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OPTIMIZATION OF QUALITITATIVE AND MOTIONAL ASPECTS OF MARINE PASSENGER TERMINAL BASED ON INNOVATIVE APPROACH FOR PEDESTRIAN SIMULATION

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Abstract:

Nowadays, designing large scale public and urban places, such as terminals, shopping centers and hospitals, with a human-centered approach has been the goal of many architects. Ease of movement for people in such buildings, bearing in mind saving time and expenses as well as health, is greatly important in these places. Terminals are a major type of these buildings whose designs are greatly affected by crowd movement in predefined spaces.

This study is aimed to optimize the design of a marine passenger terminal based on simulation of population circulation within the terminal from a practical quality point of view. Here, an attempt is made to show that in order to achieve a practical design, one of the best responses is to effect design while simulating passengers' movements in every moment. This study applied an innovative method of design while simulating the behavior of the crowd in a sea passenger terminal. In this method, a graph representing the physical plan of a marine passenger terminal was first created, followed by creating a simplified form of the graph and simulating passengers' movement using Pedestrian Dynamics software. Having obtained the statistical analyses from the software together with the visual analyses by the designer of crowd movements analysis maps in the given space, the primary form, related to the terminal physical program graph in line with the movements of the crowd, was edited. Eventually, they were compared in terms of population traffic, time and distance traveled. According to the statistical analyses and complementary mathematical arguments, there was up to 10 percent decrease in crowd traffic in the edited primary form.

Keywords: Passenger terminal, optimization, movement, circulation, crowd simulation

1. Introduction

Motion is the key feature in all spatial experiences, and our perception of space relies on motion. The universe and all its components are dynamic and constantly changing either explicitly or implicitly. Bodily motions, not due to the five senses, are the measurement criteria of objects and space. A visual transition in space gives us the chance to discover its hidden beauties (Fon Mice, 2005: 19). Architecture is a three-dimensional art; that is, one can enter it and perceive its details by motion. Time is an irreplaceable element in architecture. In fact, motion is composed of space and time, and without the fourth dimension together with the time necessary for discovering the space, a solid perception of motion is not possible. There are many complexes where motion not only plays a spatial experience role but also is a necessity for individuals to achieve their goals in the complex.

In some of these complexes, as in passenger terminals, the time element becomes of great importance so much that the passengers have to stay in time so that they should pass the needed spaces on time. Today, designing such large-scale spaces, where the pedestrian motion is the key, is performed only based upon predetermined general principles. Regarding the immense sums of money spent to build projects like these, there is an urgent need to investigate operational qualities on a deeper level. In fact, the need to facilitate crowds' movement is easily evident in such projects. The design must not cause further difficulties for individuals in the pathways, rather it must facilitate navigation and movement. The fact is that designing a project based on motional needs and operation is a fundamental notion which has gone unheeded. Sadly, it is evident that simulation software programs used by architects are limited to three-dimensional form making and drawing plans lacking a qualitative approach related to the operational design. Passenger terminals are among the most important projects serving as a major node. Furthermore, a key issue in terminals is individuals' movements within the premises which makes incorporating people's behavior, their motion to get to the gates at minimum amount of time, and easy choice of routes within the premise's inseparable from the design.

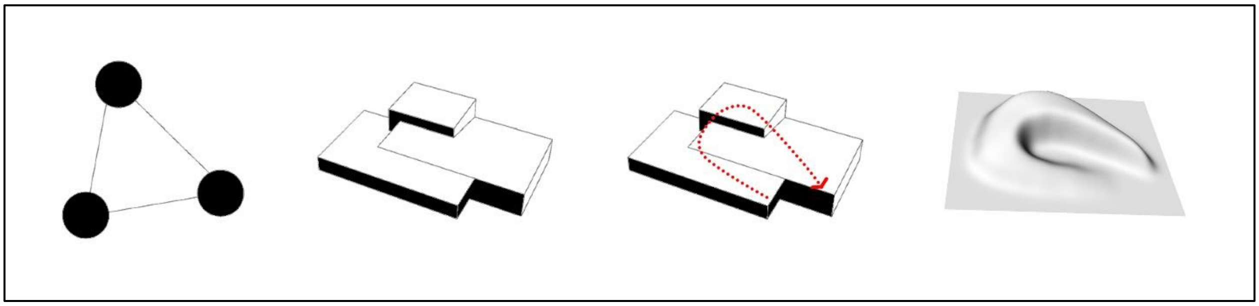


Figure 1. Designing Procedure 1. Space layout diagram 2. Form with initial geometry 3. Crowd simulation in the initial form 4. Changes in the initial form

As illustrated in figure 1, this study suggests an innovative design method using crowd behavior simulation in a marine passenger terminal. In fact, the initial design was developed according to the current principles of design in passenger terminals, then using crowds' behavior simulation, it was modified to optimize the quality of the design for crowds' density and navigation. Eventually, a comparison was drawn between the initial form and the modified form based on crowds' movement (Figure 1).

2. Methods and Material:

As stated earlier, the process encompasses four steps: first, a spatial diagram is developed based on the designer's knowledge and primary investigations; next the diagram is changed into a form with the simplest geometry, which is followed by simulation of the form via the software, and eventually, the form is modified based on lines and analyses rendered as a result of crowd simulation.

2.1. Producing space layout diagram:

Figure 2 indicates the initial spatial diagram based on relevant regulations in the Ports and Shipping Organization as well as requirements in terms of visibility and climate (Figure 2).

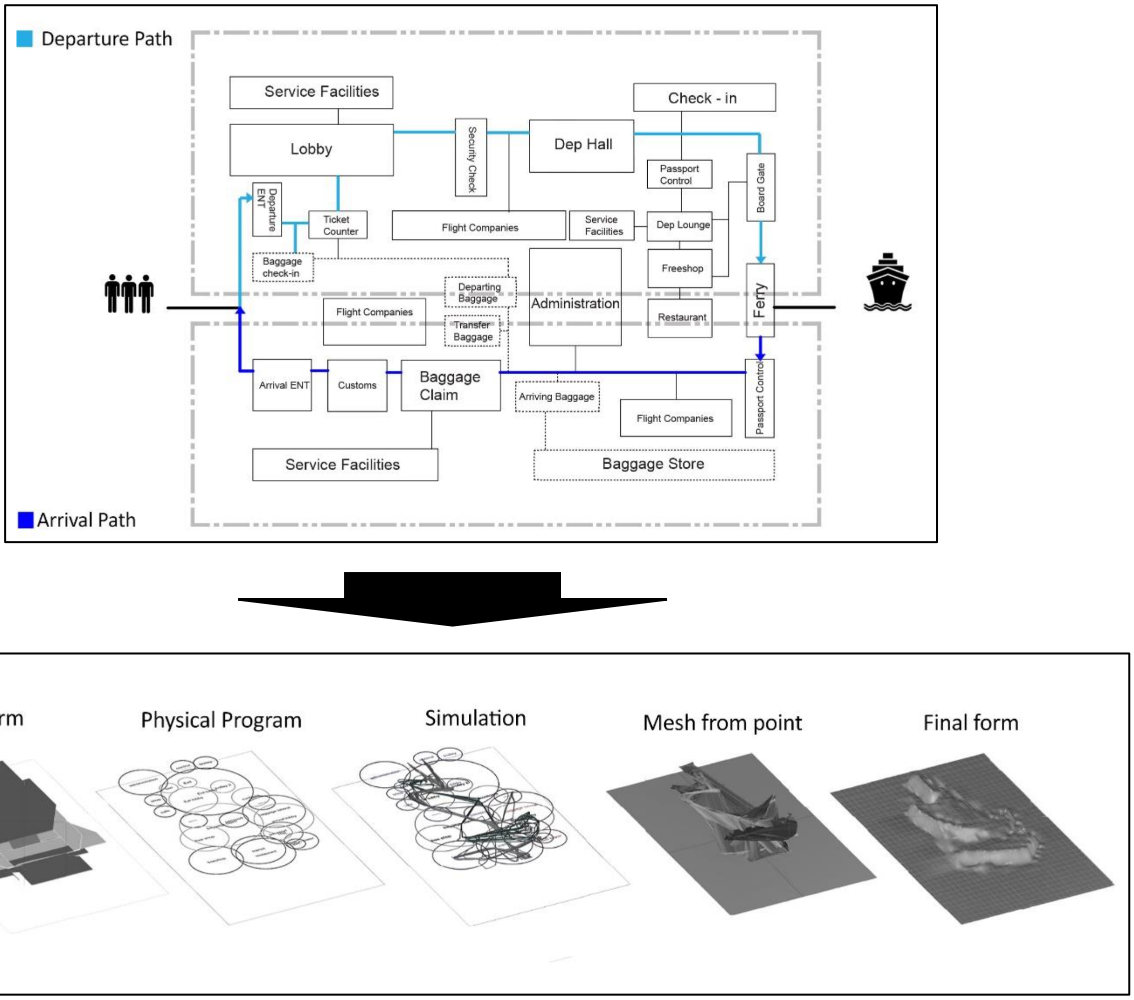


Figure 2. (Above) Passengers' motion diagram (Neufert 2008); (Below) Changed form to space layout diagram

2.2. Model production and initial plan by the diagram:

According to the diagram, every space is imagined as a cube and put together in their simplest form with no change in angles.

2.3. Crowd simulation in the initial form

2.3.1. A summary of simulation models used in order to simulate crowds' motional behavior:

Computer simulation techniques study social and population interactions; for instance, pedestrian traffic, crowd control, congestions, crowd evacuation and social interactions. There have been various methods of human behavior simulation; programmers picture humans as a Cellular Automata capable of assigning individual features in terms of age and other characters. In the meantime, the simulated people are affected by several external physical forces as an attraction or avoidance, including walls. Hogendoor (2001) has done comprehensive studies on pedestrian time-spatial behaviors. Turner and Penn (2002) used liquids to study pedestrian behaviors (Helbing 1992) and gases to simulate these behaviors.

Of the oldest and best techniques suggested for crowds' behavior simulation is the *Social Forces* technique registered for the first time by Kurt Zadek Lewin. Lewin was of the opinion that no movement occurs unless some force is employed on the pedestrian; furthermore, he believes that one force alone cannot induce movement, rather a collection of forces can affect them. For instance, *Force* in this technique means the tendency towards transportation.

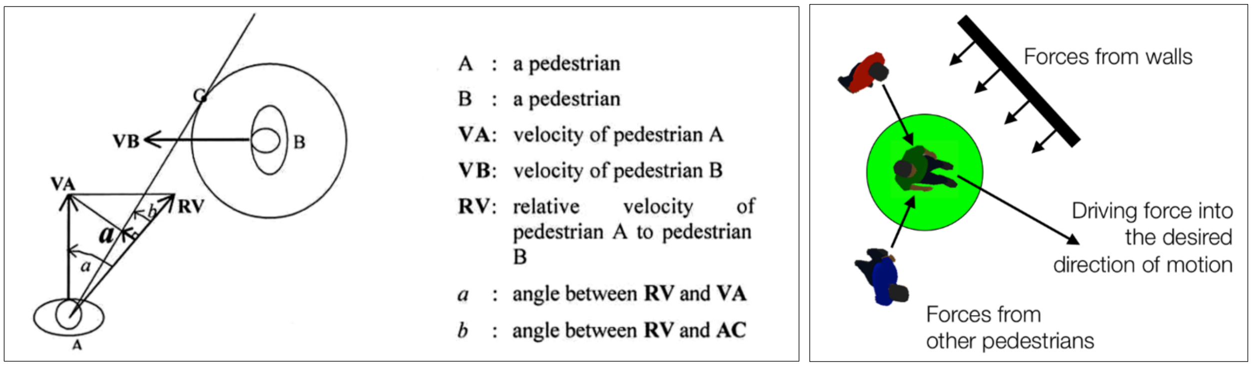


Figure 3. (Right) effects of different forces on pedestrian in Social Forces model (Helbing, 2014) and (Left) the effect of repellent forces among different people in Social Forces (Okazaki and Matsushita, 1993)

To develop the computer model for this technique, individuals' locations in a surface is considered based on coordinates capable of a change in time. Also, a variety of forces affecting a pedestrian are simulated in the form of vectors. Currently, the most advanced software programs for pedestrian behavior simulation apply this method. In this model, an agent's movement is due to the resultant vectors of force. As shown in figure 3, these forces might be the repellent forces from walls or other pedestrians, or the absorbing force from the destination (Figure 3).

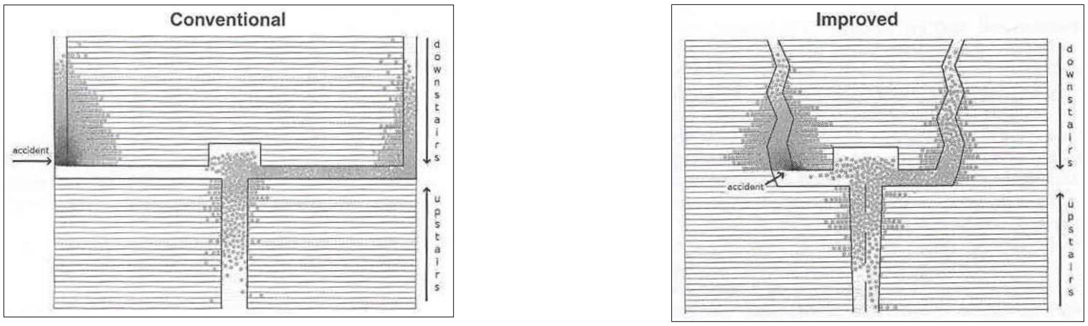


Figure 4. Crowd simulation in architectural model of a stadium, the designed figure is on the left and the optimized figure on the right (Helbing et al, 2005).

A sample of simulated crowd movement is the optimized exit corridors in a stadium by Helbing Group. In this case, an emergency situation is simulated where the exits are congested due to panic among crowds. Here, the first solution is to widen the corridors. The second is to create a zigzag-shaped form in which the crowd pressure is reduced. Other models put forward for crowd or urban space simulation include Magnetic Forces model and Cellular Automata model. (Helbing et al, 2005). The following figure depicts a comparison of the three models by Teknomo. According to the comparison, the key difference lies in the fact that in Cellular Automata agents are separated while in the other two they are not separated (Table 1).

	Benefit Cost Cellular	**Magnetic Force**	**Social Force**
Movement to goal	Gain Score	Positive and negative magnetic force	Intended velocity
Repulsive Effect	Cost Score	Positive and positive magnetic force	Interaction forces
Pedestrian movement	Discreet	Continuous	Continuous
Value of variables	arbitrary	Physical meaning	Physical meaning
Phenomena explained	Queuing	Queuing, way finding in maze, evacuation	Queuing, self-organization, oscillatory change
Higher programming orientation in	Cellular based	Heuristic	Mathematics
Evacuation Application	Possible	Possible	Not possible
Parameter Calibration	By inspection	By inspection	By inspection

Table 1. Comparison of three suggested models in crowd simulation (Teknomo et al, 2000)

Another model to simulate human behavior is Collective Intelligence Model which functions based on social interactions of the agents, similar to the case of Social Forces Model.

Collective Intelligence models are those attributed to creatures living in colonies and can be compared in some cases with human collective behavior: although it seems that Collective Intelligence simulation models and models based on Social Forces are different from Swam Intelligence Models in different roles of their agents, they share quite a few similarities:

- These models, similar to Swam Intelligence Models, are based on navigation principles including Separation, Alignment and Cohesion.
- Self-organization is the process of agents' reactions towards a collective order.
- The system automatically increases the internal order without any specific source of command. The system works in a bottom-up manner; that is, there is not a superior force in charge of leading agents. The model then keeps its natural form.
- A self-organized system has emergent features.

Collective Intelligence models which serve as the basis for a large number of models have been inspired by colonial behaviors of ants, these models follow three basic rules (Yoon and Maher, 2005):

1. Avoiding contact with the nearest agents.
2. Attempting to stay aligned with and control their speed to adjacent agents.
3. Attempting to stay close to adjacent agents (Figure 5).

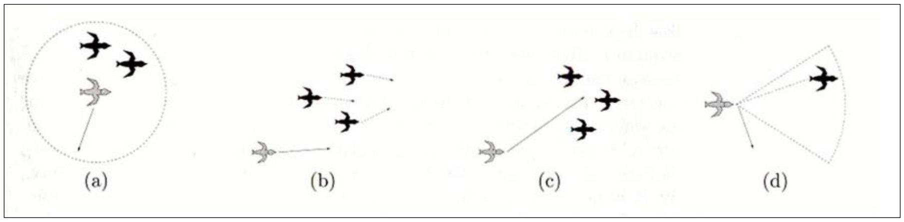


Figure 5. Basic laws of swarm intelligence and the fourth secondary law, attempt to keep the visual fields of one another open (Flake, 1998)

2.3.2. Designing crowd motional behavior stimulation model:

Pedestrian Dynamics which was used to simulate human behavior is a combination of collective intelligence and navigational techniques. In fact, route choice techniques enable agents to select paths to reach their destinations (Figure 6).

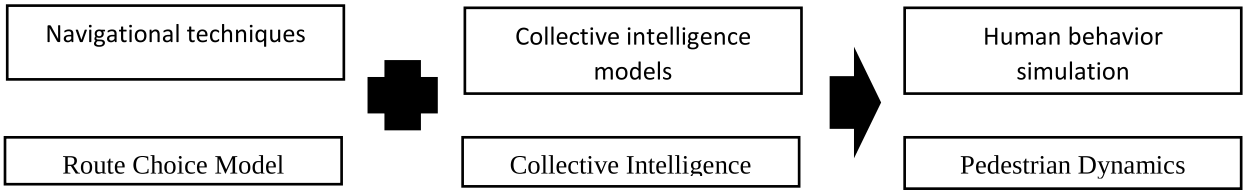


Figure 6: (Pedestrian Dynamics) the model used to simulate human behavior

The Pedestrian Dynamics Model begins with acquiring building plan and crowds' data. Plan data include internal elements ranging from walls to pillars, exits and queue places. Crowd data include individual or collective data from starting point, speed, time, direction etc.

As shown in figure 7, the software first simulates a spatial diagram converted to the architectural plan. Then, spaces like ticket counter halls and queues are simulated. Then, the software forms a virtual mesh plane between different spaces. The mesh plane includes ECM lines which help agents choose their routes (Figure 7).

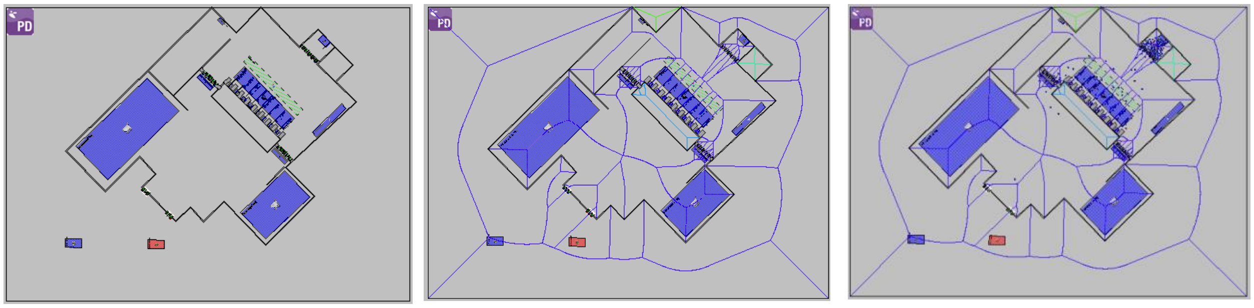


Figure 7: from left 1. The initial physical model plan 2. Producing ECM lines for ease of agents in choosing routes 3. Agents' movement

At this stage, the data related to the passengers' crowds must be inserted. For instance, passengers in the departure (i.e. passengers exiting to board the ship). To simulate, the passengers are divided to three groups:

1. Local (Iranian) passengers who intend to board the ships go through spaces in the following order:
   Entrance - lobby - cargo - ticket counter - transit lounge - restaurant - security - departure

2. Foreign (non-Iranian) passengers who intend to board the ships go through spaces in the following order:
   Entrance - lobby - cargo - ticket counter - security (passport) - transit lounge - restaurant - security - departure

3. Passengers with enough time to use the spaces as coffee shop prior to delivery of their luggage to cargo department:
   Entrance - lobby - open coffee shop -cargo - ticket counter - security (passport) - transit lounge - restaurant - security - departure

As can be seen in figure 8, these categories were marked by color coded circles during simulated passengers' movements.

In terms of the number of passengers simulated, the model considers the maximum number of passengers in one hour -the number of passengers in peak hour- which can be calculated based on the annual statistics published by the Port and Shipping Organization.

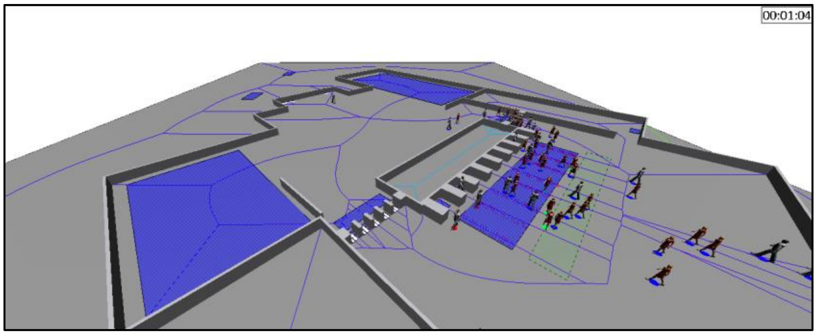


Figure 8: 3-D simulated environment and categorization of moving passengers toward the cargo delivery and transit lounge

At this stage, the data related to each category is inserted individually to determine the percentage of passengers in peak hour from each category. Waiting times are also determined, for example, at the cargo counter or cargo delivery. Each set of data adds up to the accuracy of the simulation. At this stage, the crowds will be simulated in 3D (figure 8).

2.3.3. Data Analysis

Here, the model will be put to work in a real time simulation and the average density as well as movement paths of around 500 passengers (passengers at the peak hour) will be simulated in one hour. As illustrated in figure 9, crowd simulation stages are determined in departure and arrival paths. Warmer colors indicate higher densities of the crowds. Such density is expected at gates where people had to stand in queues; the amount is controlled by software standards. As shown in population density analysis map, the highest density is at the arrival gates and crossing gates from cargo delivery to boarding gates (Figure 9).

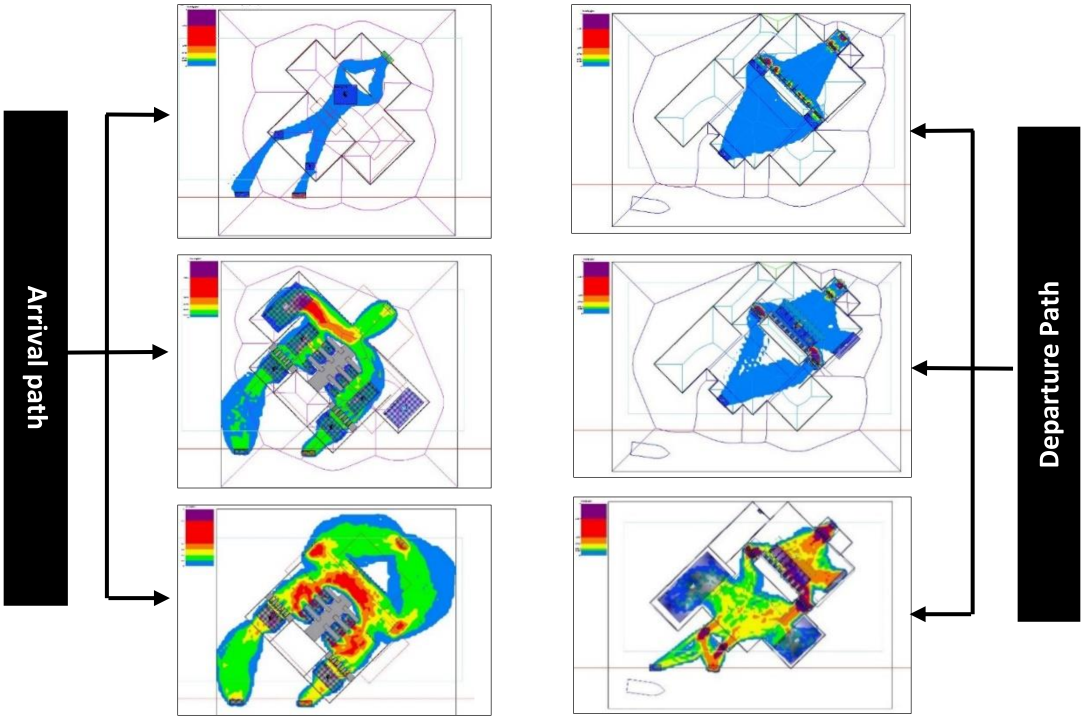


Figure 9: population density in stimulated model in departure and arrival

2.4. Edited model based on simulated population movement

In this stage, the analyses of the last stage have been considered as a basic for a form finding method (Using a surface). Wherever the population is dense, the height of the surface is more. (Figure 10).

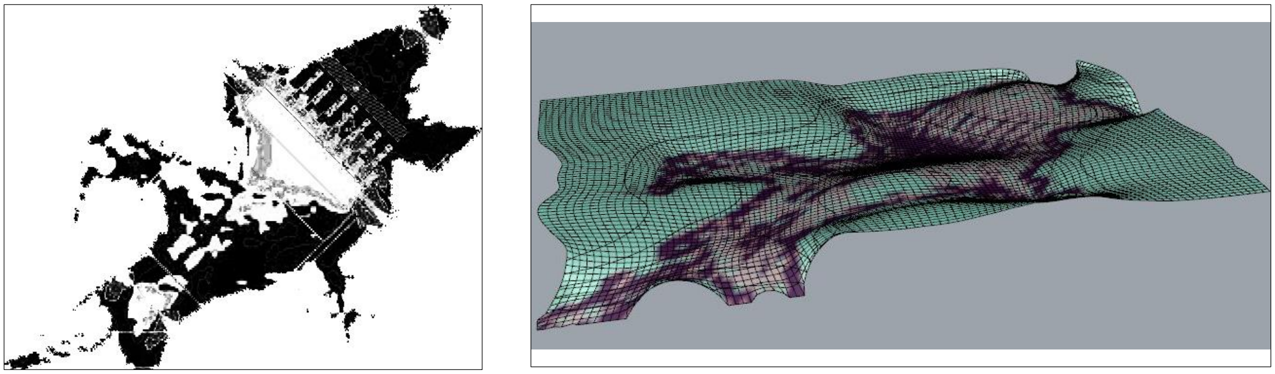


Figure 10: converting analytical diagram extracted form simulation software to form by code in Grass Hopper

Following this stage, the obtained model was reinserted into the simulation software, and simulation was performed under the initial conditions. Finally, this study was aimed to compare two models (initial model and extracted model) in terms of population traffic.

3. Results:

Eventually, the initial model and the edited one were compared. All the circumstances including space areas and demographic characteristics, except for the forms of the walls, were assumed to be the same. In fact, the two models were different in form, but they were the same in terms of space programs.

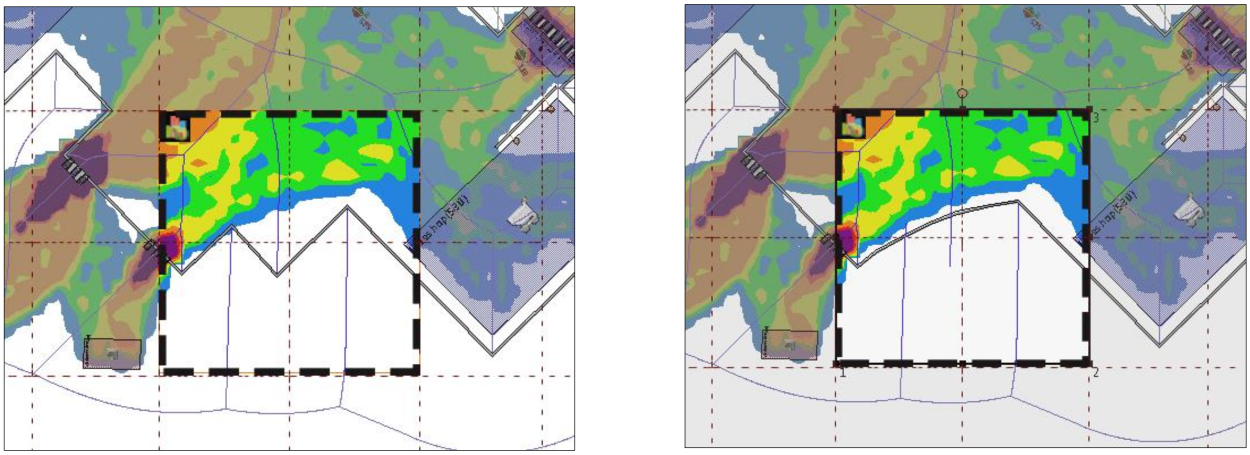
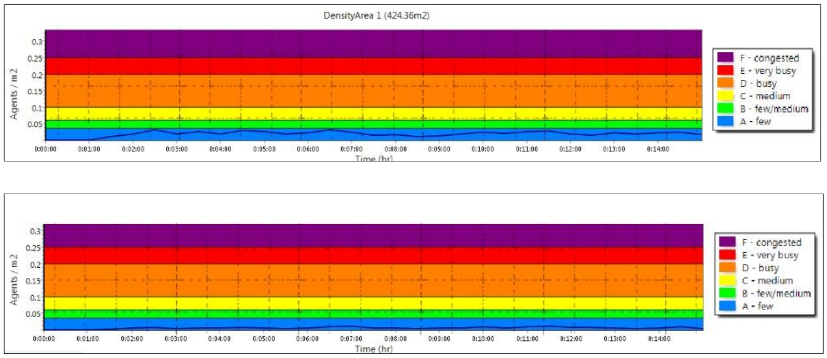
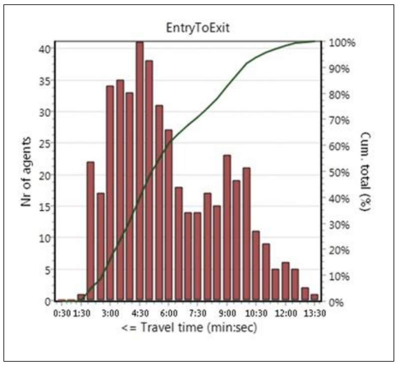


Figure 11: comparison of two parts in the initial and edited plan (right: part of edited plan; left: Part of initial plan)

In the edited model, form is made based on passengers’ motions so that it can be considered as a changed mode of initial form as a result of simulation. Here, to compare the two models, a part of the transit lounge with an area of 400 square-meter in both models is taken into consideration. Simulation was performed in both models with identical circumstances following which population density was compared in both models (Figure 11).





(Left) figure 12: Demographic analysis diagram displaying the amount of traffic in the primary model
(Right) figure 13: Demographic analysis diagram displaying the amount of traffic in the edited model

Figures 12 and 13 show a comparison of population density in the two models. The comparison clearly indicates population traffic. This, in fact, has a significant role in facilitating passengers’ movements and in reducing time to destination. That is, when the edited plan predicts passengers’ movements, the results obtained from population traffic and the time spent by passengers are always better (Figure 12 and 13).

This can be proven by a basic understanding of the laws of physics. As stated earlier about the simulation model of pedestrians’ behavior, the model as a combination of Collective Intelligence and Route choosing models. As explained before, the agents in these models move based on the sum of vector forces applied on them. According to figure 3, walls are one of the greatest forces applied on pedestrians. These obstacles affect pedestrians in two ways:

- First is the mental effect which states that people tend to move along nearby objects, thus walls direct people.
- The other is the deviating force applied to pedestrians perpendicular to the walls which can be calculated according Newton’s law of gravity.

According to this law, all objects in the universe apply forces on one another. Therefore, when a person moves along the wall, repulsive forces are applied to them which is inversely related to the square value of human’s distance from the wall (Figure 14).

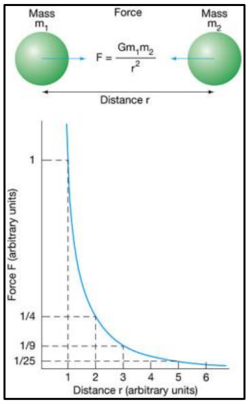


Figure 14: graph related to Newton's law of gravity (2005 Pearson Hall, Inc)

Then, the farther away the wall, the smaller the force it applies to people. Thus, one can conclude that in a continuous wall with an uncertain geometry in relation to pedestrian movement, farther points apply smaller forces and closer points apply bigger forces.

Figure 16 shows the ratio of forces applied to pedestrians when moving in a direct line along the wall from one corner. Taking the mean of the two situations on the left, there will be a third situation where the wall will be aligned with human movement. In such a situation, forces applied to the pedestrian at a given moment are equal and do not change since the wall is a direct line. Therefore, the pedestrian is minimally deviated from the direction and the wall even directs his movement (Figure 15).

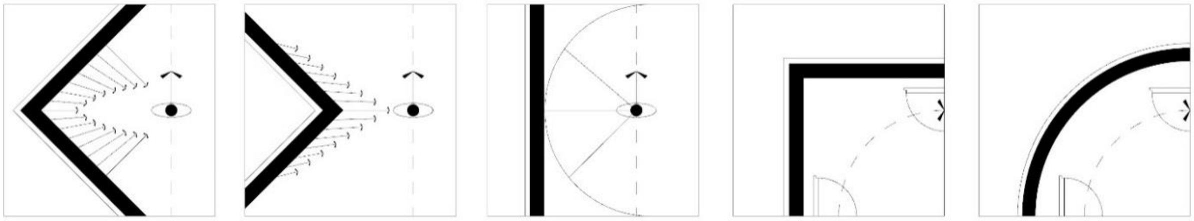


Figure 15: force from wall to human and deviation from route

4. Discussion:

Many great architects have studied dynamic architecture, Greg Lynn and Peter Eisenman to mention but a few examples. They are of the opinion in their studies that when there is motion in a given space, there will be a forming force that reforms the initial form to optimize it for the user’s life. This study was in line with their findings, with the difference that here designing is performed by a software program with proven statistical capabilities expressed in a changed form in line with motion directions of the user in terms of traffic in relation to the initial form in an optimized mode to facilitate the users’ movements. The key in this study is the comparison between the initial and the edited models. The method suggested in this study can play a significant role in designing large-scale projects such as terminals, hospitals and shopping centers so that designing together with the simulation of the users’ behaviors can give designers optimized results. Evidently, today simulation software programs are commonly used by architects, but quality of the design has been unheeded.

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