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Paper: **Generating Through Allometry in Architecture: A design approach for relational morphogenesis**

Topic: Architecture

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Abstract:
Morphology is one of the widely considered within different views in architectural and urban design. In this context, many biological terms and notions were adapted to architecture. One of them is called allometry, the study of scale and size relationship of growth in biology. Studies on allometric values in architectural design can be seen as early as Violette-le-Duc. Additionally, referring to D'Arcy Thompson's study "On Magnitude," many architects and planners have used this term in the metabolic and morphological studies on the existing buildings and the built environment. However, this study proposes a different view of allometry in architectural design. The study offers using allometric values not only on existing buildings or urban patterns but also on generating building forms and urban patterns.

Basicly, the intention of this study, comes from the supporting topological relations during morphogenesis, and considering these topological values as leading impacts during generation and formation process in architecture. Complex living systems, usually come from the organizations of different functions, forms or properties. Similar to living systems, emergence and growth of different parts depends on whole in architecture. Therefore, using allometric values would help to generate more efficient forms in building and urban scale. In this research, the allometry in morphogenetic design are offered to generate different urban patterns and building forms. When generating forms through allometry in the study, network topologies and spatial data structures are offered. Additionally, spatial data structures are used in octree and quadtree techniques. A quadtree structure based on a two-dimensional 2^{2n} grid system, considers both the parts and the whole system; and creates a hierarchical tree structure of the given data. The division of space is gathered through the position and the size of each component. An octree structure also works in the same rules but only in three-dimensional 2^{3n} cellular system. Both of these structures help to create an architectural form through hierarchical relationships of the given data. In this regard, it is expected to achieve a complex design forms through the topological relationships of different units and the environment by adapting allometry as geometrical and mathematical constraints to architecture.

Fig1. The example of generating through allometry in building scale

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Keywords: Allometry, Morphogenetic Design, Network Topologies, Spatial Data Structures.

Generating through Allometry in Architecture: A design approach for relational morphogenesis

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Abstract

Morphology is one of the widely considered within different views in architectural and urban design. In this context, many biological terms and notions were adapted to architecture. One of them is called allometry, the study of scale and size relationship of growth in biology. Studies on allometric values in architectural design can be seen as early as Violett-le-Duc. Additionally, referring to D'Arcy Thompson's study "On Magnitude," many architects and planners have used this term in the metabolic and morphological studies on the existing buildings and the built environment. However, this study proposes a different view of allometry in architectural design. The study offers using allometric values not only on existing buildings or urban patterns but also on generating building forms and urban patterns. Basically, the intention of this study comes from the supporting topological relations during morphogenesis, and considering these topological values as leading impacts during generation and formation process in architecture. Complex living systems usually come from the organizations of different functions, forms or properties. Similar to living systems, emergence and growth of different parts depends on whole in architecture. Therefore, using allometric values would help to generate more efficient forms in building and urban scale. In this research, the allometry in morphogenetic design is offered to generate different urban patterns and building forms. When generating forms through allometry in the study, network topologies and spatial data structures are offered. Additionally, spatial data structures are used in octree and quadtree techniques. A quadtree structure based on a two-dimensional 22n grid system considers both the parts and the whole system; and creates a hierarchical tree structure of the given data. The division of space is gathered through the position and the size of each component. An octree structure also works in the same rules but only in three-dimensional 23n cellular system. Both of these structures help to create an architectural form through hierarchical relationships of the given data. In this regard, it is expected to achieve a complex design forms through the topological relationships of different units and the environment by adapting allometry as geometrical and mathematical constraints to architecture.

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1. Introduction

Due to massive energy use and population growth, cities and buildings are expanding their boundaries and adapting to changes every day. The important facts of population growth and efficient design needs, have led us to develop different ideas and novel design strategies both in architecture and urban design. Yet, many of these remarkable ideas are developed through evolutionary design studies. In evolutionary design approaches, complexity of architectural forms and urban growth are likened to living organisms; and, their morphology and morphogenesis are widely considered within different strategies. In this regard, many biological terms and notions were adapted to architecture. More specifically, this paper focuses on one of these biological terms called allometry —the study of size and scale relationship of growth.

Although the impacts of size and scale relationship on form had been mentioned since Galileo Gallilei (1638), deeper studies of allometry in architecture were held in the late 20th century **[1]**. However, in most of these studies since then, allometry was discussed on existing buildings and urban patterns to calculate potentials of energy use or spatial organizations. In this study, considering the notion of allometry and its previous studies in architecture, the use of allometry is offered in a different view. The principles of allometry on form are examined through relational morphogenesis; and, evaluated in a morphogenetic design approach to generate architectural forms.

2. Allometry in architecture

As a biological term, allometry refers to “biological scaling, the change in organisms in relation to proportional changes in body size **[2]**.” Even though, the word allometry was first introduced by Julian Huxley (1932), discourses on size and scale relationship of whole form and its parts can be seen as early as Galileo’s period in literature (1638) **[1, 3, 4].**

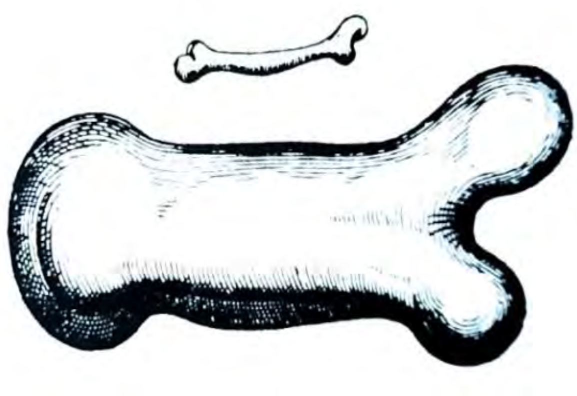

Fig.1. *An example of different size of bones on different species by Galileo Galilei (1638); reproduced from Steadman (2008).*

Later, in architecture literature, similar discourses on size and scale relationship on buildings were *held by Viollett-le-Duc. Violett-le-Duc exampled this relationship within the following words: "In the art of architecture, it is not possible to establish the following formula; that 2 is to 4 as 200 is to 400; because if you can put a lintel 4 metres in length onto columns 2 metres high, you would not be able to put, on two columns of 200 metres in height, a lintel of 400 metres. To change scale, the architect must change the method (mode), and style consists precisely in choosing the method appropriate to the scale – using that word in its widest definition* ***[1, 5]****."*

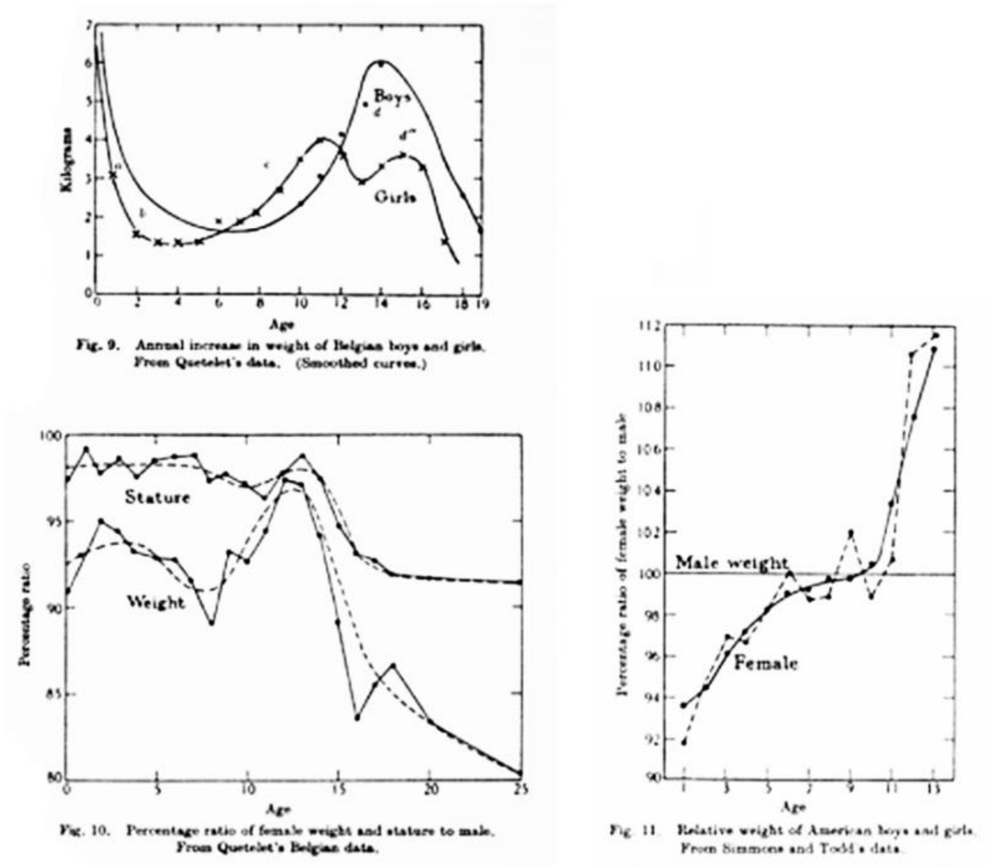

Fig.2 *Thompson's (1917, 1971) comparison graphics on genders' growth.*

Another inspirational study on size and scale proportion of form is mentioned in D'Arcy Thompson's "On Growth and Form," especially in "On Magnitude" chapter. The principles of today's allometry in biology were derived from Thompson's studies; in fact, his studies are still referenced in architecture and other design areas. In "On Magnitude" chapter, Thompson studied the progress of growth on boys and girls in several charts **[4]**.

Today, principles of allometry can be viewed in different ways. Besides comparing the proportions of different parts in growth of same species, allometric relations can be also discussed by comparing the proportion of similar parts of different species **[6, 7]**. For instance, growth of similar body parts of different species and growth of different body parts of one species can be examined through allometric relationships.

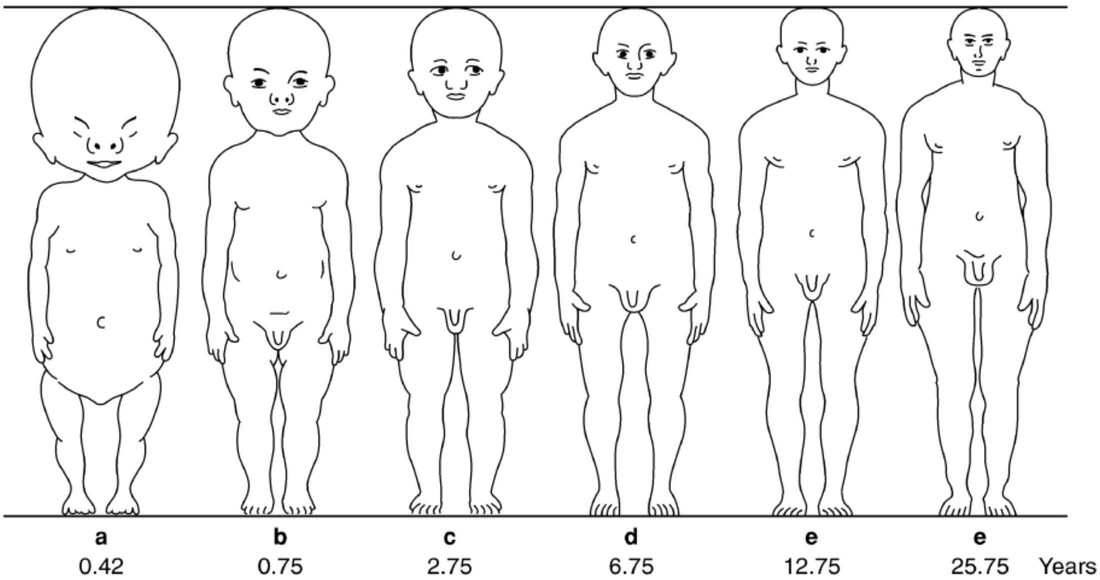

Fig.3. *Growth of human in time C.M. Jackson, Morris's Human Anatomy, London 1915 and Growth, Yale 1928. Naroll and von Bertalanffy, 1973, p. 247; reproduced from Steadman, 2006*

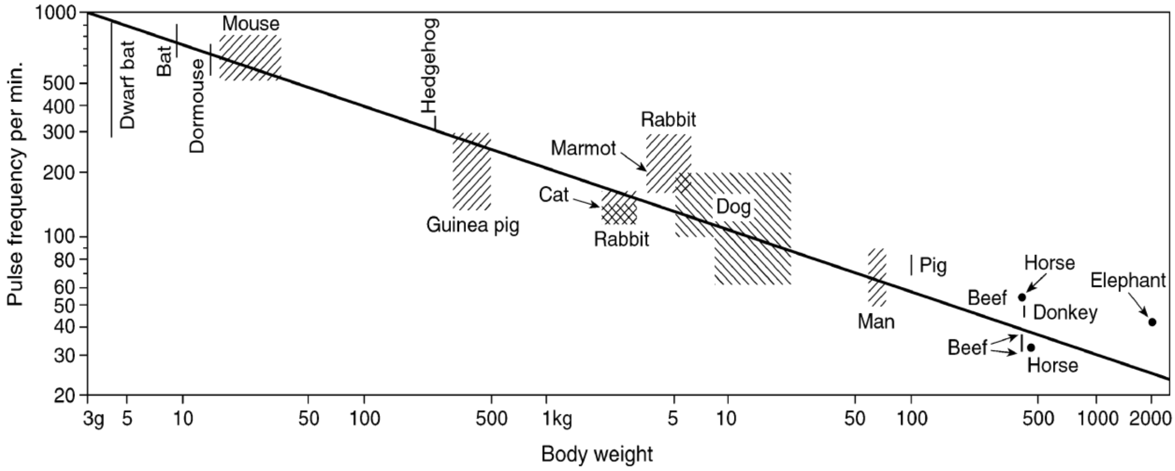

Fig.4. *Growth of human in time C.M. Jackson, Morris's Human Anatomy, London 1915 and Growth, Yale 1928. Naroll and von Bertalanffy, 1973, p. 248; reproduced from Steadman, 2006*

However, Ranko Bon (1972) was the first who discussed allometry as the proportion of size and scale relationships of building form in architectural morphology [8]. His research was held on 20 different buildings with similar plans to reveal the allometric relation between building sizes and their spatial organizations. He proportioned the distances between rooms (ft) as topological relationships and their sizes (ft^2); then, compared the results in a logarithmic chart **[7-8]**. At the end, he achieved similar proportions in these 20 houses and mentioned this relationship as a positive allometry.

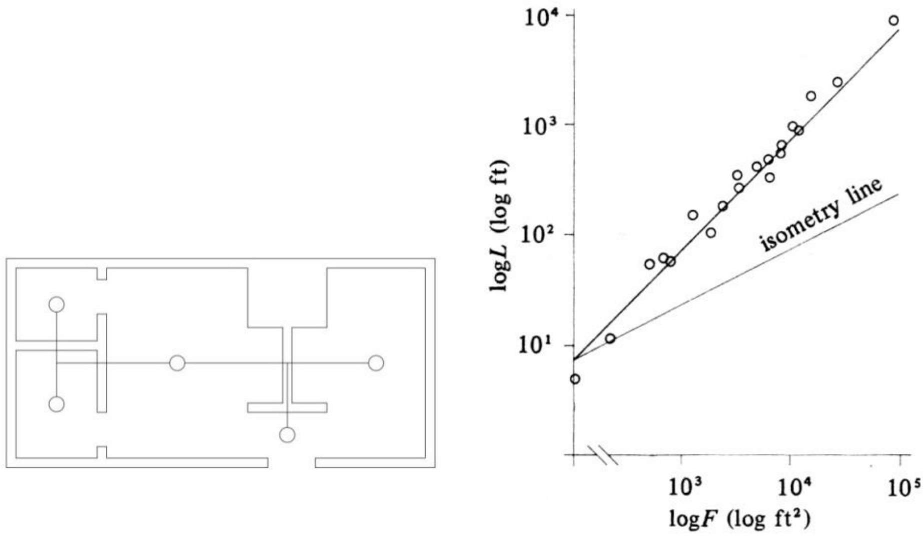

Fig.5. *An example of size and organization comparison with its allometric table by Bon (1972); derived from Steadman (1983).*

Inspired by Bon's study and many other discourses on allometry in architecture, we aim to use same principles of allometry through relational morphogenesis on generating new forms in architecture **[10]**. Within this way, by supporting topological relations of parts within allometry, whole form can be generated in a more efficient way.

3. Evaluation of Allometry in Morphogenetic Design

As John Frazer (1995) mentioned in An Evolutionary Architecture, morphogenesis is probably the most deterministic stage of evolutionary design **[11]**. All the living systems in different scales are assembled to grow and organize depending on their functions, similarities and relativities **[10]**. Also, Steadman (2008) posits, “It was an important consequence of the ‘correlation of parts’ that functional relations would not only govern the necessary and simultaneous presence of various organs in systematic combination, but would also determine the proportions and dimensions of the overall shape of a creature… **[1]**.” Therefore, it is possible to say that during morphogenesis, each living unit organizes, breeds, or grows depending on their neighbors to serve the whole system. In this context, it is reasonable to compare the formation of human civilizations to morphogenesis of living systems in some ways. Especially, in architectural design, form is mostly achieved through the order and organization of each part depending on their contents, proportions and scale. Living forms emerge through these specific organizations such as size and scale relationships.

Using morphological factors like allometry in formation process would help to achieve efficient design solutions by supporting the organizations between whole form and its parts. As in living systems, allometric relations can be created or determined, and supported in the morphogenesis of built form. Adapting allometric values to design process can be contemplated as determinative facts in relational morphogenesis; and this would help to achieve relational morphogenesis of form. Consequently, relational morphogenesis would help to achieve efficient design solutions. Considering this fact, principles of allometry can be evaluated in architectural formation in many ways. Yet, one of the ways is to proportionate the topological relationships of spaces within their order (purpose of use). Kolarevic explains the benefits of topology in morphogenesis within these words: “The notion of topology has particular potentiality in architecture, as emphasis shifts away from particular forms of expression to relations that exist between and within an existing site and the proposed program **[12]**.” In the next chapter, the implication of allometry on form is proposed within a digital design approach. Some of the digital design techniques and strategies are offered to adapt allometric notions to morphological process of design form.

4. Generating Forms through Allometry

4.1. The Implication of Allometry in Design by using Spatial Data Structures

To implicate the principles of allometry in architectural morphology, the structure of organization such as spatial use, structural use or other uses, should be acknowledged as whole and in its parts. Therefore, although parts of whole and their spatial relationships are predefined, their unexpected ways of organizations create a half-deterministic process. Within this way, top-down and bottom-up strategies will be used together in this allometric design approaches. As long as the relationships of design parts and their proportions in whole are described clearly either in mathematical or geometrical values, the implications of allometry can be applied by different techniques and strategies in digital media. In our study, to adapt the size and scale relationship in a morphogenesis of form, we offer to use octree design technique from spatial data structures.

Although there are several alternatives of octree technique in spatial data structures, in this case, we consider it in its simplest way. The principle of octree is simply explained by Hanan Samet as within these words: “We start with an image in the form of a cubical volume and recursively subdivide it into eight congruent disjoint cubes (octants) until blocks are obtained of a uniform color or a predetermined level of decomposition is reached **[13].**”

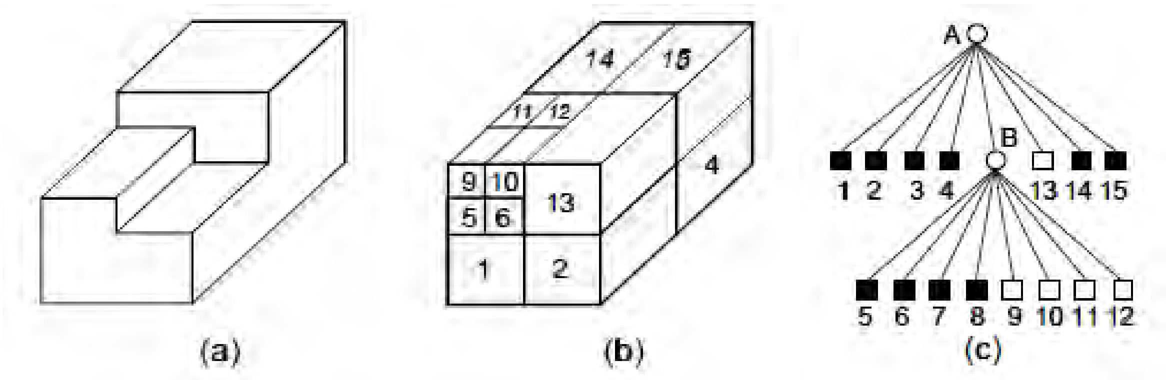

Fig.6. *the decomposition of form by Octree structures from Samet (1995)*

The use of octree would allow creating new organizations and continuous patterns through defined topological relationships and adapting existing organizations. The applications of octree may change depending on the data type (point, line, volume) and their ways of use. In this case, octree technique will be used as point-based data structure; therefore, the points will provide the division of whole space into smaller parts. And, these points will be gathered through network topologies which would help and control the relationships and proportions of the whole system as a geometrical form. Network organizations of the parts are randomized to generate different alternatives by octree structures. The reason behind this approach is to design the structure of organization that supports the relationships and the proportions to design form which may lead the further organizations by simple applications.

4.2. A Building Block Design Trial on Relational Morphogenesis (Case Study)

When it comes to plan buildings forms and cities, there are many determining facts such as ecological, cultural, topographical, functional, vernacular and historical values and so on. Also, clearly it is not possible yet to convert each of them and use as a parameter of a building form in a digital design process. However, it is possible to create topological relationships among some of these values and adapt them to a morphogenetic process. Even initially predefining any of these structural, functional or programmatic relationships would help to control the formation of buildings in efficient way.

In this study, it is aimed to shape topological relations, which are predefined depending on their purpose or content in design progress, within allometric relations. In other words, a morphogenetic process is evaluated by order of space units (purpose of use) and their different network topologies as determining parameters of allometry. It is attempted to generate different architectural alternatives by supporting both spatial organization and user groups as parameters of allometry. For this case, allometric relations created by network topologies will be examined by generating urban block design alternatives. Therefore, the design progress starts with creating the structure of topological relationships their order in spatial organization and their proportions depending on its contents.

As a first step, initial points are created through grid structures to evaluate space efficiently in the given boundaries. The size of the grid is adjusted from the façade of existing buildings which are approximately 4 meters wide and 18 meters length (three to five story buildings).

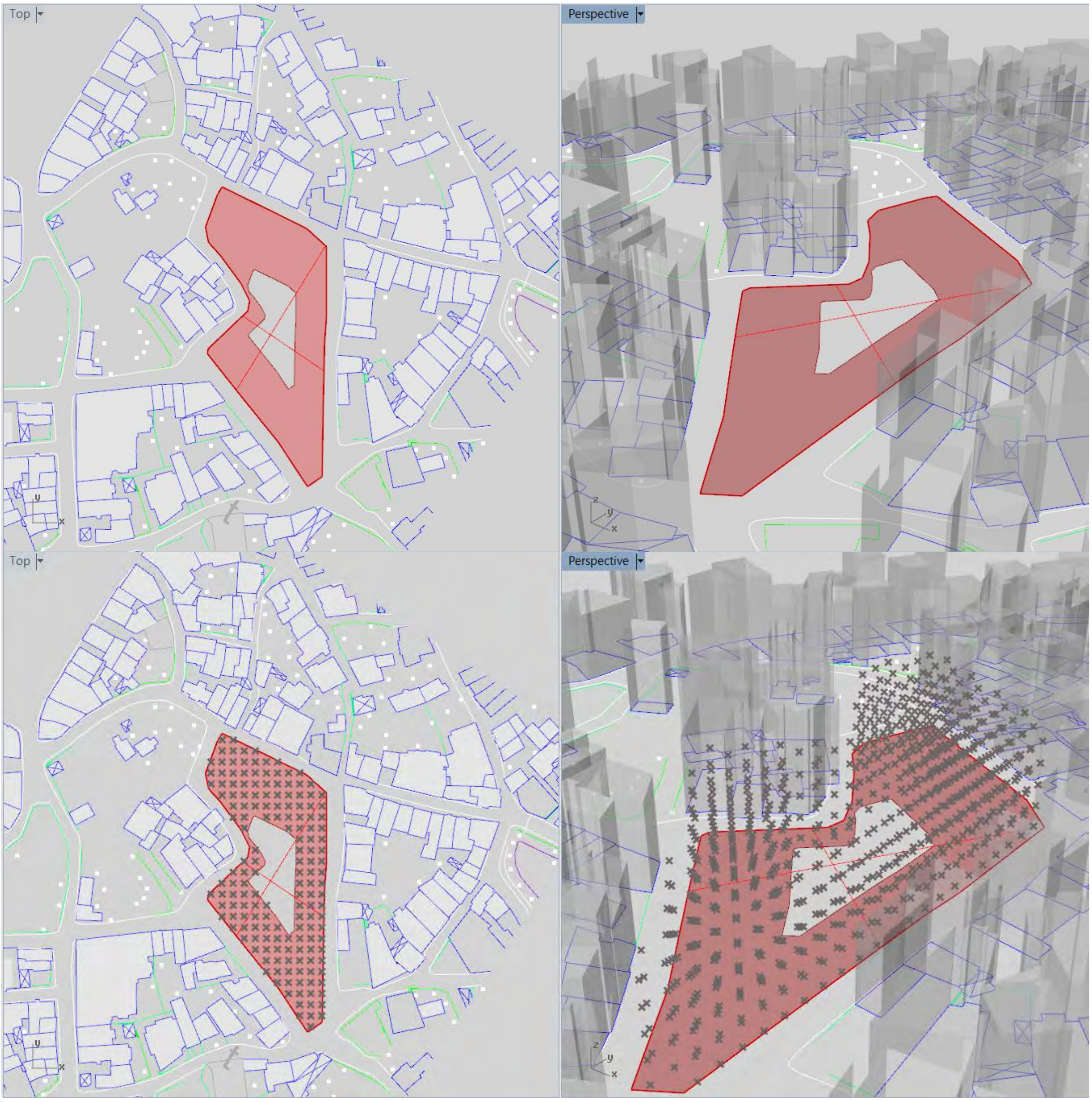

Fig.7, 8. *Determination of boundaries, and creation of initial points for spatial organization*

After creating the initial points, in this situation the network points, first allometric relationship is determined for the emergence of networks. Geometrical and mathematical values (number of networks, length of networks…) of network lines are proportioned according to the predefined order for spatial unit. As it was mentioned before, while adapting allometric principles, parts of whole can be defined as any kind; as long as the order of their relationships is structured efficiently. Therefore, for this study the order of form and their relationships are structured upon their use.

In the design scenario, the order of parts is determined by relationships of green units, semi-public units and private units (housing, shopping units and gardens). Before, creating networks, the order of their emergence points are structured in the following way: 2/6 of points are semi-public units, 1/6 of points are open spaces and 3/6 of points are private units. Also, distances between points are defined by their function. Therefore, each unit can be created by their structured organization. The partition of points are shown in the following order: yellow points for shopping units, green points for open areas and purple points for housing units. Surely, the limitations for this process might be enhanced by more criteria; however, the more limitations may cause a more density of form.

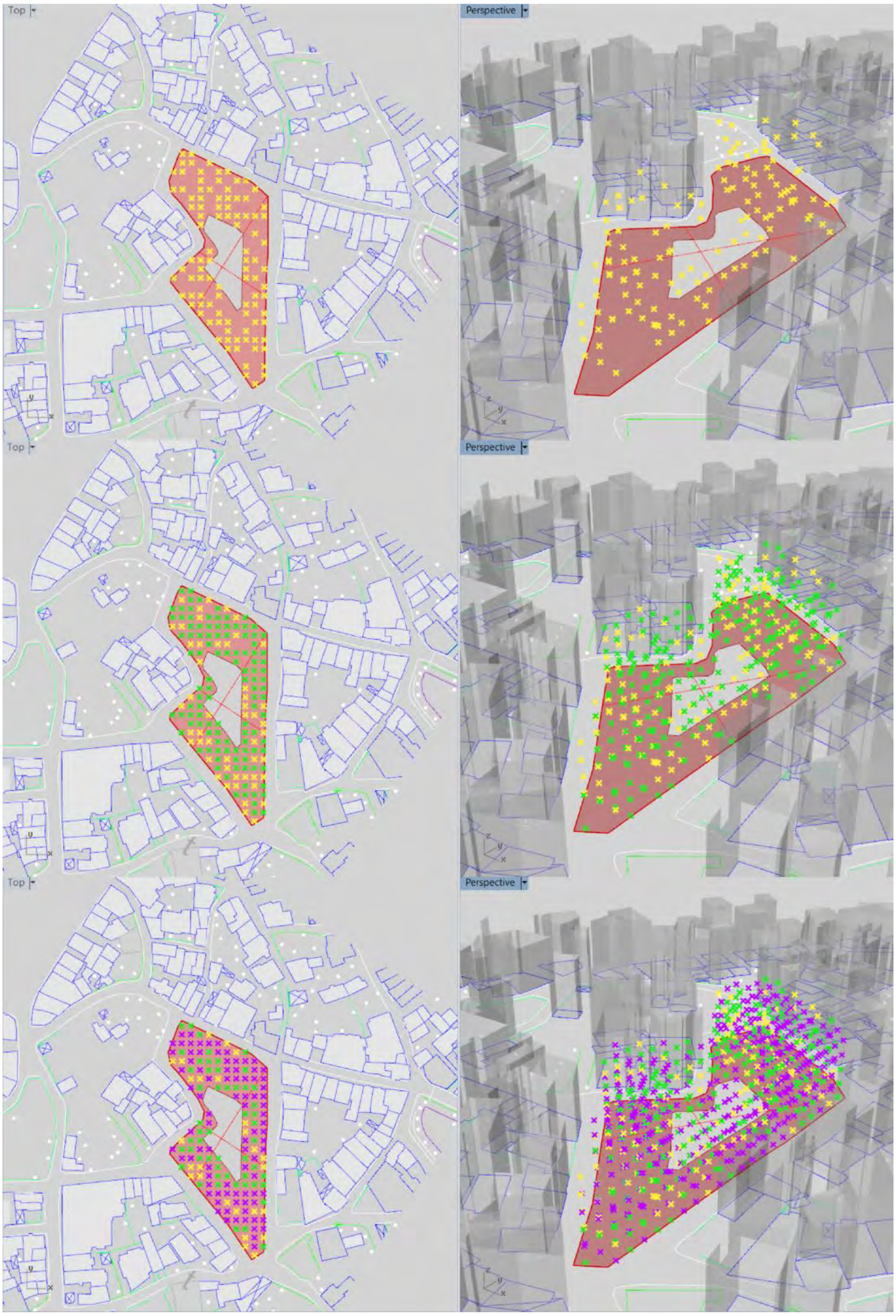

Fig.9-11. *Selection and partition of network points by units' proportion*

After the specification of their distances and proportions, networks are created among these points. Within this way, emergence of each network would depend on their size and scale relationship; also, these determinations would help to create topological relationships of parts, and support the efficiency of space use. The impacts of proximity and their proportion on whole are defined similar to allometry in biology. The parameters of networks are defined in the following order: 1 connection and 28 meter distance for semi-public units, 1 connection and 8 meter distance for green units, and min 3 connections and 4 meter distance for private units. In this step, the organization of networks can be generated vastly to reach complex and satisfactory solution(s). One of the advantages of network organizations is that even with simple rules complexity can be efficiently created or controlled.

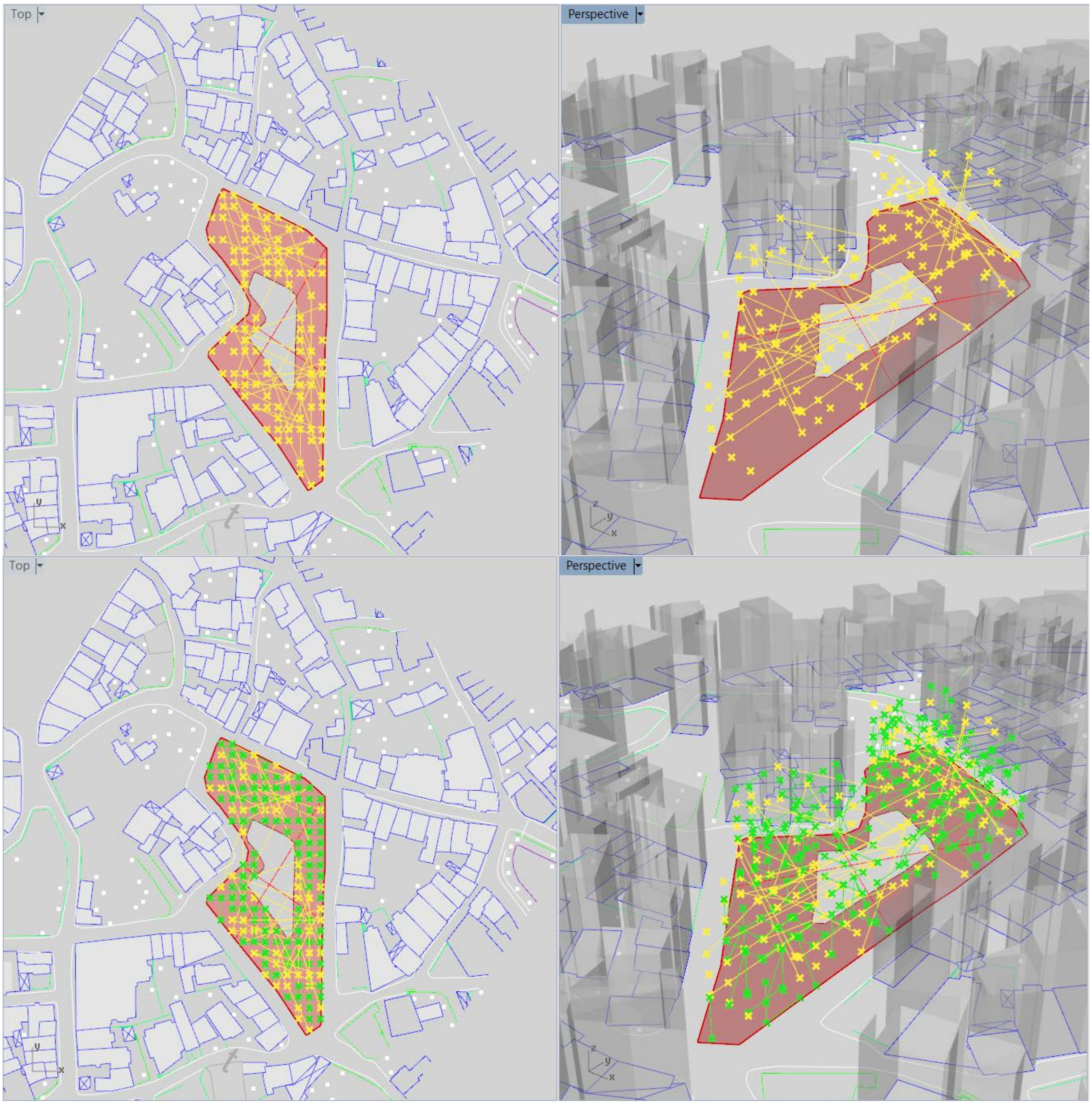

Fig.12, 13. *Generation of network structures*

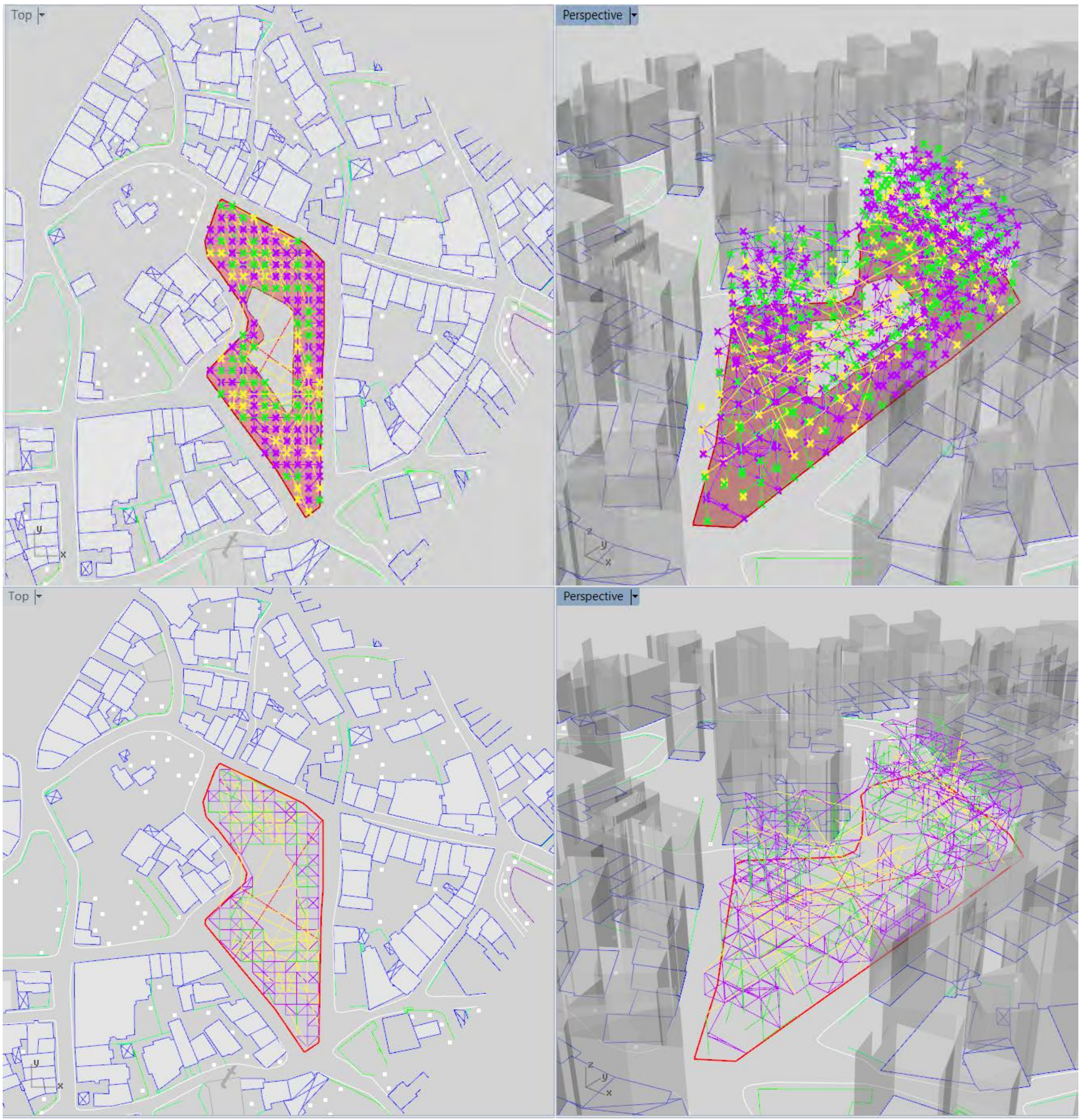

Fig.14, 15. *Generation of network structures*

In the next part, octree technique is used for partition of each unit depending on their points' neighborhood relationship. Within this way, octree structures are used to control the different growth of each cell depending on relationships which provided by network organizations. Based on the network points' positions, points were collected in cubic volumes within specified numbers. Therefore, the sizes of spaces are achieved through proportions and relations among individual units in whole system. The maximum amount of points is determined 3 for each cubic volume. By merging all network points at once in octree technique, integrated spaces (volumes with more than one type of unit point) can be created. In this case, mixed use spaces can be created or controlled easily.

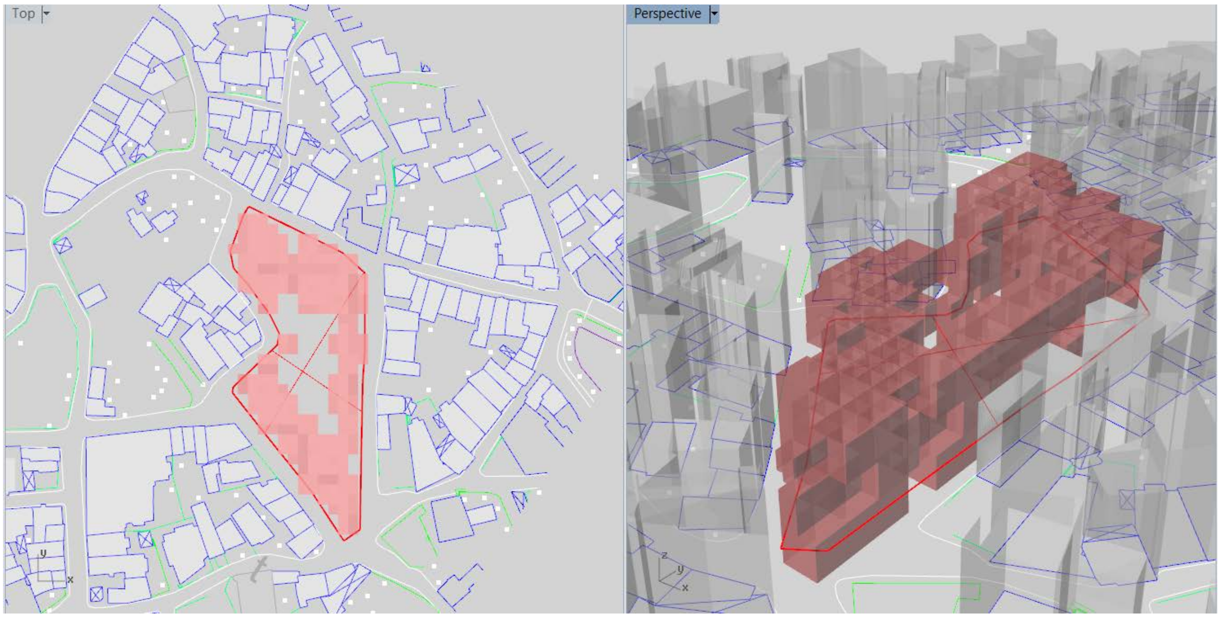

Fig.16. *Generating proportion of units in whole through their relationships by Octree structures*

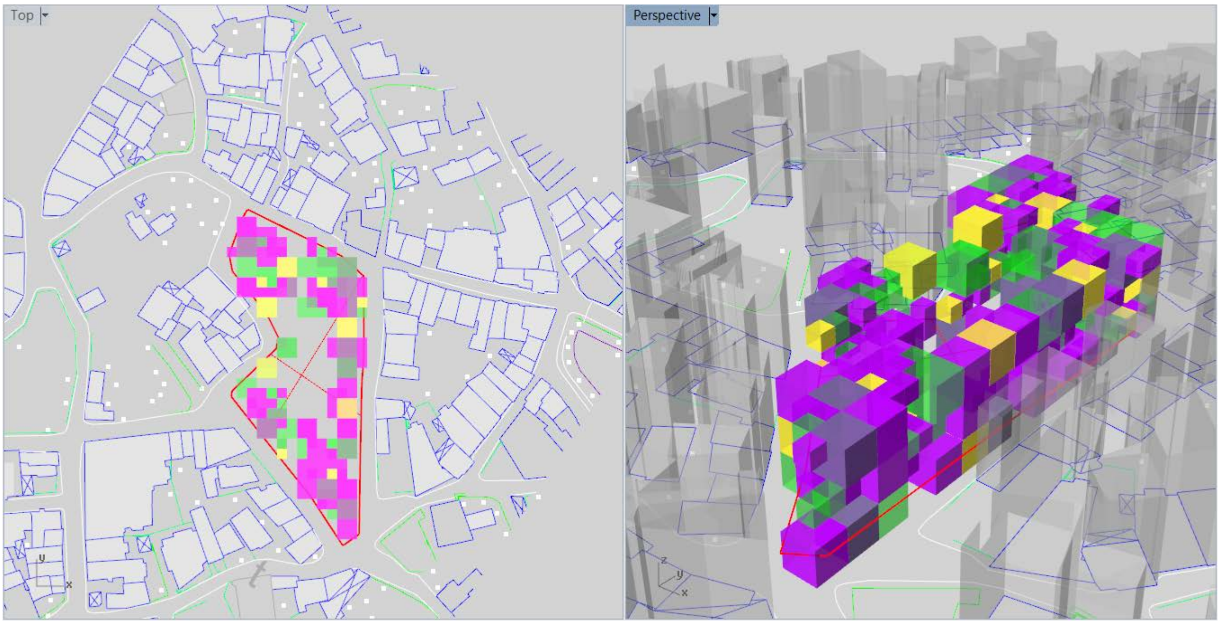

Fig.17. *Determination the units' type by their point inclusion and final form*

At the end, redefinition of space units was held by finding the exact volume of each group of network points. By clustering specific amount of points in octree structures, mixed-use spaces (different combinations in volumes) can be created as in this example.

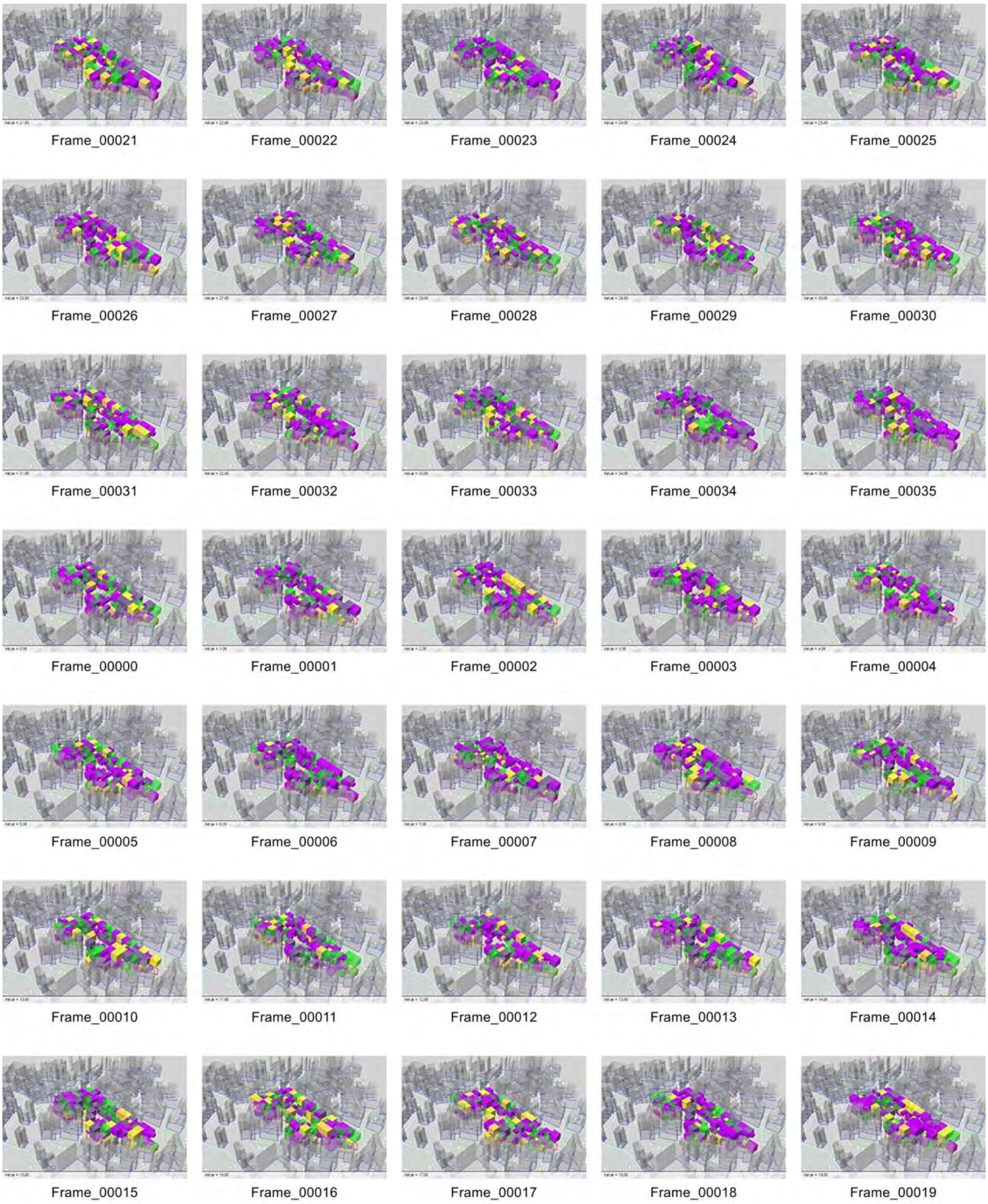

***Fig.18**. Generated alternatives by changing network topologies*

5. Conclusion

Adapting allometric principles to design morphogenesis can be considerably reckoned as a structuralist view in architecture. However, supporting any topological relationships and using their order as determinative facts of morphogenetic process would help to achieve satisfactory solutions easily. In fact, using allometry is one of the effective ways for that. Also, learning from the past organizations on existing buildings, new alternatives or continuity can be provided with this simple act. Even the smallest or simplest definition and limitation of any topological organization can be provided and controlled by networks as long as the relationships, scales and proportions between units are determined properly. In further studies, determining facts can be enhanced such as area of units, supported relationships, user types and so on. However, more network parameters might cause to reach very similar solutions at the end of the process. Within the same design strategy, networks can be applied and enhanced on existing buildings to create similar ones. By applying genetic algorithms and other evolutionary studies within this approach, it is possible to reach effective design alternatives in shorter time. For the future studies, it can be suggested that especially the use of genetic algorithms would help to eliminate and achieve the satisfactory results in shorter time.

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