A Space Syntax Based Model in Evacuation of Hospitals

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Abstract

The concept of architectural design comprises problems such as perception and security especially in buildings having complicated circulation systems. One of the main reasons of this situation arises from that in such complex buildings many functions take place at the same time and within different behaviour modes. Besides their functional complexity, the designs of these buildings may present perceivably complicated spatial appearances. In process of designing, complicated buildings may turn into some spatial plots with unclear circulation systems and the entrances and exits have no significance in memory.

As being an example of a complex building, hospitals also reflect similar circulation system problems. In addition to this, considering the different characteristics of the patients, the hospital emergency evacuation systems present an important question to the design process. This research deals with the General Surgery Building of Istanbul University, Istanbul Medicine Faculty as the case study; examines the exemplary emergency hospital evacuation systems and presents a model related to the spatial, ergonomic and perceptive parameters.

1. Introduction

The circulation systems in buildings resemble veins of organisms. The veins create a network in the body and it arranges the flow of the blood due to the pressure. The shape of these veins and their integration with cells may be compared to the spaces in a building. Either linear or circular in architectural geometry, the shape of the building, affects the legibility of the spaces. The justified graph developed from the layout of the building, the architectural form, the space and circulation relationship, the linearity or centrality of spaces can be understood in the language of space syntax, in terms of depth or shallowness as “relative asymmetry” (Hillier & Hanson, 1984).

This research paper mainly focuses on the evacuation of complicated buildings, especially hospitals. The hospital is a complicated setting comprising many functions and variety in the competences of occupants. The legibility of the building and the means of way finding are important aspects of evacuation in such complicated buildings. The parameters affecting the legibility of hospitals may be considered as the geometric shape of the corridors, the ergonomics of the spaces as well as the characteristics of occupants. These parameters may be considered as passive prevention factors against any event or disaster. On the other hand, there are active prevention factors such as sophisticated fire extinguishing systems, fire loads, sensor and detecting mechanisms and even existence of signage systems. This paper eliminates the active prevention factors of emergency safety systems, whereas it examines passive parameters in the evacuation systems of hospitals. In general, parameters indicate four important notions in the hospital evacuation system.
These subjects are considered as:

- the geometry or the shape of the building as a whole,
- the route or the circulation system of the building,
- the cells or spaces around the route,
- physiological system potentials such as the perception or competence of the occupants.

Architectural theory mainly concentrates on the issues indicated above, and architectural design elaborates these issues and implicitly motivates designers to use these inputs in the design process.

2. Theory

The evacuation of hospitals can be discussed within the context of architectural legibility. Architectural theory mainly focuses on this issue especially in scope of perceptive and cognitive studies. Many researchers consider that the evacuation routes of buildings are directly related with the legibility degree of the building. O’Neil (1991), Passini (1984) and Peponis et al. (1990) contributed to the research area and they highlighted the role of architectural legibility and way finding in design. They explained that the designed environment seems to be a part of nerve system of the building; the linkages with spaces intersect over the nodes. The circulation of the building may be considered as a network or a nerve system (O’Neil, 1991; Passini, 1984; Peponis, Zimring, Choi, 1990).

The neurosis of the buildings may be interpreted with the interaction of nodal points and linkages. The nodes are generous physical realms simplifying the architectural legibility mostly in the intersected points of the circulation system. O’Neil (1991) and other researchers used the path analysis in terms of “nodal points” for explaining or translating the legible areas. This integration highlighted new concepts in architectural theory. O’Neil (1991), Passini (1984), Peponis, Zimring and Choi (1990) suggested that the importance of nodes in architectural design especially for comprehending and linking the parts of the building components and completing the total image of the picture, based on the spatial configuration.

The nodes in the buildings are inescapable parameters that help to understand the evacuation routes. Many fire engineering scientists (Sime, 1994; Abrahams, 1994) used the notion of escape behaviours of occupants. Sime’s (1994) contribution is based on the escape behaviour, and he implemented the escape routes based on nodal points in the fire escape as the research example. Moreover, Abrahams (1994) focused on occupancy characteristics and identified five key characteristics such as sleeping risk, number of occupants, mobility, familiarity and response to a fire alarm. As an extent of modernist trends of architecture, designers briefly consider the building as a machine. However, the building in an emergency case may easily turn to be a chaotic space and it presents various human reactions and space, time and human interactions. These results may also be derived from socio cultural and psychological situation of occupants. For example, Chetkoff and Kushigian’s book (1999) titled as “Don’t Panic” is a milestone in the psychology of emergency egress and ingress in terms of panic theory.
The architectural path analysis in way finding, if we summarize as “node theory” may be expanded to “graph theory”, which may also be considered as an extent of circuit theories, regarding the implementation of the fire engineering scientists. For example, Olsson (1999) implemented “event tree technique” to assess the safety level in a model hospital building. The emergence of extensive quantitative risk analysis models or creation of fire risk assessment models has always been objectives of fire engineering scientists. These models are mainly developed in mathematical or computational science, such as the successful sophisticated software for assessment risk criteria simulated by Evacnet or Exodus.

The evacuation of buildings can easily be argued with occupants' movements. The occupants’ flow on circulation systems, confrontations with others in emergency cases, occupant’s competence such as speed and even their postures can shape the nature of occupant traffic in buildings. The occupants’ flow in buildings also can be modelled or simulated as Smith (1991) and Lovas’s (1994) contributions, revealing many ideas about the occupants’ movements. For instance, Smith’s (1991) queuing model in circulation systems makes the nature of human movements more quantifiable but complicated as an extent of stochastic methodology.

Livesey and Donegan (2003) proposed a normalization of values as mean depth, integration and relative asymmetry in egress complexity. The researchers brought the importance of space syntax values in the egress complexity. Shell and Mataric (2003) also used the space syntax values in mobile robotics domain. In the design or evaluation of mobile robotics, we should accept many parameters playing roles in various models; we should accept the vital roles of space syntax, fluid-flow or crowd behaviour models (Shell and Mataric, 2003). The mobile robot as an exemplar of an agent in the space syntax language should move on a surface and perceive the space as precisely as the human being. So, the design of mobile of robot should also cover space syntax parameters.

This research paper might be a conglomeration of theoretical matters cited above. The theory on evacuation of buildings concentrates in various disciplines e.g. fire safety engineering, mathematics and computation, operations research, industrial engineering, environmental psychology and architectural design. However, there are a few research in comprising architectural psychology and the design of evacuation network (Stollard and Johnston, 1994). So, this paper argues the interaction of variables emerged in these theories. Moreover, this paper concentrates on the occupant’s psychology in evacuation process and the spatial manifestations of architectural design. The theoretical framework of the paper depends on an intersection area of various disciplines such as crowding of occupants in fluid-flow model in traffic engineering, competence of occupants in crowd behaviour model in psychology and real integration, visibility area - isovist values of space syntax model.

3. The Method

The integrated model of egress in the paper proposes six factors based on various models. Space syntax, fluid-flow and crowd behaviour models of evacuation network point out essential parameters to present these factors:

- the crowding in the space,
- the competence of the occupants,
• the spaciousness factor of the space,
• the integration value of the space,
• the visibility area of the occupants,
• the distance between the egress point and the space.

The six factors of theoretical framework indicated above, are the parameters of the integrated egress model research. The crowding value of the space is related with the number of occupants in a specific measured area; meanwhile, the speed of escape behaviour should be added up to the value of crowding, thus, the competence value here works as the speed. The values of either crowding or human competence should be argued as extents of fluid-flow and crowd behaviour models of evacuation.

The spaciousness factor on the evacuation route mainly depends on the ratio of dimensions of space. If we add up the distance between the egress points i.e., the fire staircase, main gate and etc, and the specific hall, we should also consider the metric values, dimensions of space correlated with the human ergonomics.

The latter two factors of integration and visibility values are mainly derived from space syntax theory. The integration value points out the permeability of spaces and helps to evaluate the geometry of the buildings. On one hand, space syntax theory proposes that the “real asymmetry value” is highly specific in the configuration of spaces such as linear or circular schemes. On the other hand, the visibility value is derived from the “isovists” formed by the edge lines of spaces. If we summarize the parameters with symbols; “n” denotes the number of occupants, “A” signifies the area, “c” is the competence of occupants, “l” is the length of the space cell, “w” is the width of the space cell, “d” denotes the distance between the egress point and the space cell, “IS” is the isovist value or the visibility area of the agent in specific space cell and finally, “RI” represents the real integration value of the space cell. The term “space cell” here denotes the visual convex shape produced by the s-partition analysis, which will be later discussed.

If we articulate the determinants in the total vulnerability of the building in an emergency case, crowding is the first factor to be examined. The occupant leaves the space cell and leads to the egress point in the emergency evacuation. In an emergency case, the egress point may be a fire staircase, main gate or an evacuation hall. The competence of the occupant is also critical and varies due to the physiological outcomes. For example, low competence of occupant creates queuing in evacuation time. We may create algorithms for the human competence, for instance, 3 points for handicapped agents, 2 points for semi-handicapped, 1 point for normal agents, and so on, so forth. The issue of crowding has a linkage with the basis of crowd-behaviour model that presents a formula regarding the queuing on the circulation system. Each crowding value in the cell or circulation area should also cover other crowding values on the evacuation route. The queuing value of the crowding is symbolized with Σ and the queued crowds should be formulated as:

$$\Sigma(n,c)/\Sigma A$$

Another determinant of the vulnerability is spaciousness. The ratio between the dimensions of a space is critical in evaluating the degree of perception. Sadalla and Oxley (1984) reinforce the illusionary effect of rectangular spaces and they state that rectangularity in space creates an illusionary effect; occupants perceive more spaciousness in more rectangular spaces. However, in emergency cases, wider spaces ergonomically create advantages
especially in queuing. So, the value of spaciousness is regarded as square based spaces corresponding to a ratio of 1/1. Contrarily, the ratio between the length and width in emergency cases l/w should be less than 1, denoting that during an advantageous escape one needs to pass through cells shorter in distance but wider in extent.

The distance between the origin and the egress point is a critical measurement in fire safety engineering. Fire prevention standards in national or international codes bring out specific distances. Thus, the distance between the egress point of the room and the egress point of the building is a critical determinant of the vulnerability in emergency evacuation cases.

Another determinant of the vulnerability is the real integration value denoted as “RI”. The value of real asymmetry helps us to discuss the integration and depth values of spaces within the spatial configuration. The real integration value of the space points out the shallowness or depth, in other words, isolation situation of space. The most isolated spaces create difficulties in the evacuation and these types of spaces can be considered as vulnerable. On the other hand, spaces having more permeability and high connectivity values may be considered as convenient places in an emergency evacuation.

Isovist value IS, gives information about the visibility of the occupants. We may also title this value as “span of visibility”. In an emergency case, the area of visibility and noticing the signage system is extremely vital especially in escape behaviour. “Spatialist” software of the Georgia Institute of Technology helps us to reinforce this value and we add up the total vulnerability formula.

As for the, value of emergency vulnerability VEV, in this research, it is considered as the sum of all determinants. The theoretical framework and argued determinants propose the value of vulnerability as cited below:

\[
VEV = \left[\sum \frac{n.c}{\Sigma A}\right] + \frac{l}{w} + d + \left(\frac{1}{RI}\right) + \left(\frac{1}{IS}\right) \quad (13)
\]

The formula covers the passive prevention determinants starting from queuing, competence to space syntax. The total vulnerability value eliminates active prevention determinants and the formula brings out passive algorithms in architectural layouts. This approach may be generous for architects in evaluating the evacuation route and spatial configuration especially in complex buildings. The evaluation might be implemented as a part of POE (post-occupancy evaluation) or pre-design stages.

4. The Case Study

This research deals with the General Surgery Building of Istanbul University, Istanbul Medicine Faculty as the case study; examines the exemplary emergency hospital evacuation systems and presents a model related to the spatial, ergonomic and perceptive parameters. The building is composed of 4 wings located around the main vertical circulation core. The scope of the case study focuses on one of the wings of the plastic surgery department located at the fifth floor (Figure 65).

This conceptual model evaluates the building’s circulation system performance due to five main factors explained above. The queuing crowd, spaciousness, distance, isovist area and the real integration values of the system are determined for the value of emergency vulnerability VEV of space cells.

At the first stage of data collection of the research, the spatial real integration values of the mentioned wing are determined through the s-partition analysis obtained by the
Figure 65: TOP: The Layout of 5th Floor Plan and the Selected Wing. BOTTOM: The S-Partition Analysis of the Selected Wing
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Spatialist software of the Georgia Institute of Technology. Apart from producing the real integration values of the spaces, the analysis composed a visual set of space cells that are used for the remaining analysis of the parameters. These cells are numbered according to the s-partition outcomes and the components of the overall VEV evaluation are determined through these fixed space cells, located either on circulation routes or actual functional room spaces. At the following stages, the queuing crowd values of the space cells, the distance from each of these cells to the exit, the ratios of length of the cells to their width, i.e. their spaciousness, and the visibility area from the centre of each route cell and from the threshold of each room cell, i.e., the isovist area are determined. The outcomes of the parameters are calculated according to their mean values and coded in an interval ranging from 1 to 5, where 5 denotes the most and 1 denotes the least vulnerable spaces. These results are then converted to visual schemes.

5. Analyses

The plan layout of the selected wing is subjected to five analyses. The overall outcomes of these analyses are evaluated through an interval scale from 1 to 5. The real integration values of the selected wing are obtained through s-partition analysis of Spatialist (Figure 65). The data collected here indicates that the cells located on the circulation routes are more integrated compared to the cells located on rooms. Also it is important to note that the certain central spaces in the system, which are used mainly by the staff, have the highest mean depth values of the whole plan indicating a certain level of emergency vulnerability.

The values obtained from the s-partition analysis presents 56 visual space cells enabling a virtual base for the rest of the determinations, as well as the isovist areas of the cells (Figure 66). Isovist area determines the extent of visibility from a certain point. As the nature of isovists is based on an angle of visibility of 360°, an assumption is made considering the location of the isovist points. In this research, the isovist areas of the cells located on the circulation routes are determined from the central point of the specified cell. On the other hand, the isovist areas of the room cells are determined from the central points of the thresholds. The isovist area analysis points out that the visibility area of the cells located on the corners of the circulation routes have the highest values indicating a wider angle of way finding thus, a lower level of emergency vulnerability.

The data related to the queuing crowd is obtained through a formula explained in the previous sections. The idea here is to calculate the total queuing crowd ahead, i.e. the accumulation of occupants lined up from the specified cell to egress point of the building. Thus, the total number of people multiplied by their competences is divided to the total area ahead. The competence values are determined with assumptions that, no matter how critical his/her condition the patient has a competence value of 3 denoting that especially in a surgery department, he/she needs help for an emergency escape. The visitor’s competence is designated to be 2, denoting that he/she may be healthy enough to be in charge of his/her escape, but may have a disadvantage of way finding. Finally the staff is considered to have a competence value of 1, denoting their capability of control of the spatial escape routes. The data collected from the queuing crowd indicates that especially the spaces including more people such as the wards for patients are more vulnerable compared to professors’ offices. Figure 67 shows the visual distribution of all five analyses coded in an interval ranging from 1 to 5, where 5 denotes the most and 1
Figure 66: The Isovist Area Analysis of the Space Cells
denotes the least vulnerable spaces. The figure indicates as the colouring gets darker so the space gets more vulnerable.

The data collected from the distance parameter presents the numerical values of distance from the centre of each space cell to the egress point. This data indicates that farther the space cell is located from the egress point, the more vulnerable the cell gets.

As for the spaciousness factor, the data is derived from the ratio of l/w for each space cell. The width of the cells is considered as the extent of walls containing the door for the rooms and the width of corridors in the direction of the escape route for the circulation areas. The assumption considered here is that wider the cells get, it is easier to prevent the piling up and also quicker to leave the cell for the next in route. The outcomes of this analysis indicate that as the l/w ratio gets lesser than 1, the value of emergency vulnerability tends to decrease.

As it is explained in the previous sections, the value of emergency vulnerability VEV in the selected wing is determined from the accumulation of all five parameters. Figure 68, indicates the total VEV scores of the space cells. The figure shows that the vulnerability of spaces is related with their geometrical structure, queuing crowds and syntactic characteristics.

The emergency vulnerability value VEV of the building presents five essential determinants. As the outcomes of the case study are considered, it may be necessary to evaluate the relations of these parameters with each other and with total VEV. Thus, the analyses can be verified via regression analysis as it is shown in Figure 68. The diagram indicates that among the parameters used to determine the total VEV, especially, real integration (RI) and distance (d) values present significance with $R^2 = 0.58$ and $R^2 = 0.55$ respectively. Certainly, different building plans may present different results considering the gravity of the parameters involved. However, in this research, the correlations of parameters with the total VEV emphasize that the vulnerability of a building in disaster or emergency cases, is directly related with the syntactic value of real integration and the dimensional value of distance between the starting cell and the egress point.

6. Conclusions

Regardless of the pre or post processes of architectural designs, total VEV analysis presents the vulnerability of escape routes and room spaces in a building during any disaster or emergency situation. This method can be used as a tester for the architects to evaluate their designs according to emergency or disaster cases. Thus, the architect can consider implementing passive preventions either for the building geometry or the relationship
Figure 68: TOP: The Overlapped Distribution of Total VEV Analysis. BOTTOM: The Correlation of VEV Components
of room spaces with the circulation routes, if needed. The architect can also revise the functional distributions and the distribution of queuing crowd.

In this research, it is exposed that, although the distance from the starting point to egress point may quite be within the limits of existing standards and codes, the results may not be sufficient enough to avoid vulnerability. The main reason of this situation may be the relationship of the functional usage and the dimensional distance to the egress point. It may be a quite probable that different types of building plans will present different results considering the gravity of the mentioned parameters involved. However, in this research, the model emphasizes that human factor, geometrical structure and the space syntax inputs are especially effective for the evaluation of evacuation vulnerability.

Literature


