# Measuring the Entropy of Mass Housing Projects Through Spatial Relations

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## Abstract

Buildings as architectural design products include a high level of organized complexity and can be considered as a source of information. Previous studies looking into the relationship between entropy and architecture, calculations are performed on modular, repeating, distinct, and unambiguous components of buildings. In this context, entropy calculations can be performed for mass housing (MH) projects which consist of standardized repeating housing units. MH projects include many factors such as shape, color, height, material to make entropy calculations. Another important issue to be addressed in MH projects is the spatial relations between housing units. In the calculations where only the shape of the housing units is considered, entropy values of MHP will be relatively low because of repeating parts. On the other hand, the two same housing units can create numerous combinations and neighborhood conditions. The main objective of this study is to test a method previously developed by authors to calculate spatial relation entropy of a different context such as MH projects. In this study, Silodam MH Block (built in Amsterdam) that includes 157 individual units on 11 floors is selected for spatial relationship entropy calculations. As a result of spatial relation entropy calculation, it is concluded that a set of simple and repeating units in a MH can create a high level of entropy in terms of spatial relation. It has also been concluded that spatial relationships are an important instrument of architects in achieving organized complexity.

## 1. Introduction

Built environments, buildings, and artifacts as products of humans include a high level of organized complexity and can be considered as a source of information. The information embedded in these human products can be measured by using an objective method such as entropy which is propounded by Shannon as a key concept of information theory [1]. Entropy measurements of built environments, buildings, and artifacts can be conducted through a variety of physical features. In the literature, these physical features are named as factors and the factors cannot be limited to solid-void ratio, size, scale, shape, color, and spatial relations.

In the scope of this study, a previously developed spatial relationship entropy calculation method is applied in a new context. Previously this method developed by the authors applied to measure the entropy of man-made historical architectural elements called muqarnas [2]. However, in this study, a similar method is utilized in the building (MH) scale. In the scope of this study, Silodam MH Block designed by MVRDV in Amsterdam is selected as a case.

Previous studies looking into the relationship between entropy and architecture, calculations are performed on modular, repeating, non-intersecting, and unambiguous components of buildings [3,4,5,6]. The reasons to select mass housing (MH) projects are their characteristics such as repeating distinct parts (housing units) and the number of possible spatial relationships between these parts.

The possibility to create a large number of spatial relationships have been tested previously with Froebel Blocks and LEGOs. Based on the findings of Stiny's [7] experiments with Froebel Blocks and Durhuus and Eilers's [8] calculations with LEGO blocks, 2 identical 3-dimensional forms can create a large number of spatial relations. The research question answered in this study is:

- Is it possible to achieve a certain level of entropy value from the spatial relationships between subparts of a single MH building?
- Is there a difference between spatial relationship entropy values calculated based on floor plans and sections?

## 2. Complexity and Entropy

The term 'complex' as a noun refers to "a whole composed of interconnected or interwoven parts" [9]. In the adjective form of the term, there is an emphasis on becoming "combination of simple things or elements" [10]. Boeing's [11] definition of complexity indicates the rich behaviors that arise from the interaction of many connected parts and subunits of a system.

Salingaros [12] and Klinger and Salingaros [13] classified complexity as "organized" and "disorganized". In cases of organized complexity, the system contains internal organizations and the order resulting from these organizations ensures the sustainability of the system. On the contrary, disorganized complexity has no organization; and in the absence of internal organization randomness occurs and any kind of order cannot be mentioned [12,14]. The absence of any pattern makes perceptibility difficult and reveals randomness. While ordered complexity contains a large amount of information in an organized way, random information stored in disorganized patterns does not support establishing relationships. Due to the lack of internal organization, the information processing capacity of the human mind is overwhelmed, in other words, patterns with a mathematically simple definition are more easily perceptible, patterns that cannot be defined simply are random [13,14].

Beyond natural systems and social structures, complexity is also seen in man-made systems. Built environments, buildings, and artifacts have a highly organized complexity. In built environments, the order is achieved by creating a structure or organization. As a result of extreme order, excessive repetition and monotony occur. On the contrary, the lack of order creates a high level of complexity that leads to chaos.

There are methods used from past to present to organize the complexity of built environments, buildings, and artifacts. It is possible to obtain a complex architectural product from repeating parts by using basic operations. These operations can be listed as but not limited to: translation, symmetry, reflection, rotation, scaling. All these methods have been invented and used in the past during the development of architectural products including organized complexity. The built environments, buildings, or artifacts without the mentioned organization mechanisms show random and disorganized characteristics. The use of symmetries randomly when producing large-scale forms may lead to the collapse of information [12,14].

The concept of entropy remained limited to the discipline of physics until the late 1940s and rediscovered by Shannon in information theory. Since Shannon propounded information entropy to solve communication problems; his entropy concept was adopted by other disciplines such as psychology, art, urban design, and architecture. Bailey [15] emphasized that the concept of information entropy can be applied to any information content that contains multiple data types.

As concepts of complexity have different definitions and classifications, entropy has been also defined in different ways. Berlyne [16] defined entropy as a method to measure the disorder physically. Similarly, Shaw and Davis [17] used entropy synonymous with disorder and diversity. In this study, the entropy concept in information theory is used to measure the level of complexity of artifacts.

In cases where complexity is considered as a quantity, entropy is a convenient method to calculate complexity. According to the basic entropy equation, the entropy value can be calculated through finding the frequency of the repeating parts in a whole. In this study, the basic entropy equation is used to calculate the spatial relationship entropy in both plan and section planes.

Detailed explanation for the basic entropy equation and sample calculations can be found in previous studies published by the authors [2,6,18,19,20].

## 3. Spatial Relationship Entropy Calculation Method and Its Implementation

To do spatial relationship entropy calculations, measurable features of the MH project has to be defined clearly. In this study, spatial relationship entropy calculations are conducted over two types of spatial relation. Horizontal relationship entropy (HRE) is calculated over the side-by-side neighborhood relations of the discrete housing units (polygons) in the floor plan layout. Then, vertical relationship entropy (VRE) calculations are made based on up-and-down neighborhood relations between housing units in the sections. In this study, instead of representing the neighborhood relationships like a graph, the shared walls (lines for side-to-side relation) and slabs (planes for up-and-down relation) are named as segments and these segments are automatically counted by the algorithm. While counting the segments, algorithm neglected the length and the area of the segments. Based on parameters as the total count of segments (relationships), the number of segment types (relationship types), and the count of repetition of each segment type (relationship type), the frequency of each horizontal and vertical relationship type is found. These frequencies found are enough to conduct both HRE and VRE calculations.

## 3.1 Case Study

Silodam Housing Block is a 10-story (11 levels including rooftop) building and includes 158 housing units. It simply has the form of a single rectangular prism 130 meters in length and 20 meters in width (Figure 1).

In this project, the designers aimed to create a neighborhood by combining different types of housing units. Within the Silodam MH block, different housing unit types were created and are coded from A to T, and sub-types of each type were also tagged (ex. A1, A2, T1, T2) (Figure 2) [21].

***Figure 1.*** *Silodam MH block (Photo by Authors)*

Therefore, counting the number of different housing units and calculating entropy, based on their frequencies in all building does not provide valuable insight. The housing units in the project differ from each other in the context of many features such as the number of floors (single, duplex, mezzanine, rooftop), their orientation, plan types, colors, facades, and open space relations.

One of the factors affecting the plan and section layouts and the spatial relations observed in these layouts is the diversity of the methods to arrange housing units in the horizontal and vertical axis. For example, parts of a duplex unit can be placed completely overlapped, while parts of another duplex unit can be placed by shifting the upper part. Or a big housing unit can be placed over 3 small units.

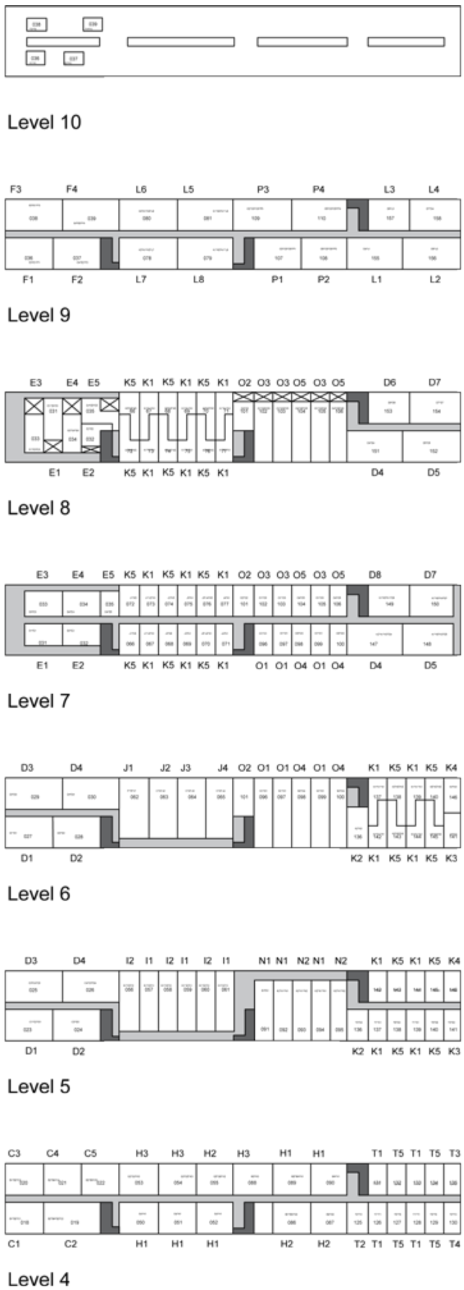


***Figure 2.*** *Floor plans, plan types, and tags of the units (continues)*

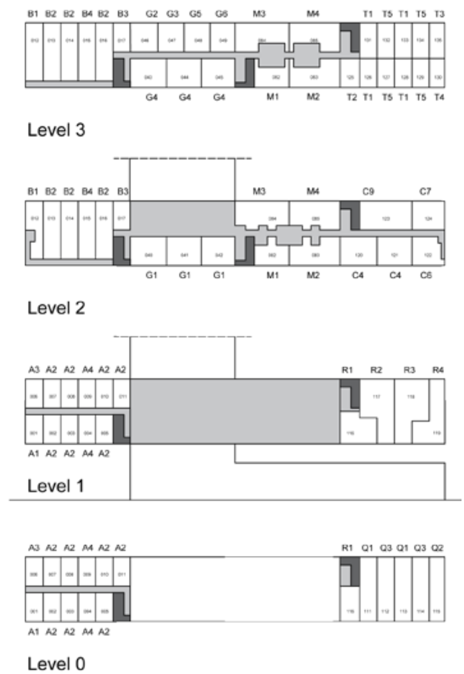


***Figure 2.*** *Floor plans, plan types, and tags of the units (continues)*

Before the HRE and VRE calculation, 11 floor plans were redrawn by the authors in AutoCAD environment by tracing the floor plans and sections derived from El Croquis [21].

Then, each segment (wall for HRE and slabs for VRE) defining a neighborhood relation between two housing units was labeled in the forms of X-X for HRE and X^X for VRE. The graphical representations of these relationships are illustrated in Figure 3 and Figure 4.

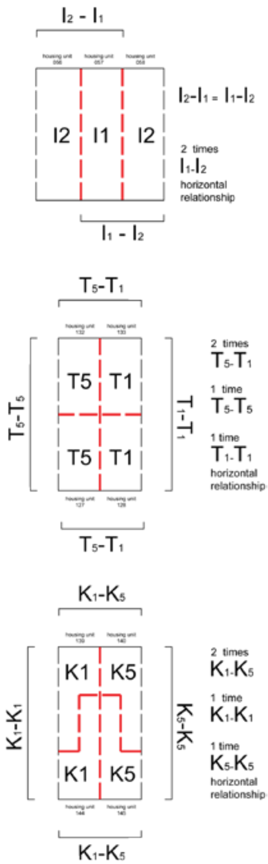


***Figure 3.*** *Labelling and counting process for horizontal relationships*

Then, the prepared algorithm transferred all embedded labels in different layers to the Grasshopper Visual Scripting Environment (VSE) using the “Dynamic Geometry Pipeline” component of the Human plug-in.

After having all segments with their labels in the Grasshopper VSE, total count of relationships, number of relationship types (horizontal and vertical), count of repetition of relationship types is found by simple listing, counting, and grouping operations.

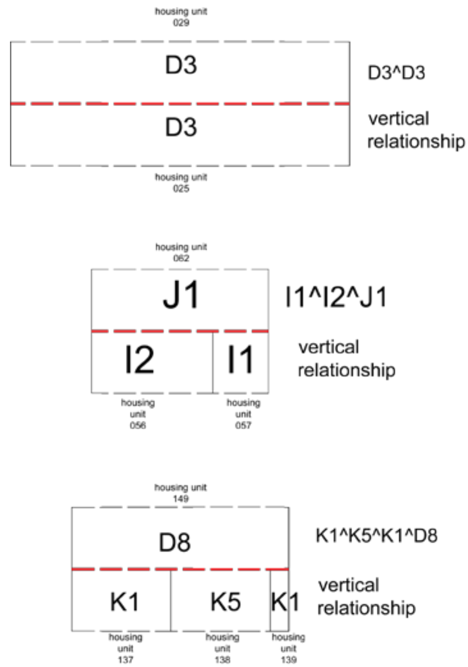


***Figure 4.*** *Labelling process for various vertical relationships*

Afterward, by using the basic entropy equation of Shannon, an entropy value was found for each relationship type according to the ratio of the count of repetition of each relationship type to the total count of relationships. By multiplying the entropy value of each relationship type by the count of repetitions of that relationship type and adding these multiplications, the overall entropy value (carried amount of information) of the building was found. Last, the average entropy was calculated by dividing the overall entropy by the count of total relationships.

For example, in Figure 5, the highlighted rows from the HRE calculation shows that the K1-K5 horizontal relationship has been seen 30 times in the Silodam MH. The fact that 30 out of 209 relationships are K1-K5, increases the possibility of this type of relationship to occur in the building. In cases where the probability of occurrence of a relationship type is high, entropy value of the relationship type (per piece) is low. For this reason, the K1-K5 relationship is clearly differentiated from the entropy values of the other relationship types with the lowest value of 2,800469 bits. On the other hand, since the K3-K4 relationship occurs only once in 209 relationships, the probability of its occurrence is minimum, and the entropy value is maximum as 7.707359 bits.

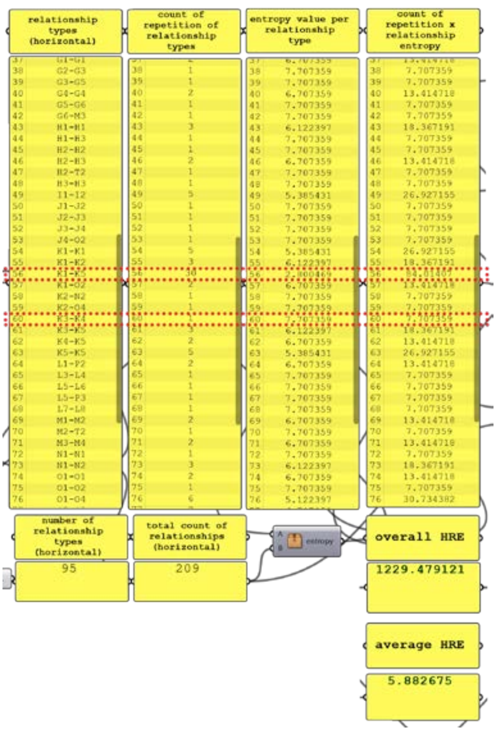


***Figure 5.*** *Calculations for HRE*

Figure 6 shows the calculation of VRE. In Figure 6, vertical relationship types are listed in the far-left column. In this case, it has been observed that in Silodam MH block, vertical relationships are established between 2, 3 or 4 units at the same time.

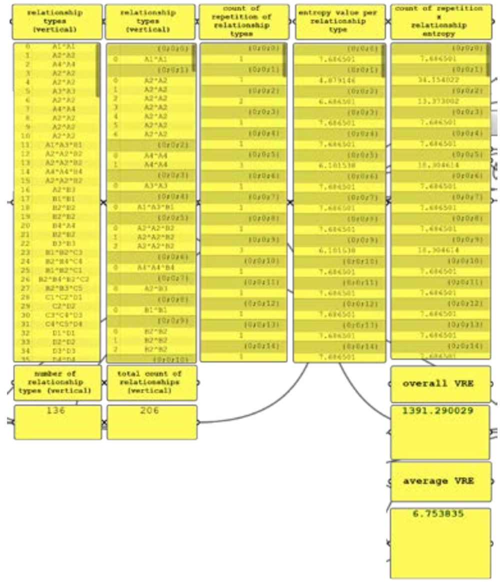


***Figure 6.*** *Calculations for VRE*

Similar to the horizontal relationship types, it has been observed that many of the vertical relationship types are repeated once. This situation increased both overall and average VRE considerably. The brief results of HRE and VRE calculations are given in Table 1.

***Table 1.*** *Results of HRE and VRE calculations*

| **Silodam MH Project** | total count of relationships | number of relationship types | overall entropy (bits) | average entropy (bits) |
|---|---|---|---|---|
| **Horizontal** | 209 | 95 | 1229.47 | 5.88 |
| **Vertical** | 206 | 136 | 1391.28 | 6.75 |

## 4. Conclusion

According to the values given in Table 1, both VRE and HRE are quite high. In this study, the developed objective calculation method is applied to a different context for the first time. Therefore, it has not been tested on any sample set yet. However, it is possible to analyze the entropy level of Silodam with comparative analysis by applying the same method to other mass housing blocks.

For a mass housing block that includes 158 housing units, it is obvious that manually counting 209 horizontal relationships, 95 horizontal relationship types, 206 vertical relationships, and 136 vertical relationship types can take quite a long time. Thus, the developed algorithm used to read similarly coded building plans and sections. In this context, Dynamic Geometry Pipeline component of the Human plug-in in Grasshopper VSE is an extremely useful method to read labels and automatize the calculations.

Last, overall and average VRE is slightly higher than overall and average HRE. This situation arises from the location of corridors that interrupt the relations of housing units located on different sides (orientation) of the building. In addition, it has been observed that large housing units are sometimes overlapped on 2 or 3 units and add variety to the relationship types.

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