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RESEARCH

Combinatorial Possibilities and Enumerations for Housing Designs: Gregory Ain's Mar Vista Tract (1946–1948)

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Abstract

This article introduces a formal method with regard to point group symmetry in the analysis and construction of housing units and their arrangements. Gregory Ain's Mar Vista Tract is the focus of this study. In this paper guiding principles of Ain's housing unit layouts and their arrangements in a city block are examined with respect to the symmetry principle. With the same method, combinatorial possibilities of the units and their arrangements are tested and computed to see how many possible designs can be generated. Finally, streetscape perspectives are generated to illustrate how they would appear when new design features are added.

Introduction

After working for Richard Neutra and Charles Eames, in the mid-1930s Los Angeles architect Gregory Ain opened his own office, collaborating with architects Joseph Johnson and Alfred Day. He also worked continuously with landscape architect Garrett Eckbo for most of his housing designs. Today Ain is known for proposing a series of housing projects for social interaction. He developed an effective and innovative solution to provide affordable housing developments for middle-class families. His approach has two aims. First, a new kind of shared open space in a housing community is actively facilitated for social interaction and a sense of

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community so that residents can interact with one another.[1] Second, an inventive design method is strategically employed where diverse housing designs and their arrangements within a city block are possible through the application of a simple symmetry method.[2]

Among his projects, Ain's Mar Vista Tract (1946-48) is the most outstanding, where his neutral spaces for the community and symmetrical approach are strategically employed in laying out housing plans in a variety of ways on a city block. A *house can* be any prototypical unit of dwelling where the unit and its variations can be generated and arranged in vastly different ways. It forms a family with certain stylistic characteristics and fundamental principles of spatial composition. Nevertheless, studies on the underlying design mechanism of Mar Vista Track are rare. Most studies have sought to present architectural descriptions of physical features, the history of its design development and its preservation, and the spatial characteristics of individual houses (Denzer 2008; Kamei 2008).

The purpose of this paper is to reveal the underlying logic of the spatial layout of the project, followed by an exploration of the range of combinatorial possibilities and design variations.

Finally, a series of eye-level perspective simulations of streetscapes are created to show how various unit combinations, along with some additions and extensions to the prototypical unit, can produce a dynamic and coherent character in streetscapes. This focus on spatial patterns and organization develops new knowledge about combinatorial design and its application in Modern domestic architecture.

Mar Vista Tract, 1946–1948

Background

In the mid-20th century, the U.S. experienced phenomenal economic growth and the rise of new suburban cities. This was partly due to the rapid success of the automobile and housing industries. In particular, the housing market was rich with opportunities because war veterans returned home, and the millions of "baby boomers" needed places to live, resulting in demand for affordable housing and the growth of suburbs. A multitude of affordable housing options were produced in response to these circumstances (Hise 1997). For example, developer William J. Levitt utilized prefabrication techniques for low-cost housing developments on the outskirts of US cities. His housing designs in Levittown all look alike. Thousands of these identical houses were iteratively mass produced, regardless of who the end-users were (Mumford 1961).

Rather than designing each house individually to meet end-users' needs, developers and builders construct and sell houses as an economic commodity. They

1 Ain's parents Baer and Chiah *Ain* were socialists and their ideas deeply influenced him.

2 Rudolph Schindler proposed an unbuilt scheme called the Schindler Shelters which had similarities but was never realized. See McCoy (1954: 12) and Jin-Ho Park (2001, 2003, 2004, and 2006).

Fig. 1 Views of Mar Vista housing units: view of a standard unit (left), a unit with a large overhang where columns act as a unique additional element of the house (right). Photographs by the authors

are interested in yielding a rapid and profitable sale, so it is hard to reflect the needs of individual end-users. The quality of such housing designs is far from the needs or preferences of consumers. Acknowledging this, Ain argues, "[t]he great majority of houses being erected today are the product of operative builders, who provide the lot as well as the finished house to purchasers who have little or no active part in expressing their preferences, or in determining the character of the structure … To the typical operative builder, a house is a commodity" (Ain 1948a: 98). Ain responded and proposed an innovative housing design called Mar Vista Tract after experimenting with a series of housing designs such as Park Planned Homes (1946-49). He proposed methods where housing units can be internally flexible and considerably variable in exterior appearance.

Mar Vista Tract housing is located in the western part of the city of Los Angeles (Fig. 1). The dense subdivisions of the lots were proposed by the Advanced Development Group and designed by Ain as a response to the pressing need for affordable housing. Upon subdividing the lots in 1946, Ain started to design Mar Vista Tract housing. Most of the units were constructed in 1948. Ain proposed a prototypical housing unit, and his methods for the variable combinations of units on lots enable a variety of habitable spaces and streetscapes, thus creating a sense of community identity.

Unit prototype

The average floor area of the standardized unit is approximately 1050 square feet. Although the standardized unit is planned to be simple, it optimizes the maximum flexibility of the unit plans according to the changing needs and lifestyles of families. The flexible layout in such a small house is not an option but a necessity, so that low or middle-income residents can modify their houses from one room to three bedrooms to suit their needs or interests without a large budget for alterations.

Ain uses a four-foot modular grid for the composition and construction of the house. He employed the module not only for the floor plan but also each component of the house, including the sizes of door and window details. This allowed them to be mass-produced, eliminating waste in material and reducing costs. In fact, the

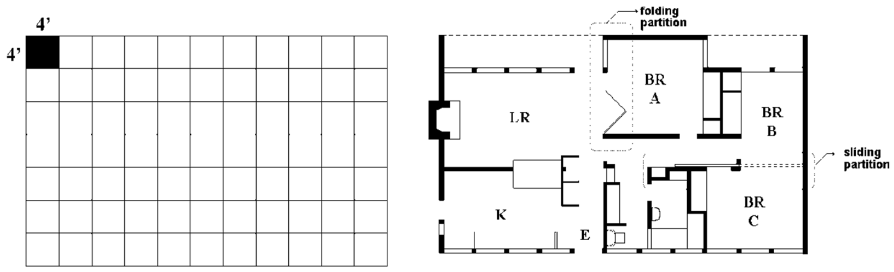

Fig. 2 Four-foot basic grid and typical unit plan of a five-room house without a garage [Key: LR-Living Room, K-Kitchen, BR-Bedroom, E-Entrance]

unit system is a logical result of the need for the efficient process of designing and constructing the mass-housing development. All of Ain's projects during the 1930s rely on a modular system. In this he may be indebted to Schindler for the use of a 4-foot plan module. Schindler employed the 4-foot unit grid system in *his* very early period, and it prevailed in *his lifelong* practice. Denzer (2008) summarized that *Edwards House* (1936), *Ernst House* (1937), and *Beckman House* (1938) used a 4-foot grid in their plans and a 16-inch vertical module. This system governs all dimensions of each house from room dimensions to details.

The main benefit of Ain's unit design is that it combines flexibility of spatial arrangement with the economy of standard parts. Although there are a few fixed walls in the interior, the major rooms are separated by sliding and folding partitions and built-in furniture. Ain cleverly used two kinds of moveable, non-load-bearing interior partitions that slide and fold. They go from floor to ceiling to close off the room completely. The folding partition between the living room and the master bedroom is composed of a pair of bi-fold doors. When the partition is open, the two rooms become one as a living room. The sliding partition of a lightweight wall is made of a full panel so that a large single room can be quickly divided into two by rolling the partition into the hallway. In Ain's words, "[f]inger-tip mobile walls convert the modern home to a choice of one, two, or three bedroom accommodations" (Ain 1948b: 3). As a result, the flexibility of interior spaces is maximized with the manipulation of the movable partitions. The whole house is transformable from a three-bedroom to a one-bedroom house. When the living room and bedrooms A, B, and C are open, the house becomes a one-bedroom house. When the living room and bedroom A are closed and bedrooms B and C are open, the house becomes a two-bedroom house (Fig. 2).

The built-in dining table between the kitchen and living room, as well as the closet partition in the entrance hallway, also offer spatial flexibility. While the built-in dining table is left open most of the time, the living and kitchen are visually connected so that a "housewife in the kitchen can participate in social activities in the living room" (Ain 1948a: 101). By lowering a dividing blind, the kitchen may be closed off from the living room. Instead of a solid wall, Ain made the closet partition in the entrance hallway shorter than the ceiling height. The intent is to create a sense of openness in such a small house. The living room has floor-to-ceiling windows to

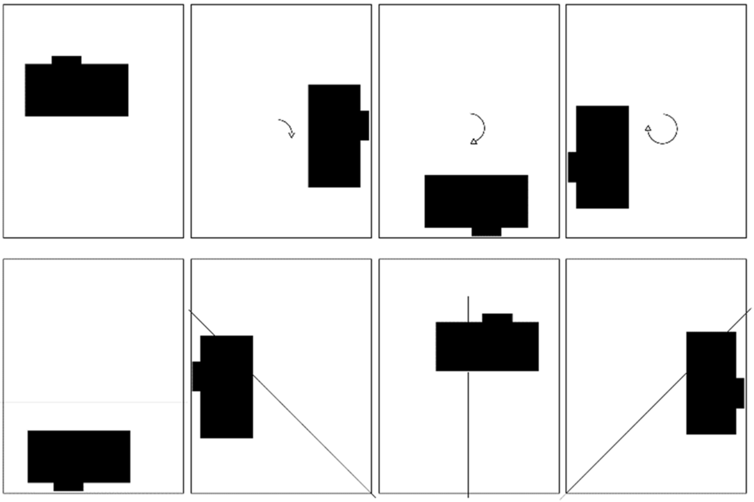

Fig. 3 A basic unit is repositioned on a rectangular outline corresponding to one of the eight transformations of the square

maximize the exterior view of the garden and patios. In addition, an inhabitant can watch who comes to the house from the street.

Underlying logic for the spatial arrangement of the house

If one takes a closer look at the Mar Vista Tract layout, one finds that the unit house is arrayed according to the point group of symmetry of the square (Fig. 3). Each of the eight elements of the symmetry of the square was exhaustively used and then, the garage is added to create variety in the streetscape. It is an extremely rare example in architectural design where eight rigid motions of the symmetry group of a square are used. Valid operations of a symmetry group of the square include rotation about its center through 90, 180, 270, or 360 degrees, and reflection on its four axes. That is, Ain rotated and reflected the basic unit in eight distinguishable transformations of the square while arranging them on the site (March and Steadman 1974; Park 2001). It is Ain's unique contribution to the project that he understood the basic notion of the symmetry of the square. Above all, he could experiment with the symmetric notion and realize its great potential for a diversity in the visual character and quality of the surrounding area.

Ain recorded in the December 1947 master plan of the project that the garage is "attached diagonally and offset to a short wall, detached in the back, or inserted under the house". Although it looks as if there are four ways for the house and garage to be attached, Ain's drawings reveal that he elaborated the relationship further. Ain carefully orientated the house according to the street and then located the garage according to the house, while considering the directions of the entrance door of the house and the marginal spaces for the driveway (Fig. 4).

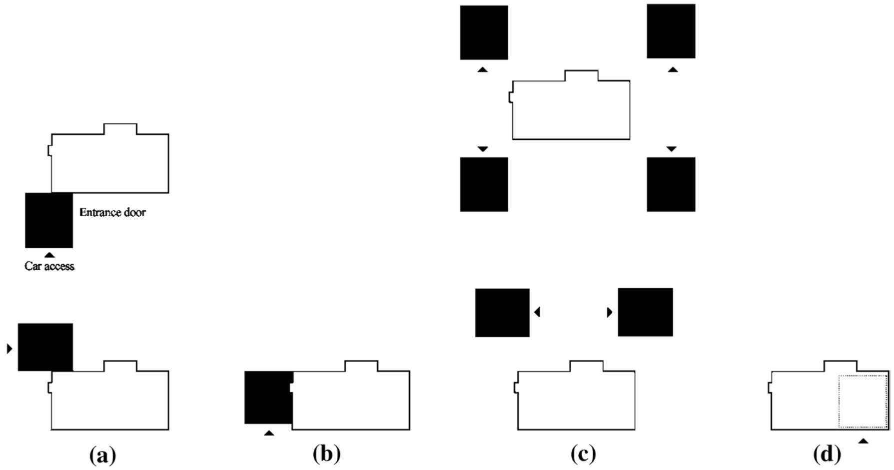

Fig. 4 Four typical ways in which a garage is connected to the basic unit. **a** Attached diagonally; **b** offset to a short wall; **c** detached in the back; **d** inserted under the house

When Ain describes the garage as "attached diagonally," two different methods are used where the garage is attached either to the kitchen side or the living room side (Fig. 4a). In the case where the garage is "attached offset to a short wall," this is the only version where the garage is attached to the side of the living room and kitchen (Fig. 4b). Ain mentioned the garage can be detached on any side of the house's backyard (Fig. 4c). When Ain's built projects are examined, six different ways in which the garage is detached from the house are found. Finally, the garage was placed under the unit due to the level of the lot terrain.[3] In this variation, which only occurred once, the garage is located under the kitchen and the living room (Fig. 4d).

Spatial arrangement of the house

Originally, a total of 102 houses were planned, yet only 52 were built. Each unit is assigned to a subdivided site, which is largely predetermined by existing adjacent streets. The average size of each lot is approximately 75 × 104 feet, and they are aligned along three 66-foot-wide broad streets. In this setting, Ain laid out the units of the Mar Vista Tract according to his own combinational methods. In addition, different elements could be added according to the site conditions and needs, resulting in different designs, types, and even sizes of houses. Each house starts with the standardized unit containing three bedrooms and a bath, in which rooms are flexibly transformed as needed. Each unit is placed according to the site conditions and end-user's needs.

[3] Number 43, 3500 Meier St. Los Angeles.

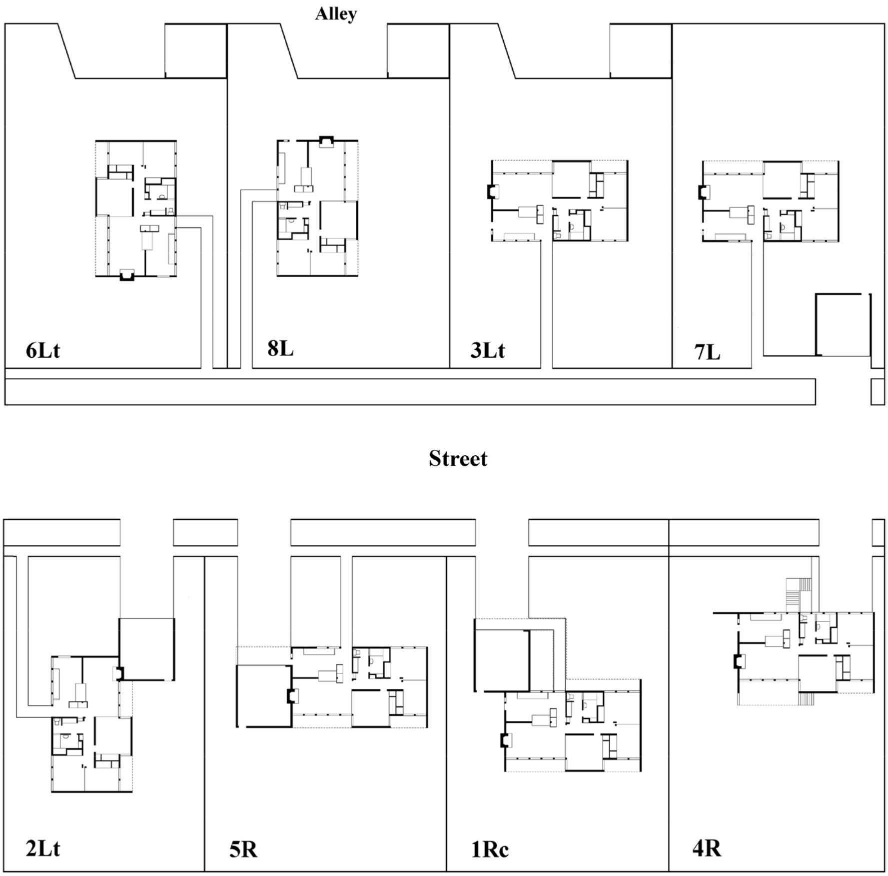

Fig. 5 Eight variations in house orientation according to the street or changes in the relation of the garage and house

Ain set up symbols to itemize a variety of spatial arrangements. The standardized unit can be rotated and reflected and then placed along the street. A garage was a separate unit that could be added according to typological situations and street conditions. He assigned numbers of 1 to 8 to indicate variations in house orientation according to the street or changes in the relation of the garage and house, as illustrated in Fig. 5. The variations are as follows: 6Lt. perpendicular with a living room towards the street and the detached garage in the back; 8L. perpendicular with bedrooms towards the street and the detached garage in the back; 3Lt. parallel to the street with the detached garage in the back; 7L. perpendicular to the street with the detached garage diagonally in front; 2Lt. perpendicular to the street with the garage attached diagonally; 5R. parallel to the street with the garage attached offset to the short wall and trellis in front; 1Rc. parallel to the street with the garage attached diagonally; 4R. parallel to the street with the garage under the house (Fig. 5).

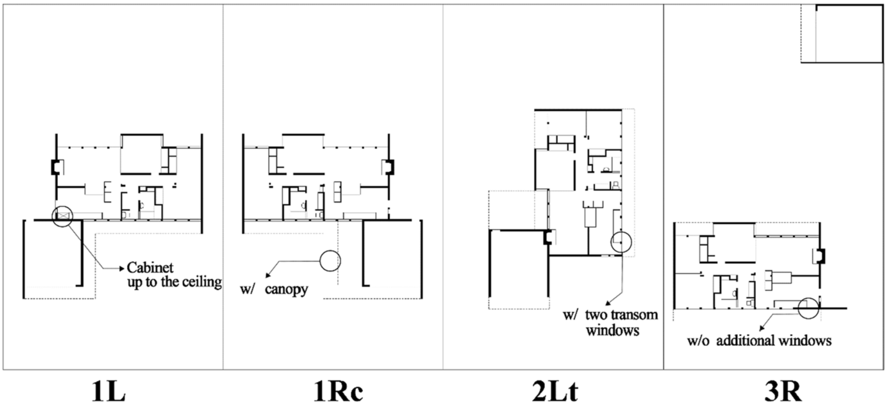

Fig. 6 Four floor plans to illustrate Ain's notations with regard to two additional transom windows, a cabinet, and a canopy

Locating the garage in different positions helps in breaking the repetitive and symmetrical collocation of the same unit along the street. This serves as another method for the creation of a variety of designs that underpin the dynamic exterior view. Not only can a unit be arranged but variations of different types of shelters can also be distinctively combined to generate a large variety of arrangements.

Ain assigned notations of L, R, t, c, and w. L and R mean placing the kitchen on either the left or right when facing the entrance door from the outside. In the standard unit, two front windows in the kitchen are a basic option. A "t" was used when two additional transom windows were to be added in the kitchen, depending on its positioning. Units without these windows allow cabinets up to the ceiling. A "c" indicates a canopy over the entrance walk, and "w" indicates a wood floor except for type 4, which always has a wood floor (Fig. 6).

As such, there are a number of combinatory possibilities in Ain's assembly. A unit may be placed in eight symmetrical ways, where a garage can be added for four different locations. Then, there are five different additional ways where the featured elements are added. The total number of combinatory possibilities is large, where the number of 8 symmetrical units is multiplied by 4 garage locations and 5 additional elements including L, R, t, c, and w. It means that 160 arrangements ($8 \times 4 \times 5 = 160$) are possible. Out of the 160 possible combinations, Ain illustrated some basic arrays to be used in Mar Vista Tract with some additional elements, as illustrated in Fig. 7. Ain recurrently arrayed these combinations when filling in the 52 lots. Nevertheless, 4R, 7Lt, and 7Rt did not appear among the 52 built projects yet were included in unbuilt arrays. Ain numbered each of the 52 houses and placed them in order from the first house at 3500 Beethoven St. (#1) to the 52nd house at 3562 Meier St (Fig. 8). According to the block-to-lot subdivision, most blocks use

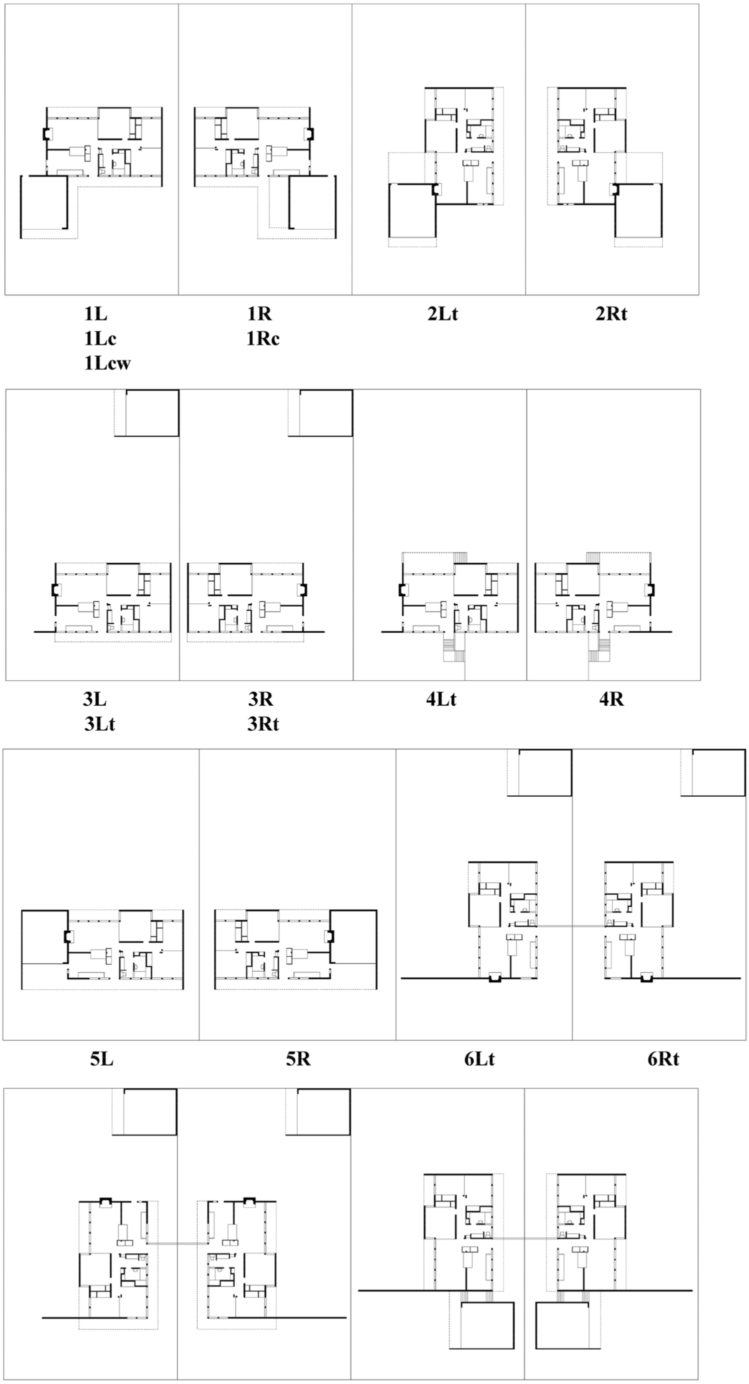

Fig. 7 Examples of basic prototype plans for Mar Vista Tract (redrawn by the author)

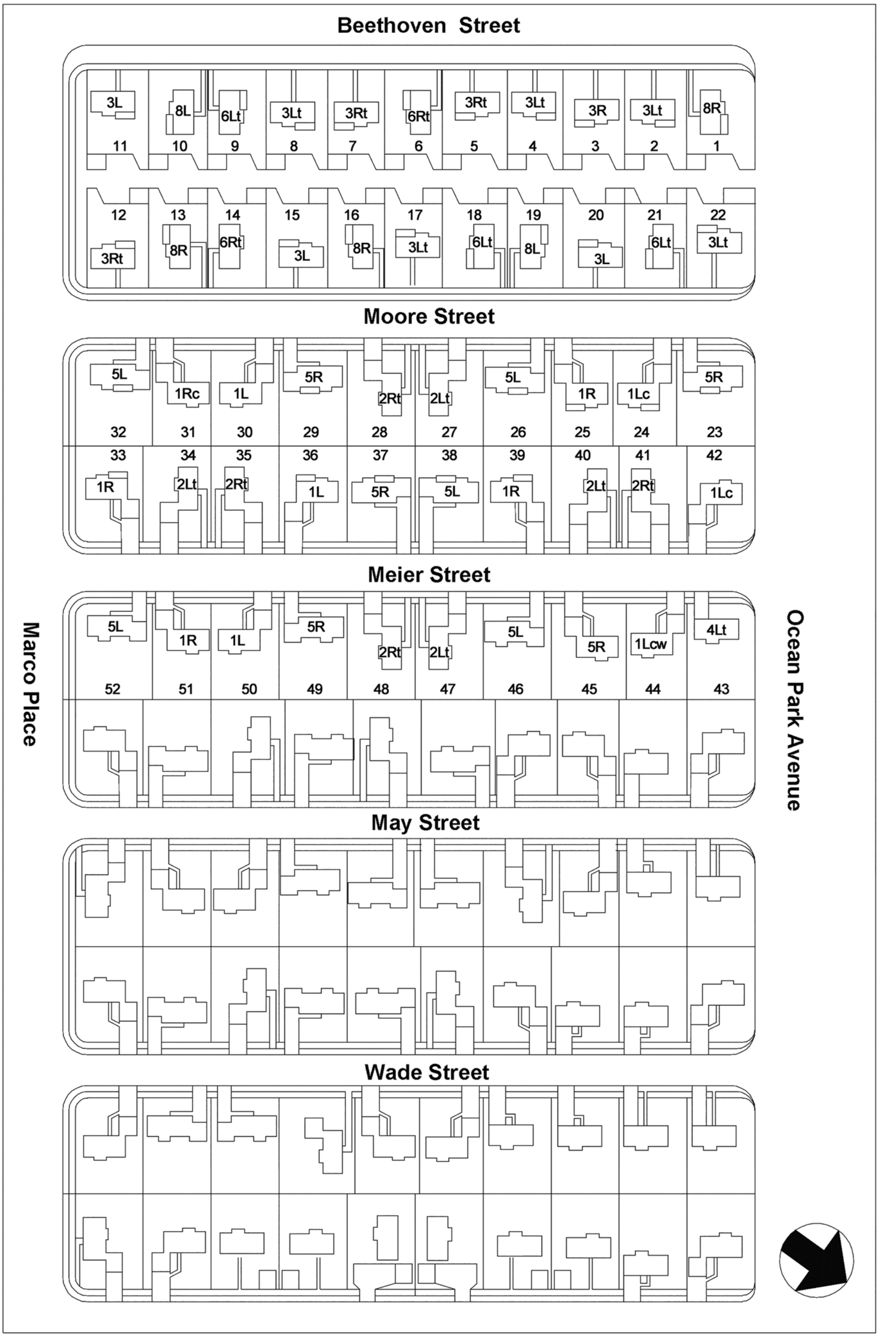

Fig. 8 Arrays of 102 houses. Each of the 52 built units is numbered and marked with its combinatory type. (redrawn by Ro, Donggyun)

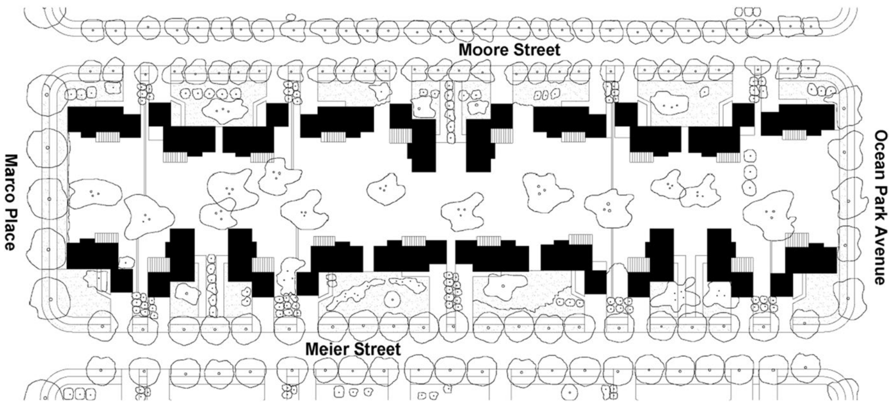

Fig. 9 The front and back yard plan on the block between Meier and Moore Street (Ain's original drawing, redrawn by Ro, Donggyun)

10 lots for a block division. However, the first block to the north has 11 lots in its subdivision. This may be due to the garage being detached to the rear side of the lot so that houses can be arranged on a narrower site. This allows for more houses to be fitted into the same block size, and the block allows for use of the back alley for parking access.

In addition, Ain used 23 different color codes for the application of the interior and exterior color choices. The interior color of each house matches that of the exterior.[4] When all 23 colors are used for combinatory color arrays for the 52 houses, the number of possibilities increases exponentially.

In laying out the units, Ain was deeply concerned with values of social interaction with shared open spaces. His socially driven approach recurs in his affordable housing designs, particularly in the placement of an individual unit in a given lot and the treatment of the front and back yards. Lots for Mar Vista Tract were developed and subdivided within a dense residential block, so it was hard to provide an open communal park as he envisioned in a series of housing projects, such as the 1946–1949 unbuilt project for the Federal Housing Administration (FHA) and the Community Homes in Reseda, San Fernando Valley. Ain's idea of the open shared community park can be traced back to his early projects such as *Preliminary Proposal "A"* (1939/1940) and *One-Family Defense House* (1939). In these projects, Ain developed site plans showing open shared parks in between housing lots. It seems that his socially driven spirit in affordable housing development was derived from his early period of design practice.

Placing individual units in such symmetric ways creates irregular front and back yards. This provides a means to allow flexibility and diversity in the development of

[4] Based on the Plochere color system, each unit was carefully painted in different color combinations to balance between the interior and the exterior of the house. See: http://marvistatract.org/tract_color_chart.html.

Table 1 Combinatorial features

Symmetry operations	Garage	Roof	Additional components
0° (I)	Attached diagonally	Composite	Pergola
90° (q)	Attached offset to a wall	Gable	Windows
180° (q^2)	Detached	Flat	Deck
270° (q^3)	Inserted under		Trellis
Horizontal (r)			Canopy
Vertical (q^2r)			Flowerbox
Diagonal 1 (qr)			Freestanding wall
Diagonal 2 (q^3r)			Column
			Gate
			Cantilever

the streetscape and the back yard landscaping. Some units have ample front yards, and the back yard is extremely small. But other units reversed this. With the help of his landscape architect, Garrett Eckbo, Ain developed the landscaping of front yards together with sidewalks and streets with a variety of plants. Individualized landscaping designs for each house unit were also provided to allow the neighborhood to look intricate and *dynamic*. This served as a crucial instrument to create a cohesive residential environment, facilitating social activities and providing an extensively open streetscape.

Most importantly, rather than providing individual back yards behind each house, Ain offered a portion of each to a communal back yard in between back-to-back units as an open shared space (Fig. 9). The group of houses within a block is not physically separated with walls or high fences so that the residents may feel closer together. Yet trees, shrubs, and bordering hedges are used to differentiate the properties, thus creating a more natural separation. His intention for the communal backyard was to encourage shared use of the green spaces for social interaction among residents. Unfortunately, Ain's original idea was not sustained for very long because most *homeowners in Mar Vista Track soon* built fences for *backyard privacy, safety, and security*.

Combinatorial possibilities of arraying different units of the project along the street

Although Ain offered a few possibilities of laying out the Mar Vista Tract, his ideas can be elaborated further. Whereas a range of houses with unified principles exist, Ain never thoroughly explores all possible layouts but provides only a few examples of the kind of layouts that he developed. A thorough number of possible designs could be spawned as a set of probable designs. The set may result in huge compositional possibilities (Park 2004). With similar rules and principles, some additional architectural options may be added. Then, the range of combinatory possibilities and design variations on the same theme increases greatly. Ain's ideas serve as a vehicle to generate an array of new designs. Nevertheless, this

Table 2 Total numbers of possible combinations depending on the number of design components that are counted

Selected number of additional components	Counting the total number of possible combinations
1 out of 10 = 10 possible combinations	960
2 out of 10 = 45 possible combinations	4320
3 out of 10 = 120 possible combinations	11,520
4 out of 10 = 210 possible combinations	20,160
5 out of 10 = 252 possible combinations	24,192
6 out of 10 = 210 possible combinations	20,160

research is not intended to draw all possible schemes, yet it is easy to envision the combinational possibilities and dynamics.

Number of different combinations

To expand the combinatorial possibilities, some of the different design features of Ain's designs are adopted. These include different types of roof forms, pergolas, windows, decks, trellises, canopies, flowerboxes, walls, or other features. Some of the partial components could be added by the residents, after the houses are built. Some others may be changed when the houses are remodeled. This scenario increases the variety of *housing* types and strengthens the diversity of external views where users can choose different conditions to accommodate their needs and wants.

In the case of designing a house in different combinations, as shown in Table 1, it would be interesting to find the number of possible outcomes that can be combined together to design a house. Assuming that one of each item in each section is to be selected, any combination is acceptable. Then, it would be interesting to find how many different ways can be chosen from the eight symmetrical operations, four garage locations, three roofs, and 10 additional elements. Here the garage locations are limited to four ways. If all of possible combinatory options between the garage and the unit that Ain used are counted, the number increases considerably. For example, the total number of combinatory possibilities is 8 symmetrical units multiplied by the number of garage locations, roofs, and additional components ($8 \times 4 \times 3 \times 10 = 960$ possible arrangements). Typically, a house contains various architectural elements. For example, a house can have two, three, four, or more additional elements in its design. These combinatorial possibilities can be also calculated.

10 additional architectural components components can be selected and added to a unit. With 10 elements (a through j), there are 45 combinations when considering them two at a time (for example, ab, ac, ad, ae, af, ag, ah, ai, and aj), if ab and ba are not differentiated. This can be counted simply with a formula. For example, if there are 10 additional components and any 2 of them can be

selected, 2 out of 10 components can be selected. The formula for calculating the number of combinations is nCr for n distinct components taken r at a time $(1 \leq r \leq n)$.

From the combination formula, $nCr = [n!/(n-r)!\ r!]$, so the total number of possible arrangements 10C2 is 45 (10!/(8!2!) = (10X9)/2, 5 × 9 = 45). In all, the number of possible combinations of all elements where two additional components can be selected is 4320 possible combinations (8 × 4 × 3 × 45). The total possible combinations, depending on how many additional components are selected, are summarized in Table 2.

Here, colors are not discussed because the total number becomes extremely high. But consider 52 houses on a city block and 23 possible colors. Any of 23 colors can be chosen for the first house. Whatever color is chosen for a house, there are 23 colors with which to paint the second house, so there are 23x23 ways to paint the first two houses. Thus, a total of 23^{23} different color assignments to the houses are possible.

Changes and variations in streetscapes of the block

The symmetry principle as a design tool has powerful potential to be used in spawning combinations of the units and their variations for a larger assembly. While maintaining formal continuity among them, the result will become a dynamic streetscape that allows residents and visitors to experience the lively streetscape in the neighborhood, similar to the use of the frieze group symmetry (Park and Ji 2019).

Not only can basic units be arranged on a site, variations of different types of units can be distinctively combined where new design features are added to generate a huge number of possible arrangements. For example, different roof forms, trellises, external walls, gates, and other components can be added to each unit, creating a changing outlook and individual identity to each unit. Although developed from the same prototypical unit, with subtle changes and additions, each unit will have its own distinctive identity, and a group of units will produce a vibrant and diverse community that is unlike any other. It is also expected that an integration of such dynamic arrangements will form a coherent formal language of streetscapes to create a sense of overall ensemble of the community.

Trees and hedges contribute to property values by providing visual protection and maintaining privacy, as well as improve scenery by diversifying the streetscape and enhancing appearance. Trees and hedges are not grown yet when planted at the beginning of the development, so the landscape is not obvious from the street. After some years, the landscape will change and along with the diverse unit designs, trees and hedges become a major feature to provide dynamic scenery in the streetscape. When driving or walking along the street, it may be hard to figure out whether such methods are used to achieve the distinctive variety.

Perhaps, some may argue that standard units in affordable housing developments are poorly arrayed at times, thus creating a dull and repetitive

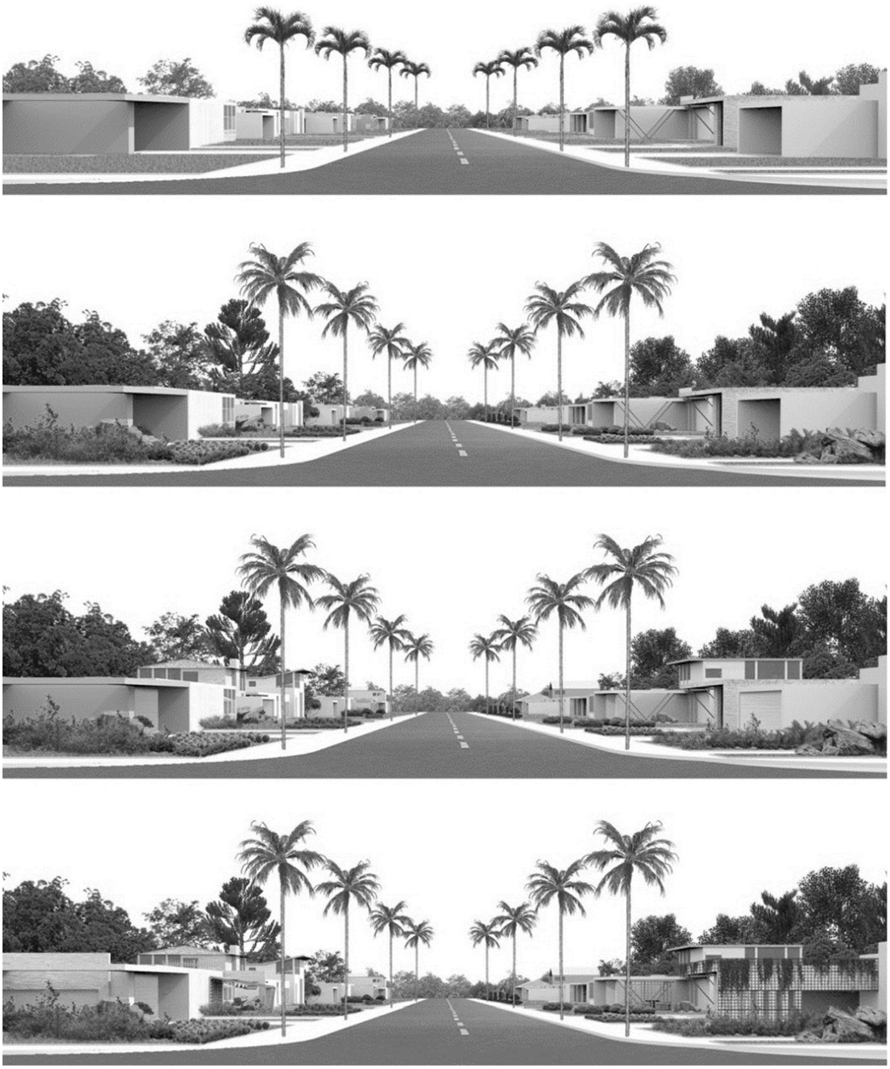

Fig. 10 Eye-level perspective simulations of streetscapes of the block

look of the neighborhood from the streetscape. This is not the case if sufficient combinations are used. Figure 10 demonstrates that the arrays of various unit combinations along with some additions and extensions produce a dynamic and coherent similarity in streetscapes. In the top part of the figure, units and their derivations are arrayed and built on hypothetical yet typical urban lots, providing an overall look might be repetitive and monotonous. In the second part, trees and hedges are integrated between neighboring units in streetscapes. In the next part of the figure, some are built with an extension on the second level, or some rooms are extended on the ground level. At the bottom, some elements like trellises, external walls, pergola, canopy and gates are added to give visual complexity to the streetscape.

The set of steps and the mathematical method discussed in this article produce a *dynamic* and elaborately textured *streetscape view*. In fact, Ain himself *predicted and envisioned the consequences of the spatial images of the neighborhood in his earlier works,* such as Park Planned Homes of 1946–1949.

Conclusion

The late 1940s, when Mar Vista Tract was designed, were the heyday of Ain's professional career. He developed various socially driven housing projects during this period. Mar Vista Tract deserves a prime place among his most accomplished housing developments and offers a very distinctive pattern of spatial organization. Standardized units and their diverse variations are strategically generated and then arrayed in a variety of ways through careful placement of houses, planting, and other design features as additional options. Ain utilized symmetric transformations in laying out housing designs, and the garage placement in particular remarkably increased the presentation of symmetric transformations in the creation of design diversity. In this project, Ain showed a keen understanding of symmetrical organization where the symmetries of the point group were articulated, as in patterns. From the symmetric point of view, the spatial arrangements of housing units and patterns may be similarly treated because both are regarded as the rigorous sum of basic motifs. Accordingly, both architects and designers can infuse stimulating playfulness into their designs through tapping into infinite resources of symmetry.

In the project, Ain argued that this combinatorial approach would provide diversity and interest, rejecting the dull repetitive schemes of the past. The mathematical results developed in this paper confirm that a level of diversity would be produced, and the analytical study could serve as a foundational tool for the synthesis of new designs. By simply transforming unit designs, replacing the garage, and adding new options, a huge number of combinatorial possibilities are made possible. With new options, the number of probable designs would increase immensely. But most importantly, extensions and additions to the houses and a dense landscape give visual complexity to the streetscape. As illustrated, when arranged in a city block, the final design turns out to be surprising and unanticipated.

Ain's approach provides unique practical solutions to some of the most common issues in affordable housing development, such as repetition, boring streetscapes and a lack of integration with the neighborhood. His method is effective and economical in the development of social housing, even in contemporary practice.

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