‘Qelizë’: Configurational Description of Floor Plate Shapes with Linear Depth in Java

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Abstract

This paper suggests a new method for describing shapes of floor plates based on the unitized grid representation and the analysis of relations between elements according to graph theory. In previous studies, merging dimensionless configurational representations of convex spaces with unitized ones has resulted in difficulties of dealing with ambiguous cases typical of open-plan architectural spaces, and has proved insensitive to differences between regions in some complexes. We propose a syntactic analysis that consists of a three-layered convex and linear depth representation. The occupation spaces transcend convex depth between each other, the circulation ones transcend linear depth, while both of them contribute to the overall depth of the complex. The linear depth analysis reveals the existence of areas with low depth in the shape that act as pivotal points when introducing depth-minimizing circulation systems into the floor plate.

Keywords: computational design, graph theory, configuration, Java software.

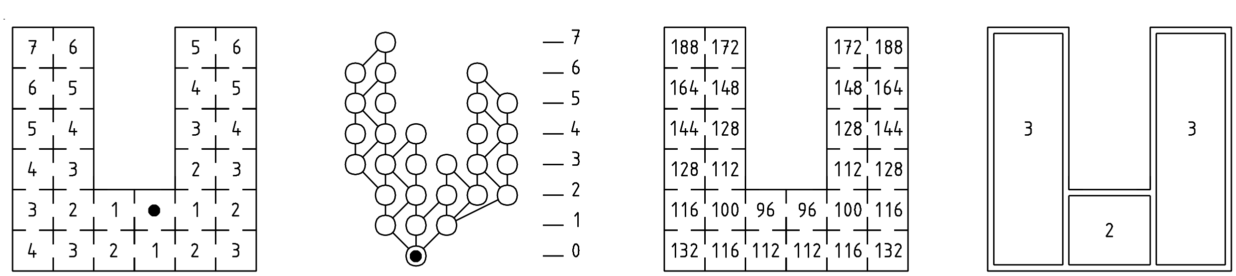
Introduction

The description of shapes of floor plates represents an important aspect of architectural research and practice. Attempts to describe shape have traditionally focused on their metric properties. Thus, length, width, angle, and area are used as measurements. These measures are basic for most of the dealings and transactions between architects, engineers, developers and clients. However indispensable, metric measures have proved unable to cope with a wide range of problems that designers encounter. Of such nature is the negotiating between local moves and global outcomes of designs, the fitting of circulation systems into floor plates, or enhancing circulation systems with spaces around them. These operations take into account not just whether an element fits into another from the geometrical point of view, but whether the global outcome of, say, embedding a corridor into a floor plate, has desirable results. The criteria for evaluating design solutions regard the way the building fits the needs of the organization that will use it, among other concerns. In this context, several studies in the past thirty years have used the configurational description of shapes and spatial complexes. Configuration as a concept refers to relations between parts in a complex. In order to analyze a shape from this perspective, two main prerequisites must be fulfilled: finding a way to divide it into parts, and deciding on the nature of relations between parts.

The analysis of shapes as being a compound of unitized elements was introduced many years ago in the architectural discourse.[1] Set theory was used to describe relations between units, which were represented with two-dimensional matrices. Later studies introduce the distinction between fixed modular and dimensionless representations of architectural plans following the distinction between discrete and continuous representations of form.[2] [3] Plan shapes were analyzed using the mathematical theory of graphs.[4] According to that model, units were represented as graph vertices and their adjacency relations as graph edges. Thus the adjacency graphs were argued to capture important topological properties of shape such as continuity, connectedness and adjacency. Of special interest to this discussion is the measure of graph distance which represents the shortest distance between two elements in the graph. Later used as the depth between two elements, this measure was crucial to the studies of space syntax in analyzing features of built environment.[5] Traditionally the measure of depth has been calculated for graphs that represent the connectivity relation among convex spaces, which are obtained after the division of the shape into the fewest and fattest convex elements. The methodology of s-partitions and e-partitions, proposed by Peponis et al., represents a finer level of configurational dimensionless analysis.[6] According to that model, the set of subspaces is based on the thresholds at which edges, corners, and surfaces appear into the field of vision of a moving subject or disappear outside it. In contrast to the dimensionless representation of convex partitioning, Hillier has proposed a fixed modular representation for describing shapes.[7] An interesting approach on analyzing built environments has been taken by Turner and Penn.[8] Built environments has been mapped with modular elements whose relation is based on the visibility between each other, i.e. belonging to the same isovist.[9] The integration of complexes is based on the connectivities of a set of isovists represented as a graph. This paper proposes a configurational method of representing shapes as being composed of modular units and analyzing them in a multi-layered analysis that captures both convex and linear relations between the units.

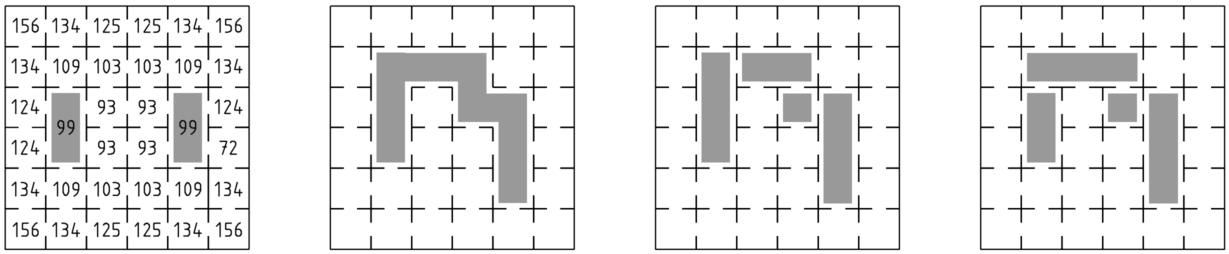
Convex Depth Model

The first of three layers of the model that is proposed here are based to a large extent on the model of Hillier, which we, thus, will describe in detail. The model aims at analyzing real buildings in two ways. First, it investigates the complex as composed of unitized elements. In this viewpoint, shapes have been represented as connectivity graphs of units that emerge from their partitioning with rectangular modular grids. From now on, we will adopt the terminology of that model and will refer to the modular units as *cells*. After laying the rectangular grid, units have been connected to each other by means of partly opening the partitions between them. Thus, the depth from a certain cell increases each time a permeability threshold between cells is crossed. The analysis has been based on permeability graphs that result from this operation, as opposed to adjacency ones such as Steadman's model. Considering each cell as a graph root, its depths to other cells have been calculated and their sum, the *depth value*, is given to it in order to characterize its relation to the rest of the complex, figure 1. Their sum, the *total depth*, is used to characterize the overall complex. The location and the depth values of cells give a global picture of the complex in terms of the way depth has been spread. The central areas have lower depth values, since the rest of the complex is closer in comparison to the peripheral ones where the complex is farther away. The shape affects the distribution of depth values, thus there is more differentiation between center and periphery in an elongated shape as opposed to a compact one. In order to quantify differences between shapes, derivatives of the measure of total depth are used such as the average for each cell, standard deviation, and difference factor. Given the modularity of partitioning, the overall depth gives a sense of the metric inertia of the shape, a sort of hindrance of metric



a b c d

Figure 1: Hillier's unitized convex model - a) divison of a shape into cells and depths from a certain point, b) justified graph from the same point, c) total depths for each cell, d) dimensionless convex partitioning of the same shape



a b c d

Figure 2: Introducing openings - a) Hillier's merging cells into larger openings and depths values for each space, b) typical open circulation system, c), d) ambiguities of dividing symmetrical turns into convex partitions

distances to one's movement in the complex.

Second, the model addresses the structure of partitions in real case floor plates by dividing them into entities according to convex partitioning. Here, the partitions respect the division that exist due to walls, door thresholds, changes of levels, and so on, and further they aim at dividing the open spaces into fewest and fattest convex spaces. While the first part of the model is modular and is based on the dimensions of the rectangular grid, the second is dimensionless and operates with entities of different sizes and proportions that have resulted from the convex partitioning. Each convex entity is considered as a graph vertex and the permeability connection between them as graph edges. The values of depths of all convex spaces from each one are calculated and the values are assigned to them respectively. This configurational representation show what spaces are better connected to others and vice versa in respect to the whole system regardless to their size and position in the complex, i.e. no matter how close to the gravity center or far from the perimeter. This method has proved to be successful in dealing with cases where there are no ambiguities in drawing the partitions such as cases when easily distinguished rooms are connected to each other. In contrast, the method remains problematic and offers little consistency when open plans with spaces merging into another are concerned. Dividing a symmetrical L-shape, or a rectangular shape with an atrium in the middle are some such cases. Here, the symmetries of the shape are not regarded since different functions and activities may occur in apparently symmetrical positions.

In Hillier's model, cells are merged with each other to form larger entities that coincide with the convex partitions in the complex. The large agglomerate ones have the same properties as the cells that created them, they increase in depth each time a threshold or a boundary between cells is crossed. This allows for combining the result of two aspects of analysis to give a more complete picture of the real case. Merging of some cells into larger entities results in inserting an opening into a uniformly divided complex of cells. If we are to think of a case where the openings come together to form a system that is not convex, then we run into the difficulty of deciding the proper partitions without ambiguities, figure 2. Almost in all buildings and urban settlements, openings of corridors, hallways, streets, and squares form continuous non-convex complexes. Thus, we need to suggest a model that captures the peculiarity of open spaces of circulation systems to occupation spaces, so as to avoid the problematic convex partitioning.

Linear Depth Model

From a convex partition stance, what is common about the above-illustrated examples is the ambiguity of thinking about corners, the difficulty of deciding with what space the corner associates. While it is difficult to decide which convex partitioning a portion of space belongs to, it is always easy to determine the relation of that region to a point of reference. Given a point of reference, two regions of space belong to the same convex space if there is no obstacle or change of direction between them, and this is always true if the reference is kept the same. Representing shape in cells overcomes the problems of convex partitioning because of shape properties are analyzed separately for each cell in a consistent way. Therefore, for the configurational representation of the floor plates, we need cells such that their relation to others in the complex depicts the fact whether they belong to the same space or not. The key feature of cells that belong to the same space is that they share the same relation to other cells in the complex, i.e. they have the same depth when viewed from a point of reference.

The cells of the convex model can be thought of as being about local conditions of a space. They present obstacles to overcome when moving from one part of the building to another, as each time a boundary between two such cells is crossed, the depth value increases. In this regard, we will refer to them as *occupation cells* or else *o-cells*. In contrast, the cells that will be proposed are about discarding metric obstacles. Each time a group of such cells belongs to a single space from a certain reference point, they get the same depth value no matter how distant they are from each other. These cells are about movement in the building and are typical of circulation systems such as corridors, hence will be referred to as *circulation cells* or *c-cells*. In other words, two parts of a spatial complex have the same depth if there is an uninterrupted linear sequence of spaces to link them. In order to clarify the distinction between a linear part of an open space and a turn, the concept of *linear depth* is introduced. The concept is qualified as follows: when a c-cell has two adjacent and aligned c-cells in the direction from which the depth is spreading, it gets the same depth value as the adjacent one. Once this condition is not satisfied like in the case of corridor turns, a depth increase occurs, figure 3. Note that the depth is spread according to orthogonal directions unlike *link distance* that considers all possible ones.[10] [11] Except the linear depth effect, c-cells share the same qualities with o-cells. Thus the depth between two adjacent cells increases each time by one when: 1- a threshold is crossed between an o-cell and c-cells; 2- c-cell and o-cell; 3- two o-cells; 4- two c-cells when linearity is broken. In a few words, c-cells are about acceleration, spreading depth or else transferring the same depth condition to areas that belong to the same uninterrupted convex space in contrast to o-cells, which are about resistance or depth augmentation.

L1 representation in which the shape is mapped entirely with o-cells.

L2 representation in which the shape is mapped entirely with c-cells.

L3 representation in which the shape is mapped both with o-cells and c-cells.

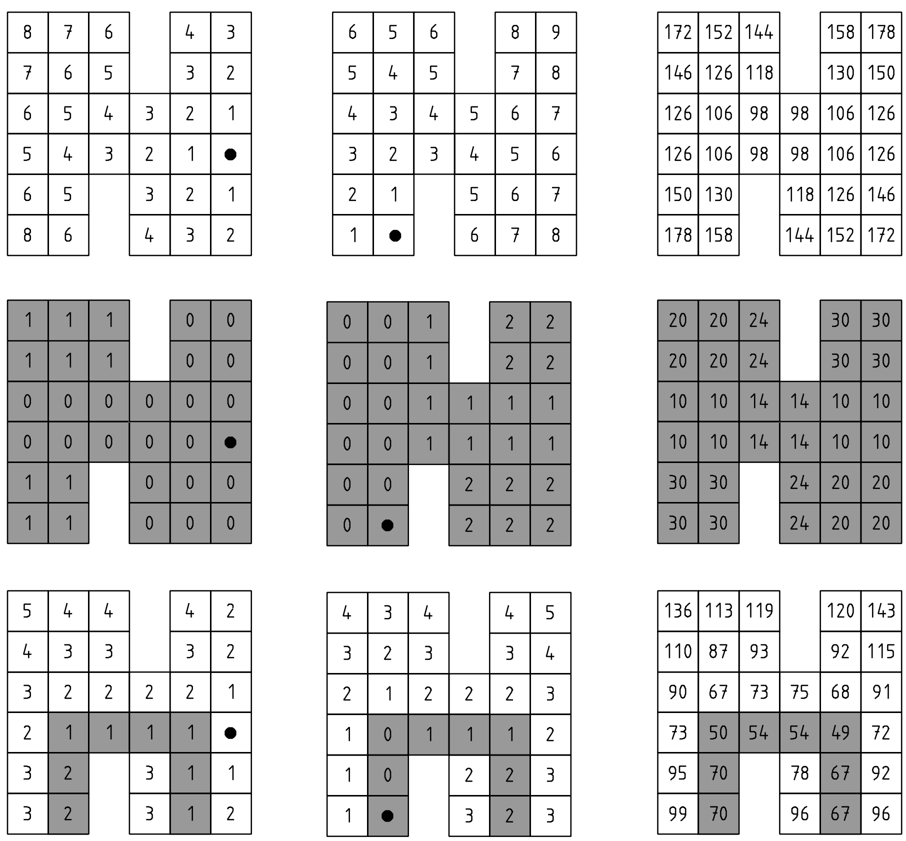


Figure 3: Three-layered representation of shapes. left), center) depth values from a certain point, right) total depths for each cell.

Applet Description

In order to carry out the calculation of depth measures for both o-cells and c-cells, a computer application has been developed in Java language. The building plans, both theoretical and real, are represented through a number of cells according to a rectangular uniform grid. Cells can be of two types: o-cells and c-cells. The tool allows drawing and analyzing of complexes either with only one type of cell or with both of them in a combined state. The tool is about analyzing building plans by calculating several measures, of which only the total depth calculations of convex and linear character are considered here.

The applet is called *Qelizë* which means ‘cell’ in Albanian. It is composed of a drawing canvas, a panel of buttons, a displaying panel and a transfer text area, figure 4. The left side buttons are for zooming in and out which gives the user the possibility to reduce the size of cells in order to increase the approximation in the case of analyzing real buildings. The ‘draw’ button allows the user to draw cells on the canvas by clicking with mouse. The drawing is done by sequentially changing the state of the box from nothing to o-cell to c-cell to nothing. O-cells are shown in squares with white sides and a red dot in the middle, whereas c-cells are shown in red. The numbers displayed inside each box show the values of the chosen measure. The button ‘local’ allows the display of depth values from a cell that is chosen by mouse. This is used in order to clarify how the global value of a certain cell was summed up. The ‘global’ mode displays the total depth values for all the cells. ‘Add data’ transfers the current state of measures into the bottom text area allowing transfers into other applications for further analysis. The ‘color’ and ‘number’ button changes the display of the depth values from numerical to colors according to a range that is displayed in the bottom of the canvas.

Although several measures are deployed in order to analyze the shape in two levels, we will describe only the ones that are used for the purpose of this paper. *N-o* is the number of o-cells in the system, and if the length of a box is given the value of a unit, it also gives the total area covered by o-cells. *N-c* is the number of c-cells and the area of c-cells. *Dep-o* represents the sum of the individual depths of each o-cell. *Dep-c* is calculated by summing up the total depths of each c-cell to all other cells. The total value is assigned to each c-cell respectively. *Loss* is defined as the difference of total depth to the state of entirely o-cells.

The model that is proposed here combines the analysis of the convex modular model with the linear one in a three layered analysis. The first layer, which we will term *L1*, maps the complex entirely with o-cells and aims at capturing the metric inertia of the shape. The second layer, *L2*, represents the complex entirely with c-cells and aim at investigating the linearity of the shape. The third layer, *L3*, which can be thought of as being an intermediate state between the two previous layers, represent complexes with both o-cells and c-cells. Occupation spaces of rooms, offices and so on are represented with o-cells, and open spaces of corridors, hallways, and streets with c-cells. We will add the sign (‘), (‘’), (‘”) to distinguish the measures of L1, L2, and L3 respectively.

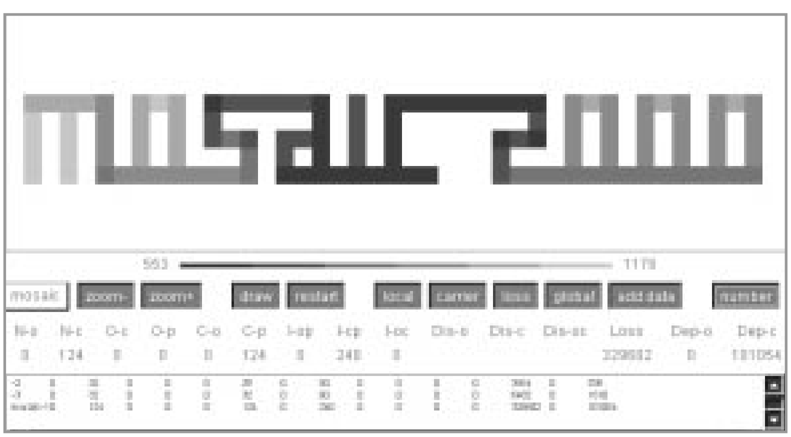


Figure 4: Java applet - from top to bottom, drawing canvas, legend, panels of buttons, transfer data area.

Compactness

The sum of all individual depths in the complex, Dep-o', depends on the number of o-cells that contribute to it. For the purpose of characterizing shapes and in order to allow a comparison between complexes of different sizes, we need to propose a way to disregard the effect of the number of cells in total depth values. We start by investigating a theoretical shape according to the convex model, or else in L1 of all o-cells. We represent the shapes with 7 and 28 o-cells in order to see whether there is any regularity on the way the total depth increases with the increase of the number of cells, figure 5. Two regions of the shape A and C, which are covered with one o-cell in 5a and four o-cells in 5b, are compared between each other by summing up the depth values of o-cells that fall within them. In the first, region A has a depth of 21, and region C a depth of 13. The sums for regions A and C in the second case equal 672 and 464. For the two representations we compare the ratios between the depths of regions A and C, which are 21:13= 1.615 for 7 units, and 672:464=1.448 for 28 units. Because of the difference between these ratios, we can conclude that by changing the fineness of the modules, the regions of the shape are not differentiated from each other in constant degrees. Despite this, we would tend to think that finer modular grids would result in greater consistency. Indeed, when we compare the ratios of depth values for 63 and 112 units we find ratios betweem depths of regions A and C result in 1.411 and 1.395, therefore suggesting a stability as the grid becomes fine. When the total depth value Dep-o' is divided empirically by N-o in the power of 2.5, we find that the measure practically does not change at all for finer modular representations. For instance, for the shape analyzed above with 7, 28, 63 and 112 units the modified Dep-o' changes from 0.864 to 0.895 to 0.896 to 0.898 respectively. We call the modified measure *compactness* as its captures this property of the shape:

$$compactness = \frac{Dep.o'}{N.o^{2\sqrt{2}}} \qquad (1)$$

The values of compactness are shown for each of the theoretical shapes in a sample, figure 7. The areas with low depth form uninterrupted clusters, and they are positioned around the gravity center of the shapes. As the shapes become more elongated, we see an increase of the value of compactness and a differentiation between regions in the shape.

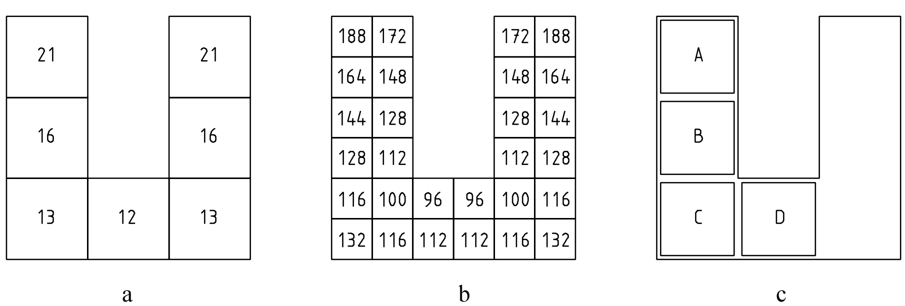


Figure 5: L1 analysis - a) representation with 7 units, b) representation with 28 units, c) regions

Concavity and Low Spots

The next step involves trying the same exercise for the above shape now represented with the linear depth model in L2 entirely with c-cells, where depth relation to each other is based on the linear depth. The shape is differentiated in regions depending on the changes in directions and the areas of the regions that are positioned behind these turns. Figure 6 shows the same shape analyzed entirely with c-cells with both 7 units and a finer representation of 28 units. We can see three distinct regions A, B, and C in regard to the depth values. In figure 6b, c-cells of region B have a depth of 8 because there are 8 c-cells one linear step away 8x1. Region E c-cells have a depth of 24 because regions A, B, and C are not in convex relationship with E, hence 24 = 8x2 + 8x1. Thus, the overall depth value of the shape, Dep-c'', has a built-in component of the number of c-cells. The effect is twofold: first because the individual total depth reflects how many c-cells are in a certain depth from it, and second because of how many c-cells add their individual depth in the overall measure. When investigating the property of the shape in regard to the number of wings, i.e. the degree of turns and wings in relation to the whole, we should discard the effect of number of c-cells, which is a result of the fineness of the modular grid. Therefore the overall depth of c-cells, has to be modified by taking out the effect of number of c-cells twice, therefore dividing it by the number of c-cells in the power of two. The modified measure will be referred to as *concavity* of the shape and will be calculated from the formula:

$$concavity = \frac{Dep.c''}{N.c^2} \qquad (2)$$

We can see that the value of concavity for this particular shape remains the same at 0.625, and it is constant regardless of the modular grid for any other shape. By investigating the examples in figure 7, we can see that shapes that have no wings, i.e. that are entirely convex such as 7k and 7r have a concavity equal to zero. As the shape is compound of more wings and parts that are not aligned, the concavity increases such as the case in figure 7s, which has the highest concavity in the sample at 1.475.

Looking at the sample of theoretical shapes, we see an interesting phenomenon. In contrast to the L1 of all o-cells, here we see that the areas with low depth are often distributed and do not necessarily form a continuous cluster. Their positioning coincides with the crossings of wings, from where one can have the highest access to the surrounding areas in the shape. We term them low spots due to the scattered position and their low depths. Their importance in architectural terms is significant. When we address the problem of introducing circulation systems in the shape of the floor plates, connecting low spots together with segments of circulation guarantees the best moves in regard to achieving the lowest possible depth of the overall system.

When introducing circulation systems, we start from a floor plate represented entirely with o-cells and progress by carving out open spaces by converting some cells into c-cells. The product of this operation results into a combined state of o-cells and c-cells in which o-cells map areas of occupation such as offices and rooms, and c-cells areas of circulation such as corridors and hallways. Thus, we are operating in the third layer L3 of both o-cells and c-cells, which represents a close approximation of real buildings. While taking out the effect of number of modules was shown to be possible in the above discussion on L1 and L2, following the same procedure would run into the difficulty of deciding about the percentage of each type of cell. This is so due to the fact that they contribute into depth measures in different orders of 2 and 2.5. We propose to approach this problem by means of comparing the combined state of L3 with the two states of L1 and L2 which represent the extremes that depth values can reach for the shape of the floor plate in consideration.

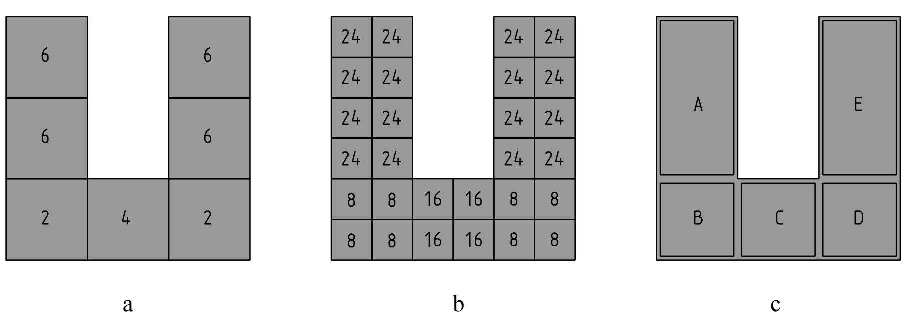


Figure 6: L2 analysis - a) representation with 7 units, b) representation with 28 units, c) regions

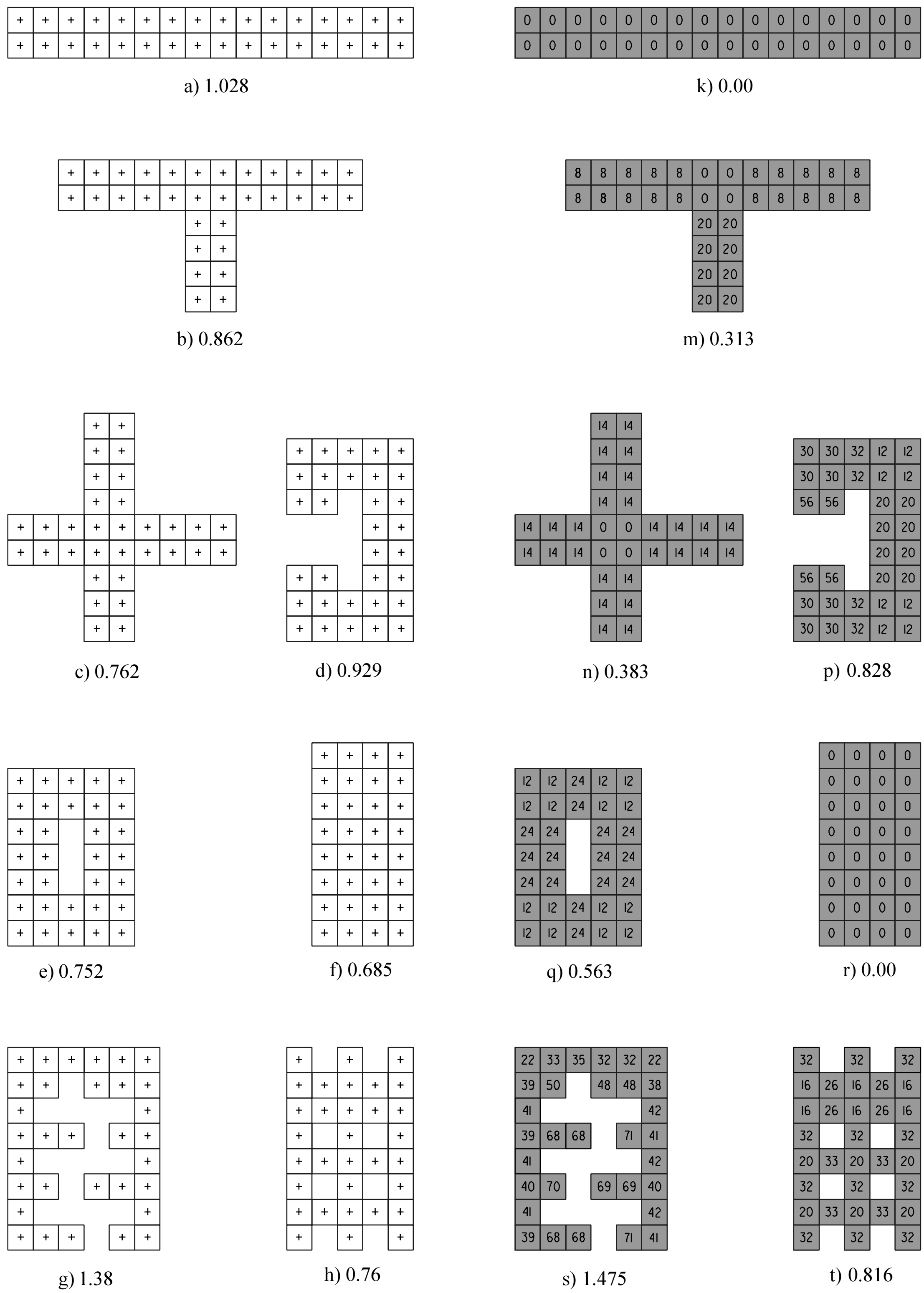


Figure 7: left) L1 analysis showing values of compactness, right) L2 analysis showing values of concavity

Given the definition of convex depth model, layer L1 of all o-cells has the highest possible depth value, while layer L2 of all c-cells has the lowest one. Thus, we propose a modified measure of the actual depth, which will be termed *RelDep-oc*, as the percentage of the actual combined state to the range between two extremes:

$$\mathrm{Re}\,lDep.oc = \frac{Dep.oc''' - Dep.oc'''\min}{Dep.oc'''\max - Dep.oc'''\min} = \frac{Dep.o''' + Dep.c''' - Dep.c''}{Dep.o' - Dep.c''} \qquad 3$$

where Dep-o''' is the depth of o-cells in L3, Dep-c''' is the depth of c-cells in L3, Dep-o' is the depth of o-cells in L1, Dep-c'' is the depth of c-cells in L2. This measure changes for different representations, although for finer modules the changes become smaller and the measure gets towards a stable state. The value of RelDep-oc ranges between 0 and 1 and shows how close to each extreme the combined complex is, or the percentage of depth loss in the system comparing to the state without circulation system. For instance, a value of RelDep-oc at 0.35 would show that the system becomes 65 percent more integrated due to the introduction of the circulation system.

Conclusions

This paper proposed a new method for describing shapes of floor plates from the configurational point of view using the mathematical apparatus of the theory of graphs and presented a computer application that was developed for that purpose. Shapes were represented as a complex of small and unitized elements, and their relations were investigated. In contrast to previous methods that have considered adjacency relations between cells in the shape thus giving a convex description, this work has suggested the linear depth as the key to capturing shape properties from the acceleration and movement perspective. The interesting differences between the convex representation and the linear depth one have suggested a way to quantify the convexity of the shape as the degree of branches and turns. These findings are important for the architectural research in terms of the interrelations between shapes of floor plates and the circulation systems due to the significance of areas with low depth. In the creative realm of architecture design, having a good understanding of the properties of shapes and their effects in the organization, allow for programming better generation rules for producing schematic designs of architectural plans. There is a great potential in adding new generative features to computer tools based on shape grammar rules, where chosen combinations of values of several measures will serve to restrict the vast possibility of shape generation.

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Note: The applet may be viewed at http://www.prism.gatech.edu/~7531b/ Qelize/qelize.html