	0.42	2.37	0.33
$K=11$	Mean	24.09	2.41	0.31	3.72	
#	CR1 transformed	TD	MD	RA	i	CV
0	Living-dining	16.00	1.60	0.13	7.50	3.30
1	Kitchen	21.00	2.10	0.24	4.09	0.70
2	Distributor	21.00	2.10	0.24	4.09	2.20
3	Porch	23.00	2.30	0.29	3.46	1.20
4	Bedroom 1	25.00	2.50	0.33	3.00	0.20
5	Bedroom 3	25.00	2.50	0.33	3.00	0.20
6	Patio	28.00	2.80	0.40	2.50	1.50
7	Bathroom	29.00	2.90	0.42	2.37	0.33
8	Bedroom 2	30.00	3.00	0.44	2.25	0.33
9	X	32.00	3.20	0.49	2.05	0.50
10	Corridor	37.00	3.70	0.60	1.67	0.50
$K=11$	Mean	26.09	2.61	0.36	3.27	

Asymmetrically from that point, a deep linear arrangement begins from the laundry towards the patio and a bush-like arrangement from the living-dining area towards the private rooms. The house has a deep plan of 4 levels and a high mean total depth of 24 (Table 8). The most-integrated space is the living-dining room, with a value of 5.63, closely followed by the porch at 5.0. Yet, since the living-dining room has more connections, the highest control value is exercised by it (3.33), 54% higher than its closest competitor, the porch.

Given the neighborhood's peripheral location, the owner of EN3 Candelaria decided to transform both her living-dining room and a bedroom into a stationery store, taking advantage of the need for one in the neighborhood (Fig. 14). Simultaneously, she closed the porch and turned it into a dining room and the store's warehouse. With these changes, the design maintains an entry ring-like configuration that departs from the store and encompasses the dining room, the laundry, and the kitchen as well. Moreover, the ring configuration has only

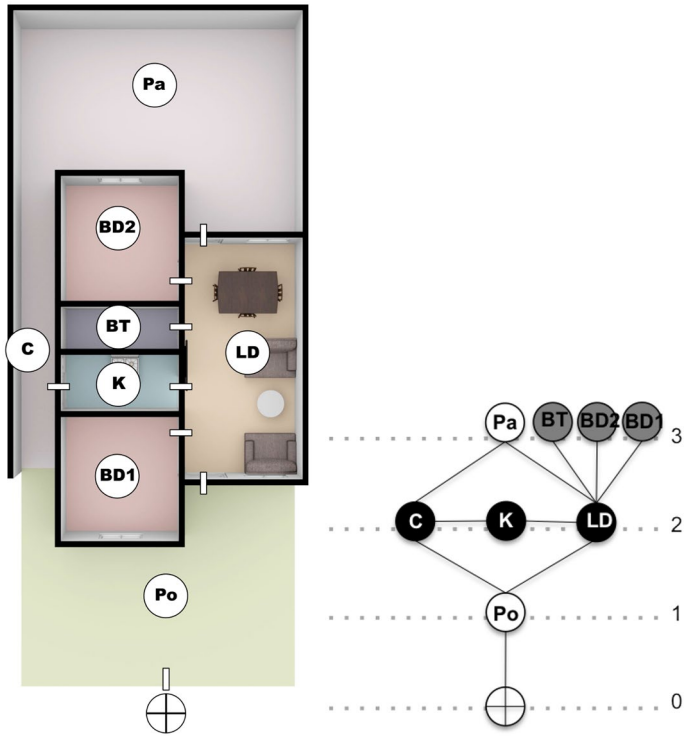


Fig. 11 Original CR3 annotated floor plan and JPG, with the exterior as the carrier

indoor spaces, while it used to have the porch. The outdoor spaces outside the ring linearly depart from the laundry, while the distributor, bedroom, and bathroom depart from the store. Interestingly, while the JPG increased from 4 to 5 levels, the average total depth decreased by 15%, from 24 to 20.33. This decline was due to the arrangement and reduction of rooms by the annexation and transformation of the living-dining room and the bedroom into the store. The house's mean integration yielded fairly similar results with the initial design, only decreasing by 3%. In turn, the store has become the space with the most integrated and highest CV: it increased its control value from 3.33 to 3.50 but lowered its integration from 5.63 to 5.14. As in the cases before, the patio is the least integrated of all spaces, even before the house was transformed, evidenced by only using it as an outside storage area.

House EN4 (Fig. 15), the same model as the previous one, introduces a minor but more determinant change in its configuration. The owner Esmeralda closed the kitchen's access from the outside due to a robbery she had after living three months in the house (Fig. 16). Esmeralda has more control over the house's access with this transformation, and the ring-like configuration is canceled. An asymmetrical configuration is rendered with a bush-like structure departing from the living area and a linear one with the exterior spaces. This change in the configuration did not

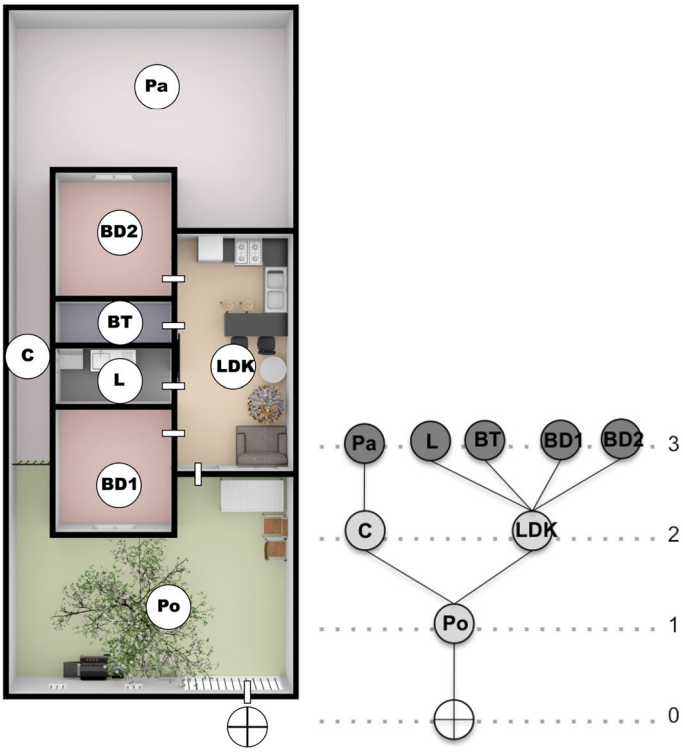


Fig. 12 Transformed CR3 annotated floor plan and JPG, with the exterior as the carrier

change the four-level deep plan configuration it had, but it did increase the average total depth by 13.6% (Table 9). In turn, the average integration yielded similar results reducing its value by only 0.01 points. With this strategy, the living-dining room space became even more integrated with a change in value from 5.63 to 7.07 while exerting 15% more control, from 3.33 to 3.83. All spaces slightly increased their integration except for the kitchen that reduced it by 24%. As seen in other cases, the patio is the least integrated space, it waits expectantly, as if it were land in inventory, for future construction to settle in it.

Comparative Analysis: Spatial Configurations and its Transformations

Several trends can be found when visually analyzing the characteristics of both the original and the transformed JPGs of the six houses (Table 10). All of the homes are asymmetrical. The average total depth increased in most cases after transformation by an average of 28%, except for EN3 that reduced the number of rooms by creating the store and altered the arrangement reducing TD by 15%. Although the total depth is increased, the number of levels stays the same for CQ2, CQ5, CR3 and EN4, while on the other hand CR1 and EN3 increase by one level.

Table 7 Summary of JPG results for original CR3 and transformed CR3

#	CR3 original	TD	MD	RA	i	CV
0	Living/dining	10.00	1.25	0.07	14.00	4.33
1	Porch	13.00	1.63	0.18	5.60	1.49
2	Patio	15.00	1.88	0.25	4.00	0.49
3	Kitchen	15.00	1.88	0.25	4.00	0.49
4	Corridor	16.00	2.00	0.29	3.50	1.33
5	Bedroom 1	17.00	2.13	0.32	3.11	0.16
6	Bedroom 2	17.00	2.13	0.32	3.11	0.16
7	Bathroom	17.00	2.13	0.32	3.11	0.16
8	X	20.00	2.50	0.43	2.33	0.33
$K=9$	Mean	15.56	1.94	0.27	4.75	
#	CR3 transformed	TD	MD	RA	i	CV
0	Living/dining	12.00	1.50	0.14	7.00	4.33
1	Porch	13.00	1.63	0.18	5.60	1.70
2	Corridor	18.00	2.25	0.36	2.80	1.33
3	Bedroom 1	19.00	2.38	0.39	2.55	0.20
4	Laundry	19.00	2.38	0.39	2.55	0.20
5	Bedroom 2	19.00	2.38	0.39	2.55	0.20
6	Bathroom	19.00	2.38	0.39	2.55	0.20
7	X	20.00	2.50	0.43	2.33	0.33
8	Patio	25.00	3.13	0.61	1.65	0.50
$K=9$	Mean	18.22	2.28	0.37	3.28	

These changes speak of the existence of spaces that are further from the root, the entrance.

Second, based on its type of configuration, we can see several patterns. Most original designs presupposed a flexible spatial experience through a ring-like structure, encompassing the outside and inside of the houses, allowing more permeability to the house's interior and travel flexibility. However, with the inhabitants' transformations, configurations change substantially. Four of the six homes removed the ring-like configuration and arrange their spaces in either linear or bush-like arrangements (Table 10). This has two consequences. First, private spaces become relegated to a hierarchical structure that departs from a social area, such as the living room. Second, the most highly controlled spaces become those that lead to the outside area of the patio through an enfilade configuration. This suggests that the inhabitants tend to prioritise greater control of their spatial experience with their transformations. However, CQ5 and EN3 didn't conform to this pattern. House CQ5 was transformed from a highly controlled enfilade structure to a ring configuration at a deeper level of the graph, encompassing all areas except the private ones and the porch (Fig. 8). Moreover, house EN3 maintained the ring configuration even though the spaces changed their function.

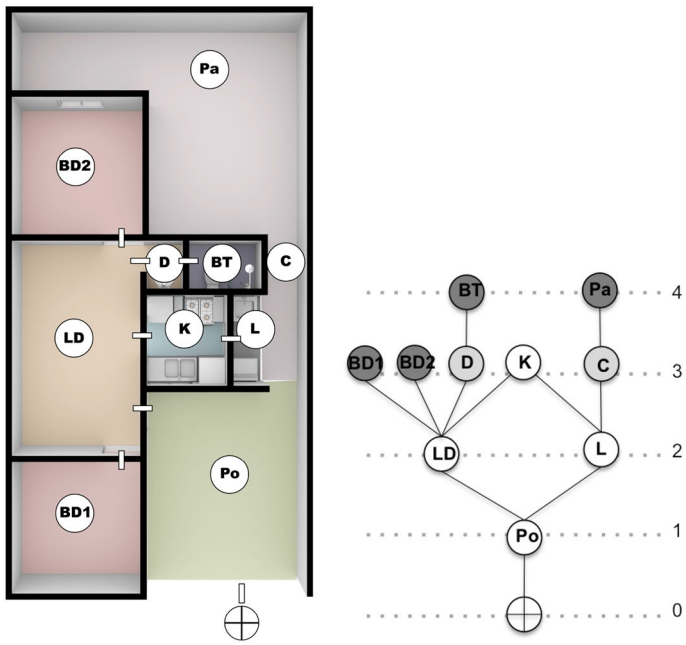


Fig. 13 Original EN3 annotated floor plan and JPG, with the exterior as the carrier

Further research with a larger sample could clarify if transformations in social housing tend to modify a flexible space experience into a more controlled and hierarchical structure.

The mathematical analysis of all the cases reveals that the original market housing design had higher mean integration values than the State housing, as Fig. 17 shows. Additionally, inhabitants' house transformations had profound repercussions on the overall integration of each. The average integration was not benefited by the inhabitant's changes since the houses decreased in value by an average of 10% overall. Notable exceptions were CQ5, whose integration value increased with the ring configuration, and EN4 stayed almost the same.

Furthermore, when comparing the integration of spaces, recurring patterns in the inequality genotype suggest several trends. First, with the exception of transformed CQ5, the living-dining space is the most integrated space of all cases before and after the house is transformed (in one case the store occupies the original area of the social space). Yet, after the spatial reconfiguration, this space reduces its integration in five of the six cases, EN4 being the exception. The porch was the second most integrated space in four of the six cases. Second, spatial configurations have an unbalanced distribution of spatial hierarchy, whereas fewer spaces are above the mean than below it, like the living-dining area and the porch; in other words, few spaces dominate the configuration. Consistently, areas located below the average integration are private spaces like bedrooms and bathrooms and outside areas like the exterior entrance and the patio. One of

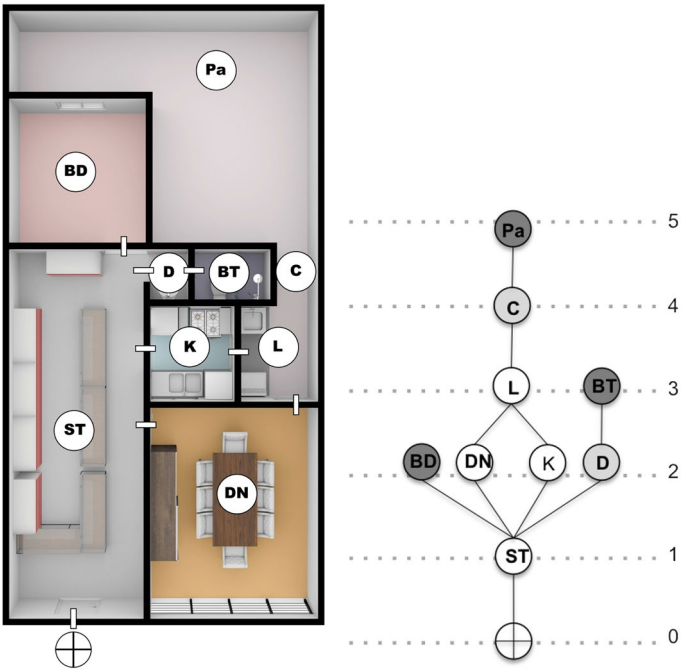


Fig. 14 Transformed EN3 annotated floor plan and JPG, with the exterior as the carrier

the least integrated spaces of all, common to most houses, was the patio, which presents a conundrum. In the original designs, this property seems to be born from the idea of a suburban backyard. Yet, even initially, the whole house turns its back against it, further confirmed by how inhabitants remove access to it. The patio could offer an outdoor haven, yet it is used as storage, to keep the dogs, or as land inventory for when the family grows even more.

Finally, comparing the control value *CV* (Table 11), in all cases except CQ5, the space with the highest control value increased its pull after inhabitants' transformations. The living-dining room was the space with more *CV* in market housing and only in CQ2 from welfare housing after its configuration's modification. CQ5's highest control value spaces before and after changes are circulation ones, distributor, and corridor, respectively, and the value of the latter was reduced by 8%.

By mathematically analyzing these results, we can see that the difference between housing from the welfare state and the market is that the houses from the latter have a higher mean integration (Fig. 17) and 50% higher average total depth (14.55 vs. 21.91). On the other hand, they both promote the living-dining room as the room with the most significant potential for social interaction, being the one with the highest integration value overall. Yet, the same cannot be said for its control value, which originally for CQ2 was the porch and CQ5 the distributor. Some further weak patterns in a visual and mathematical JPG analysis could be found, such as whether all social housing begins with a ring configuration, later

Table 8 Summary of JPG results for original EN3 and transformed EN3

#	EN3 original	TD	MD	RA	i	CV
0	Living-dining	18.00	1.80	0.18	5.63	3.33
1	Porch	19.00	1.90	0.20	5.00	1.53
2	Kitchen	21.00	2.10	0.24	4.09	0.70
3	Laundry	22.00	2.20	0.27	3.75	1.33
4	Distributor	25.00	2.50	0.33	3.00	1.20
5	Bedroom 1	27.00	2.70	0.38	2.65	0.20
6	Bedroom 2	27.00	2.70	0.38	2.65	0.20
7	X	28.00	2.80	0.40	2.50	0.33
8	Corridor	29.00	2.90	0.42	2.37	1.33
9	Bathroom	34.00	3.40	0.53	1.88	0.50
10	Patio	38.00	3.80	0.62	1.61	0.50
$K=11$	Mean	24.00	2.40	0.31	3.57	
#	EN3 transformed	TD	MD	RA	i	CV
0	StorE	16.00	1.78	0.19	5.14	3.50
1	Dining	18.00	2.00	0.25	4.00	0.53
2	Kitchen	18.00	2.00	0.25	4.00	0.53
3	Laundry	20.00	2.22	0.31	3.27	1.50
4	Distributor	22.00	2.44	0.36	2.77	1.20
5	X	24.00	2.67	0.42	2.40	0.20
6	Bedroom	24.00	2.67	0.42	2.40	0.20
7	Corridor	26.00	2.89	0.47	2.12	1.33
8	Bathroom	30.00	3.33	0.58	1.71	0.50
9	Patio	34.00	3.78	0.69	1.44	0.50
$K=10$	Mean	20.33	2.26	0.31	3.45	

canceled by the inhabitants, and whether all inhabitants' transformations will reduce overall integration and increase total depth. Since this sample's scope was small to draw deeper conclusions, further research is suggested along these lines, with a more extensive selection of social housing that would clarify and highlight this possible tendency.

Conclusion

The spatial configuration of a house reflects how its social properties are inscribed in its design. Through JPG analysis, several trends, albeit weak ones, revealed the difference between the designer's perception and the inhabitants'.

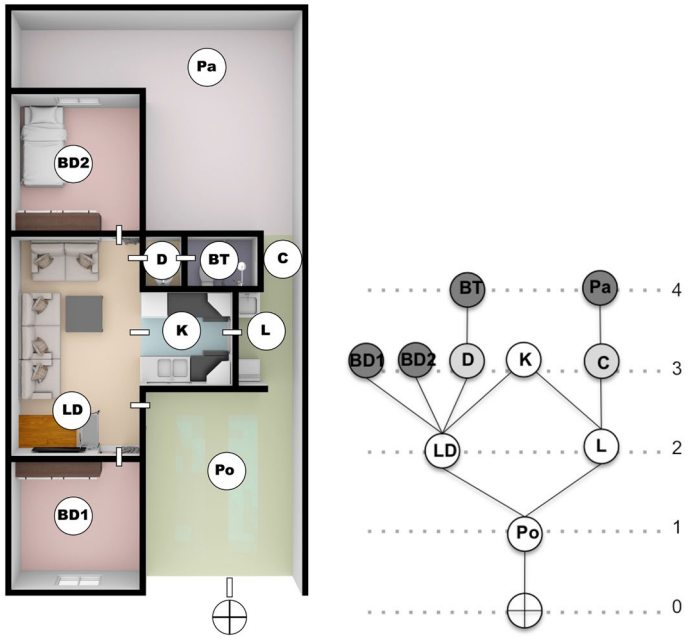


Fig. 15 Original EN4 annotated floor plan and JPG, with the exterior as the carrier

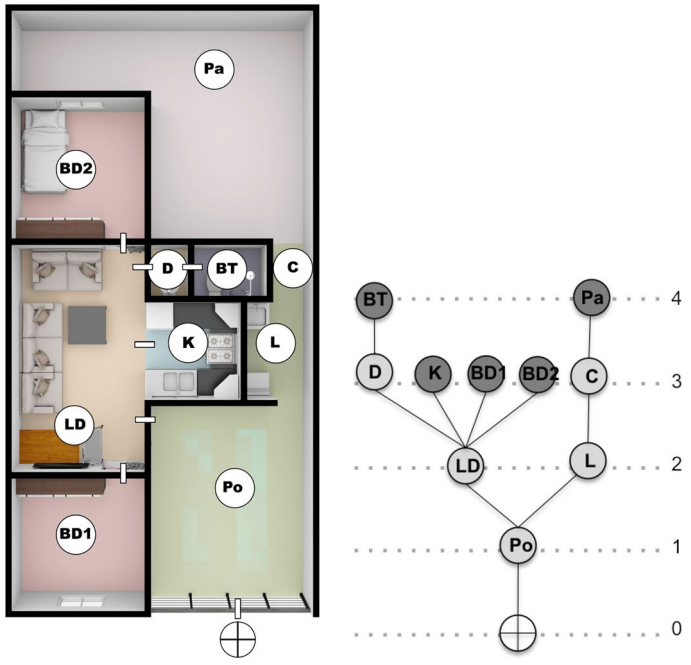


Fig. 16 Transformed EN4 annotated floor plan and JPG, with the exterior as the carrier

Table 9 Summary of JPG results for original EN4 and transformed EN4

#	EN4 original	TD	MD	RA	i	CV
0	Living-dining	18.00	1.80	0.18	5.63	3.33
1	Porch	19.00	1.90	0.20	5.00	1.53
2	Kitchen	21.00	2.10	0.24	4.09	0.70
3	Laundry	22.00	2.20	0.27	3.75	1.33
4	Distributor	25.00	2.50	0.33	3.00	1.20
5	Bedroom 1	27.00	2.70	0.38	2.65	0.20
6	Bedroom 2	27.00	2.70	0.38	2.65	0.20
7	X	28.00	2.80	0.40	2.50	0.33
8	Corridor	29.00	2.90	0.42	2.37	1.33
9	Bathroom	34.00	3.40	0.53	1.88	0.50
10	Patio	38.00	3.80	0.62	1.61	0.50
$K=11$	Mean	24.00	2.40	0.31	3.57	
#	EN4 transformed	TD	MD	RA	i	CV
0	Living-dining	18.00	1.64	0.14	7.07	3.83
1	Porch	19.00	1.73	0.16	6.19	1.70
2	Laundry	24.00	2.18	0.26	3.81	0.83
3	Distributor	25.00	2.27	0.28	3.54	1.20
4	Bedroom 1	27.00	2.45	0.32	3.09	0.20
5	Bedroom 2	27.00	2.45	0.32	3.09	0.20
6	Kitchen	27.00	2.45	0.32	3.09	0.20
7	X	28.00	2.55	0.34	2.91	0.33
8	Corridor	31.00	2.82	0.40	2.48	1.50
9	Bathroom	34.00	3.09	0.46	2.15	0.50
10	Patio	40.00	3.64	0.59	1.71	0.50
$K=11$	Mean	27.27	2.48	0.33	3.56	

Five of the original social housing designs suggested great richness and potential of use through a ring-like configuration that the inhabitants canceled, reducing mean integration results in the houses' layout. These results show a growing desire for a more controlled and hierarchical environment during the nineteen seventies and eighties, and in the market housing from the nineties onwards. Moreover, the analysis revealed that welfare state housing was less integrated and more easily accessible from the outside than market housing. Yet, both housing types revealed an unbalanced structural genotype with only a few spaces above the mean. Finally, the priority for social interaction in the living-dining room has persisted in housing design through time, reaffirmed by the inhabitants' spatial transformations in both welfare and market housing. However, this is a small

Table 10 Original and transformed spatial configuration comparison

Neighborhood	Dwelling	Depth	Type	Symmetry/Asymmetry
Constituyentes de Querétaro (1975)	CQ2 original	High	Ring	Asymmetrical
	CQ2 transformed	High	Arborescent	Asymmetrical
	CQ5 original	Very high	Arborescent	Asymmetrical
	CQ5 transformed	Very high	Arborescent + ring	Asymmetrical
Colinas del Rio (2000)	CR1 original	High	Arborescent + ring	Asymmetrical
	CR1 transformed	Very high	Arborescent	Asymmetrical
	CR3 original	Average	Ring	Asymmetrical
	CR3 transformed	Average	Bush-like + linear	Asymmetrical
Los Encinos (2015)	EN3 original	High	Ring + (then bush-like & linear)	Asymmetrical
	EN3 transformed	Very high	Ring + linear	Asymmetrical
	EN4 original	High	Ring + (then bush-like & linear)	Asymmetrical
	EN4 transformed	High	Arborescent	Asymmetrical

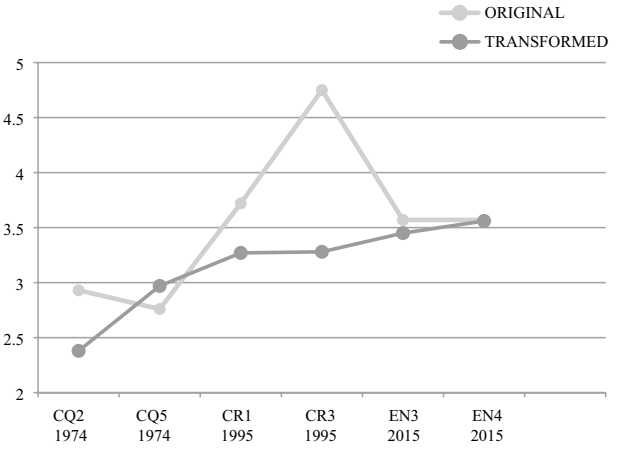


Fig. 17 Original and transformed houses' mean integration

sample, and a more extensive selection of cases would be needed to corroborate these possible tendencies.

In light of these results and with a larger sample, some further lines of research could analyze potential spatial configuration differences between welfare and market housing. Researchers could investigate if a recurrence for an unbalanced structural genotype in social housing design is expected as well. Finally, a larger sample could prove if the tendency for a more controlled and hierarchical environment holds in a more extensive selection of transformed homes. This paper demonstrates that graph-based analysis of social housing has proven potentially significant to reveal further insights in describing how social structure is inscribed in social housing space.

Table 11 Highest Integration (*i*) and control value (*CV*) in original and transformed dwelling spaces

Neighborhood	Dwelling	Highest integration value (i)	Value	Highest control value (CV)	Value
Constituyentes de Querétaro (1974)	CQ2 original	Living-dining room	5.25	Porch 1	1.83
	CQ2 transformed	Living-dining room	4.00	Living-dining room	2.83
	CQ5 original	Living-dining-kitchen	7.50	Distributor	2.00
	CQ5 transformed	Corridor	5.14	Corridor	1.83
Colinas del Rio (2000)	CR1 original	Living room	9.00	Living room	3.16
	CR1 transformed	Living-dining room	7.50	Living-dining room	3.30
	CR3 original	Living-dining room	14.00	Living-dining room	4.33
	CR3 transformed	Living-dining room	7.00	Living-dining room	4.33
Los Encinos (2015)	EN3 original	Living-dining room	5.63	Living-dining room	3.33
	EN3 transformed	Store	5.14	Store	3.50
	EN4 original	Living-dining room	5.63	Living-dining room	3.33
	EN4 transformed	Living-dining room	7.07	Living-dining room	3.83

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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