Spatial Complexity: Identifying Critical Zones in the Egyptian Underground Reciprocal Stations

Eman Abou Bakr, Noheir Elgendy

(Eman Abou Bakr, Teacher Assistant, New Cairo Academy, Cairo, Egypt, eman.aboubakr@gmail.com)
(Noheir Elgendy, Assistant Professor, Cairo University, Cairo, Egypt, noheir@gmail.com)

1 ABSTRACT

Greater Cairo, the Egyptian capital, hosts around 10 million inhabitants, in addition to 2 million commuting, 5 million of that total are daily subway users. Large subway stations are considered, nowadays, one of the most frequently used public spaces in cities nowadays. The underground reciprocal stations are quite complex, and the majority of their users, no matter how familiar they are with the building facilities, are observed to face difficulties in wayfinding behaviors. The users perceptions, in terms of spatial configuration, strongly influence the success of wayfinding, with a specific consideration to the case of illiteracy of the Egyptian users, which is estimated at 20.9%. This paper aims at providing an objective approach to validly predict wayfinding performance. It attempts to to determine the critical zones features of wayfinding and the possible ways of dealing with them to avoid adding movement patterns to the expected planned stations layout and the surrounding urban context.

Keywords: reciprocal subway stations, space syntax, wayfinding, critical zones, spatial complexity

2 INTRODUCTION

Most of the wayfinding literature focuses on the wayfinding process rather than the environment in which wayfinding takes place (Rüetschi, U. J., & Timpf, S. 2004, October), but as wayfinding is an interaction between the wayfinding and wayfinder (Allen 1999, Darken et al. 1999), to focus on the environment is essential. Following that perspective, several studies started to determine features of the environment and different that improve the wayfinding process through settings, and confirm that people's movements is affected to a remarkable extent by the spatial configuration through spatial cognition (e.g. Wiseman, 1983; Kim & Penn, 2004).

However, there is a gap to be bridged between the design process and architectural design disciplines. In the design of large-scale underground stations spaces where the level of difficulties in spatial cognition increases such as wayfinding and legibility, architects have difficulty with perceiving the outcome of a design in terms of the spatial configuration and cognition, which strongly affects the success of wayfinding, and therefore designers and operational teams tend to use signage system. In the Egyptian context that witnesses a high degree of users illiteracy, the presence of signage is an important factor but could not compensate for floor plan complexity (Raubal, M. 2001), which highlights the importance of settings in wayfinding according to its ability to deal with different culture, the level of cognition and literacy. In that context different authors have mentioned different underlying factors that influence user's judgments of complexity, those factors related to the plan configuration symmetry, the number of possible connections between parts of setting and observer view point (O'Neill, M.J.1991, Werner, S., & Long, P.2002, Le Corbusier.1931/1986).That adds to Hillier's concept of "generic function" (1996, p.258). which refers to three aspects of human occupancy of buildings that is prior to particular functional programs or activities, first, to occupy space means to be aware of its relationships to others, second, to occupy a building means to move in it, finally to move in a building it depends on being able to retain an intelligible picture of it. So, we would follow the more holistic view to understand the Egyptian context. The Egyptian underground reciprocal stations would be our selected case study and space syntax (SS) techniques would be applied to explore station settings and its implications on users perceptions and choices. We would analyse the reason why the users struggled to find their ways or tending to re-find way through surround urban context by adding more pattern of movements, wasting time and effort.

3 SCOPE AND METHODS

The research methodology can be summarized in four stages as follows; Firstly, the study of the three main underground reciprocal stations in Greater Cairo through basic architectural analysis, using j-graph analysis by Hillier. This would lead to the selection of the case study, presenting higher complexity, in terms of spatial configuration with respect to functions of spaces and user's flow. Secondly, underground network case study analysis using decision point density analysis and route mapping by Xiaoling Dai. This would be

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done in order to determine the number of directions at all decision points of the case, helping to select the studying zone depending on the higher points of directions. Then, the space syntax analysis would be followed and include Axial and VGA analysis to spot and identify the features of movement's critical zones. Thirdly, the selected case study redesign, using space syntax analysis for activation of spatial configuration. Finally, the fourth stage includes a comparison of the redesign with the current status of the case study, concentrating on the importance of the four wayfinding factors (number of turns, symmetry degree, distance to the target, the visual field) and how to control wayfinding performance, with respect to the functional relationships. This would include an identification of the critical zones and its visual field properties, which mainly affect the quality of wayfinding, and the sequential paths priorities on the multi possibilities paths as the main reason to improve user's perception and mental map. Thus, the paper concludes by providing a proposal for the design process and guidelines for underground reciprocal stations, based on the above results for station space activation.

4 BACKGROUND

The selected reciprocal stations represent the of intersection of the three lines. Attaba station combines lines 2&3, Ramsis and Tahrir stations combine lines 1&2. The three stations are located in downtown to target the most crowded contexts of greater Cairo. According to Cairo's future development prospects, the underground network will include 3 lines, and this would increase the number of reciprocal stations from 3 to 14. These new additions would highlight the importance of studying wayfinding and settings of the reciprocal stations to be able to improve pedestrians movements, fig.1.

Fig. 1 Subway current & future lines, Red circle for current reciprocal stations

5 COMPARATIVE STUDY

This section tries to elaborate the distinctive spatial features of the three reciprocal stations by comparing them through basic architectural analysis (the layout features, vertical and horizontal movements) and j-graph analysis, to provide a cross reading for the reciprocal stations as a preliminary stage to understand stations and users movements patterns.

5.1 Basic architectural analysis

The following table illustrates the different spatial configuration effect on users movements patterns as follows: Attaba station represents the simplest configuration and least number of exits. As a result of its symmetry and radiation pattern of movement, which emanates from the ticket hall, disconnecting the users movements patterns. The small space of the station and near distance between exits supports the ability of path adjustment of the urban context. In the case of Ramsis station, it represented the least symmetry in terms of configuration and path, on the other hand, it also represented the most connected case with the urban context, due to its large circular path between tickets halls and available exists. Finally, Tahrir station presented the middle situation between Ramsis and Attaba stations, having symmetry and simple configuration as Attaba, and circular path and overlapping movement patterns as Ramsis station.

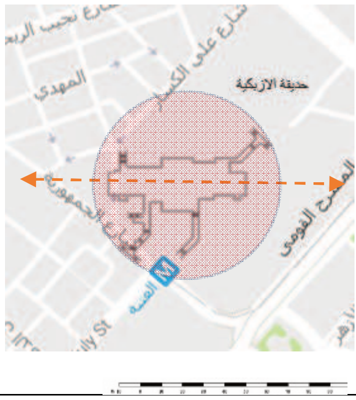
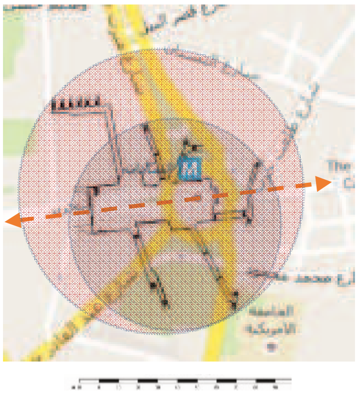
Comparison	layout	Analysis				
		Exists no			symmetry	Av. of adjustment path from urbn
		real	Op.	co.		
Ataba Station		3	4	6	High degree of symmetry on one main axis With slight variations according to the relation with urban context	25182m^2
Tahrir Sation		6	4	6	High degree of symmetry on one main axis With slight variations according to the relation with urban context.	44793m^2 after subtracting area for un working exist 33486m^2
Ramsis Station		8	7	7	Complex relation between two axes, in addition to numbers of axis revealed for the relation of urban context (low symmetry).	45117 m^2
Spatial						

Table 1. Movement pattern analysis according to urban context, Red circle represent area of adjustment path at urban context.

Comparis	Horizontal movement	analysis	Vertical movement	analysis

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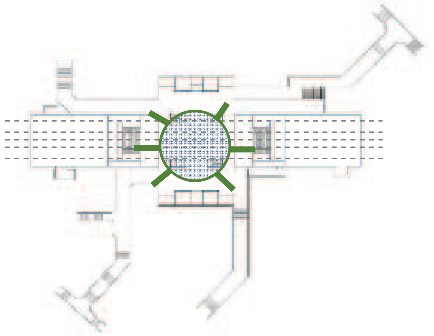
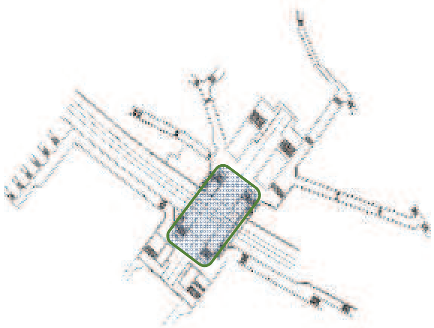
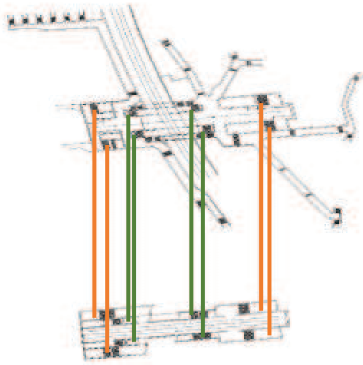
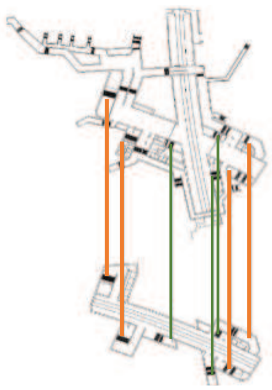
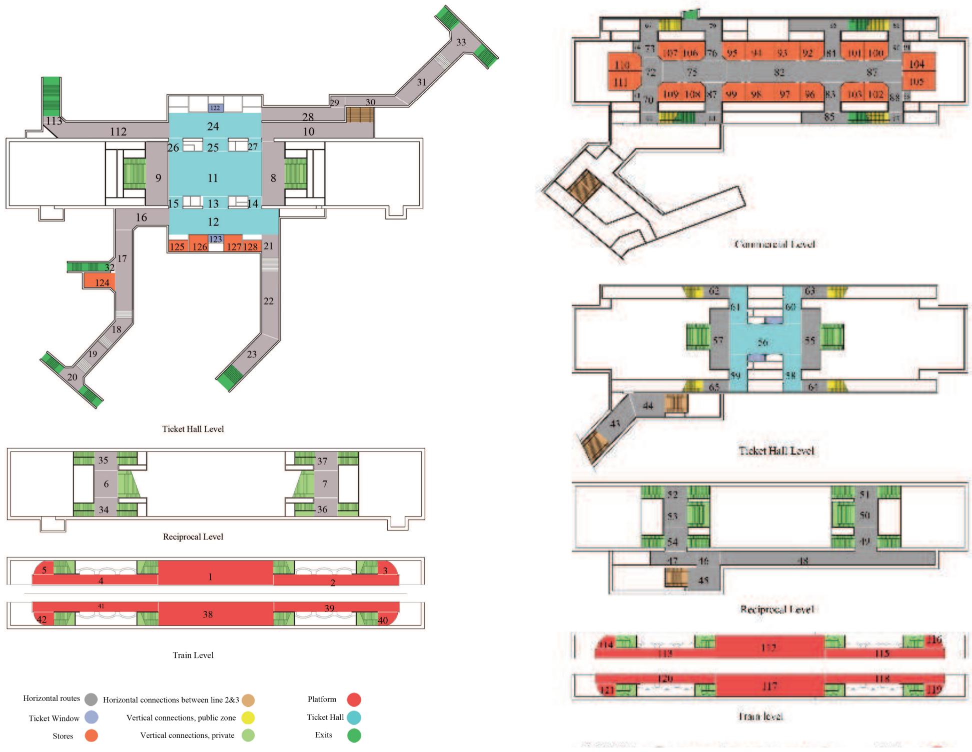
on		Movement pattern		Movement pattern
Ataba Station		Emanating from ticket hall		Separate movements with ability to connect from ticket hall(L2)
Tahrir Sation		Emanating from each ticket hall, connected together with small symmetrical circular path		Fully overlapping movement of the users
Ramsis Station		Emanating from each ticket hall, connected together with large symmetrical circular path		Fully overlapping movement of the users

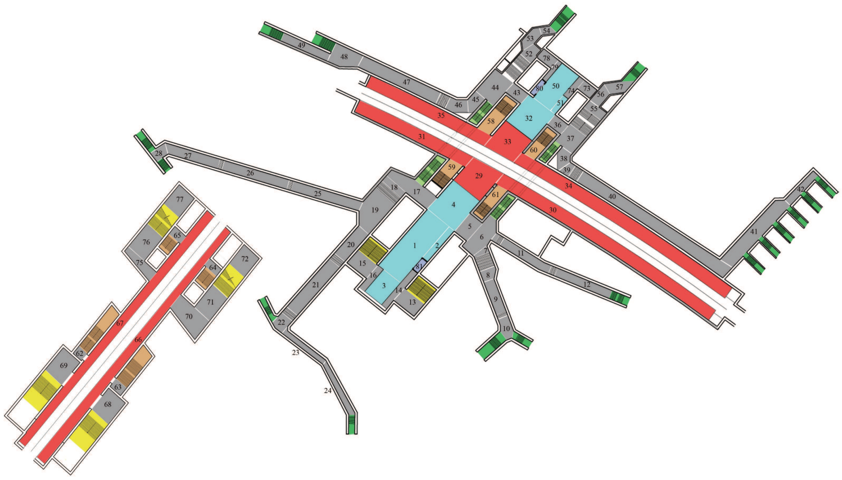
Table 2. Movement pattern analysis according to vertical and horizontal configuration. Green vertical lines for line or direction changer, Orange line for arrivals and departing users.

5.2 J-graph analysis

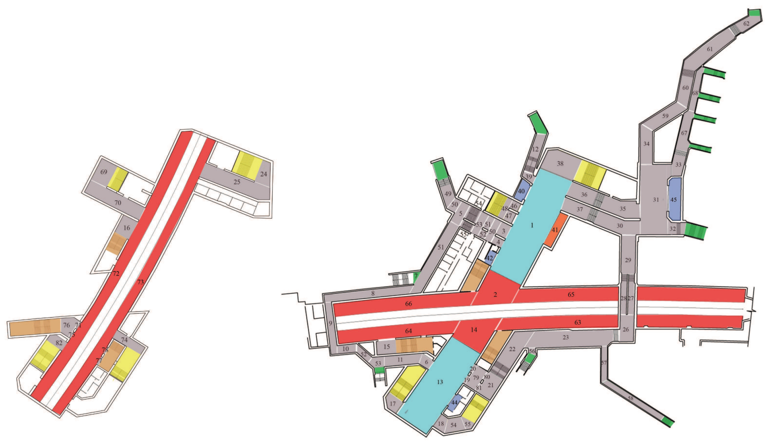
The j-graph analysis provides a clearer vision of the differences between stations (Figure 2) by determining the depth degree, spaces integration and losing way possibilities according to possible routes in each node. The three j-graphs are drawn starting from the same deepest space of the system (Tickets Hall), and in order to embed the accuracy of movement's routes with the current operating status, the closed routes nodes are all indicated by special symbols.



Attaba station



Tahris station



Ramsis station

Fig. 2: Reciprocal stations plans

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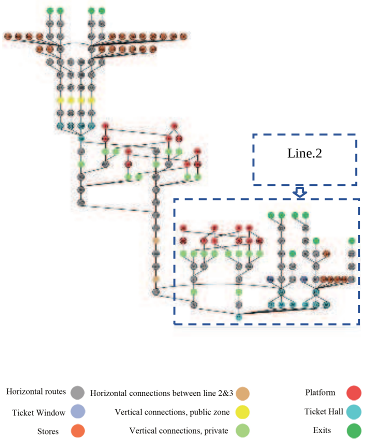
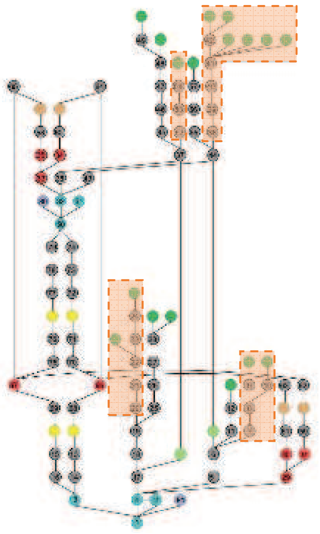
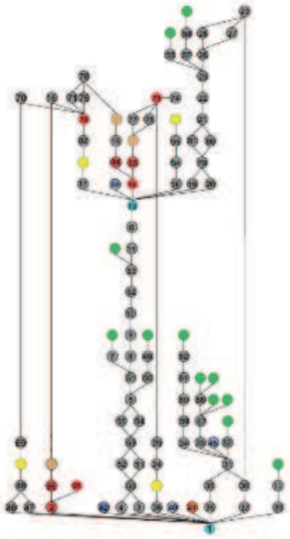
Compari-son	Ataba Station	Tahrir Sation	Ramsis Station
Analysis			
Depth & dependencies	A tree like structure shows different possibilities of routes from hall space which belongs to d-type. Long routes are an indicator of the depth degree especially for line3 users, but according to functional side this could decrease decision point and enhance user's flow. High degree of similarity leads to only 4 sets of rings, which increase mental map quality. High integrated degree for line 2 enhance movement intelligibility.	A structure combines tree and rings type. Hall space is a d-type node, in its absence the building turns into four. Closed access turned routes to mandatory ones which enhanced decisions and flow.	A structure combines tree and rings type. Hall space is a d-type node, contains numbers of overlapping movement. Low degree of similarity leads to difficulty of mental map present and remembering. Long routes with many decision points, once the users are in the route it's easy to lose your sense of direction.

Table 3. J-graph Analysis, Red rectangle represent closed exits.

The previous table shows that Attaba station represent the most popular sample of underground single stations which is characterized by the limited number of exits (not more than 4) and clarity of its configuration, which support the ease of mental map process although it contain many deep spaces as a result of long routes. In the case of Tahrir station, it shows a great similarity with Ramsis station configuration, but according to operational conditions in Tahrir, routes turned to semi mandatory as a result of closed exits with respect to low users density which supported perception quality. On the other hand, Ramsis station is somehow ‘out of control’ this reflects overlapping relations which produce overlapping routes, in addition to frequent turns and movements detour to gain low visual connection and high possibilities of direction. This all led to low quality of mental map and disability to determine the short route.

Respectively the comparative study would conclude that Ramsis station configuration could be seen as the most complex sample, focusing on the ticket hall as a study zone that belongs to d-type space according to Hillier's classification.

6 RAMSIS STATION ANALYSIS

The pervious comparative study analysis suggested that the circulation system of Ramsis station is very different from the other reciprocal stations, thus Ramsis station could be counted as the most complex case. In the following part, the quantitative analysis was then conducted to uncover critical zones and their feature that causes complexity through decision point density analysis by X Dai (2015) and space syntax technique by Hillier (2007).

6.1 Decision point density analysis

X Dai, Q Dong & J Guo (2015) have modified Both O'Neill (1991) and Peponis (1990) definition of decision point by developing the idea from Hillier's (1996) statement on a/b/c/d topological type classification. Therefore, in an "L" shaped corner, the effort for making a decision is almost nothing compared to a crossing with many directions. So, only "d" space is regarded as a decision point, where the forward route choice is more than one direction, that is to say the directions at that point is more than two. This descriptive image may be captured by a quantitative measure as the decision point density analysis. This measure should be able to tell whether there are too many decisions to be made when a user is entering a building and has a navigation task.

In the following part, the (DPD) map will be used to reveal the rates of decision points and their relationship to walking distance according to optimal route for each type of users, thus determining meeting points that have high density flow as a factor effecting perception quality, and finally ensure J-graph results to locate studying zone.

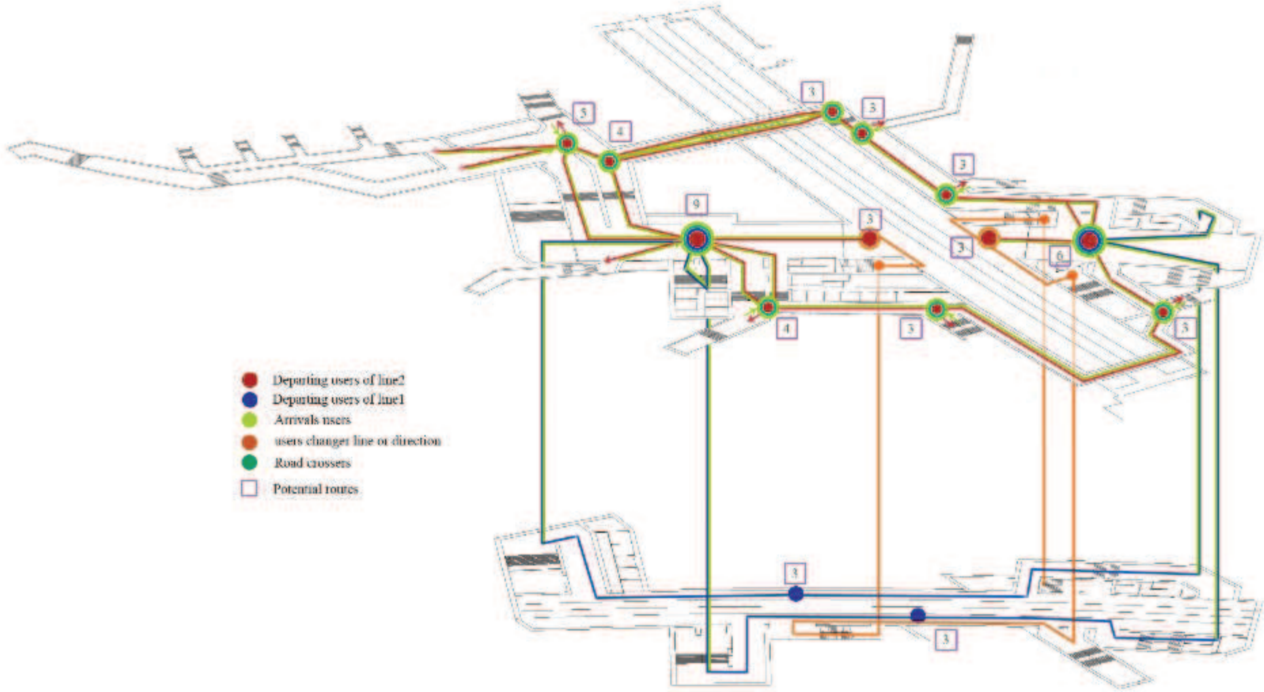


Fig. 3 Route Mapping, Decision points are noted as spots, a number is assigned to the spot represented the number of directions at this point.

High rate of decision points along the path reached 14 decisions, estimated in average as, a decision every 15 meters. The ticket hall at (El- Marj) represents the highest rate which stood 9 decisions, followed by Helwan hall at 6 decisions. After that the possibilities began to decline to 4 at two positions, but actually those positions which stood 2 decisions were raised to 4 by structure elements that opposed with function.

According to the pervious analysis, wider movements represented to users at ticket hall level, where ticket hall had the highest users density, collecting all routes and users types thus j-graph analysis result confirmed for the ticket hall classification as d type space.

6.2 Intelligibility of Ramsis station

Conroy Dalton, 2000 suggested that the correlation between some measures might describe some characteristic properties of layouts that relate to wayfinding, where Kinda Al-Sayed, 2015 clarified the intelligibility through the correlation between integration and connectivity graphs. According to Hillier (1996), intelligibility means the capacity of a single space to give an impression of the integration of the whole system, so high degree of intelligibility could ease making decisions through an unexplored environment.

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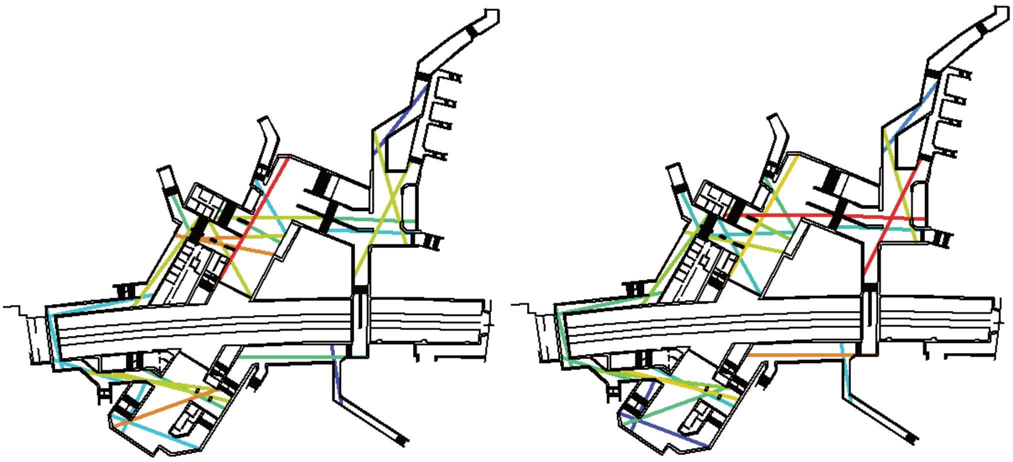

Fig. 4 Left, the axial integration HH graph. Right, the axial connectivity graph

Fig. 5 Scatter plot of the correlation between axial integration and connectivity (R^2=0.25).

According to the color coding, axial connectivity graph is the opposite side of the integration graph which represents the low value of R-square of 0.25. This signifies that it is difficult to obtain a guide to the overall system from single spaces . Thus, this building would be hard to navigate and the wayfinding task should be complicated to perform.

6.3 Determining critical spaces

The VGA analysis was brought in to provide the quantitative measures. It would give us the mean visible area in every position of the spatial system through four patterns. Starting with VGA integration would clear the locations where people tend and pause to evaluate their navigation, visual control to locate places where route choice decisions need to be taken, the visual clustering coefficient is indicative to how much one loses in terms of visual information when moving from one location to another, Finally, the through vision graph clarifies the longer lines of vision with higher values. The data map is drawn in the way that every door and window is open to the line of sight; the grid in depthmapX program is set as 500mm*500mm.

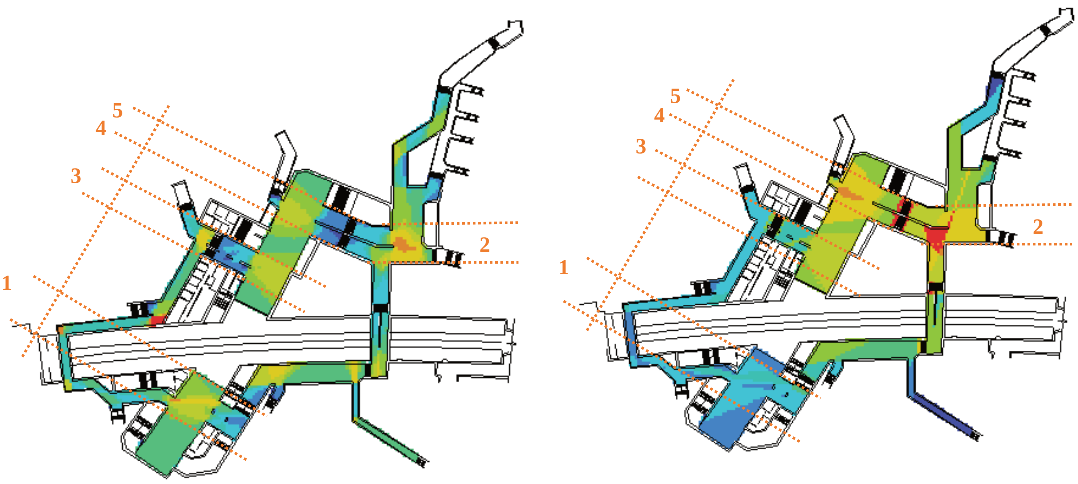

Fig. 6 Left, the VGA Visual control. Right, the VGA integration HH graph

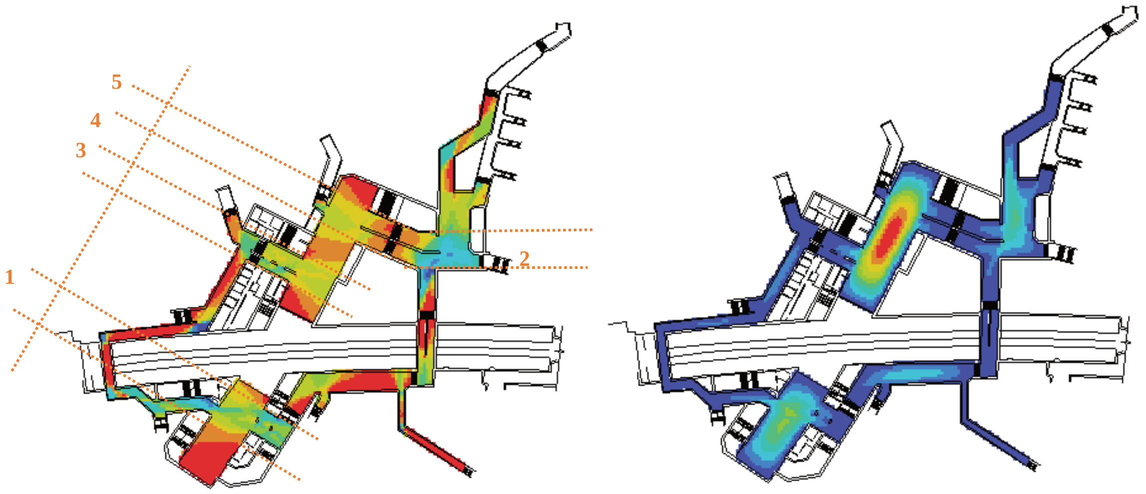

Fig. 7 Left, the VGA clustering coefficient. Right, the VGA through vision

Following depthampX's color scheme, graphs located 5 main critical zones where people tend to pause whether to evaluate their progress, take route choice decision or lose visual information. Additionally, the last graph (through vision) highlights that the tickets halls record longer lines of vision with higher values which means the ease access of arriving users and many challenges for departing users. Consequently, the characteristics of those poses would be studied to determine abilities of improvements depending on the visual control graph.

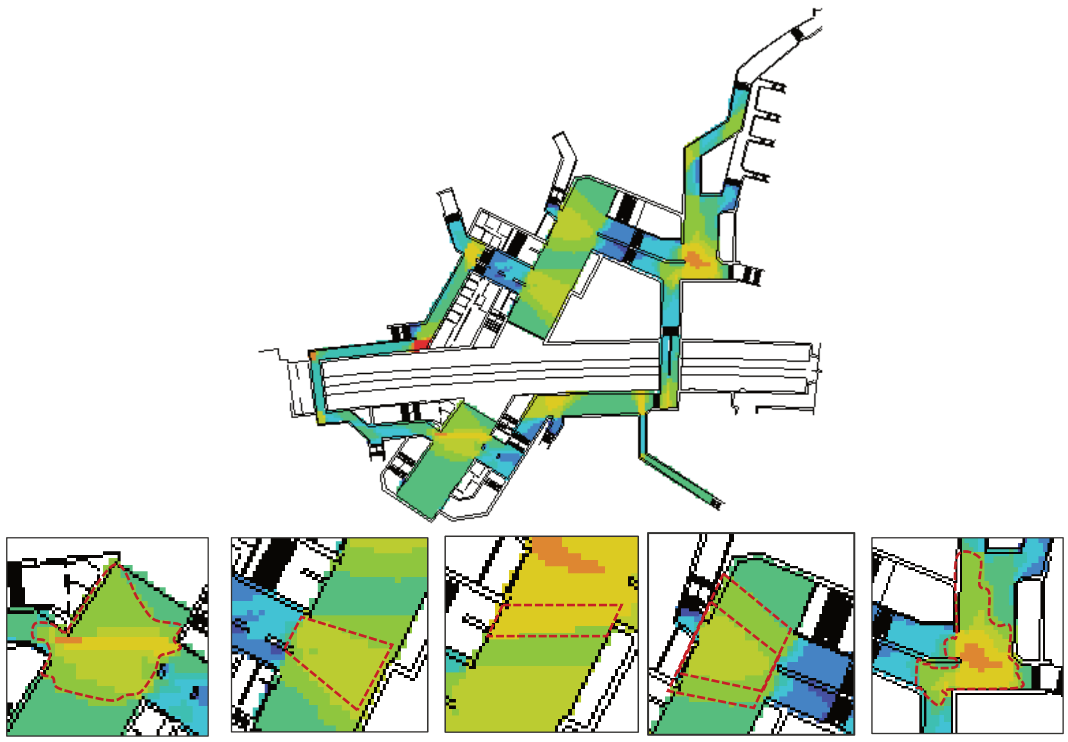

Fig. 8 Movements pattern and critical pauses characteristics

6.4 Features of critical space

According to studying critical zone features it was clear that:

- Structural system location feeling up paths and decisions, plus its impact on the percentage of vision as shown in (pause 3,4) thus confirming the Prejudice to the objective on increased path width to withstand flow.
- It is preferred to locate structural elements in the middle of paths due to the relation between visual field and path width (pause 1,2,5).

- The involvement of movements' routes in the same visual field would ensure wayfinding ease (pause 1) and also could explain the low overcrowding rate in Helwan hall.
- By following directions of movements flow, in Helwan ticket hall, movement of users of line 1, 2 converge in the middle of the hall to decide destination directions whether left or right without overlapping. One the other hand El-Marg Hall has a different kind of movement scenario, users flow of both lines1,2 converge in three sequenced positions, in additions to their opposite directions. This would conclude that Helwan hall direct movement better than El Marj Hall.

7 STATION REMODELED SCENARIO

In the analysis above, the spatial system of Ramsis station has been compared with other Egyptian reciprocal stations as a benchmark. A detailed understanding of how to construct an extremely complicated circulation system is then achieved. It is mainly about how you design the horizontal routes leading to vertical connections between ticket hall and urban context.

By creating a series of redevelopment actions, we can benefit from Helwan hall by reducing the number of critical pauses, possible routes, and increasing similarity degree and width of the visual field to obtain all routes. On the other hand, reducing number of turns by straightening station routes to have a continuing line of sight instead of abrupt turns. By a simple visual inspection, we can realise that the new version is a much simpler structure than the original one even with maintaining all functional spaces fig.9.

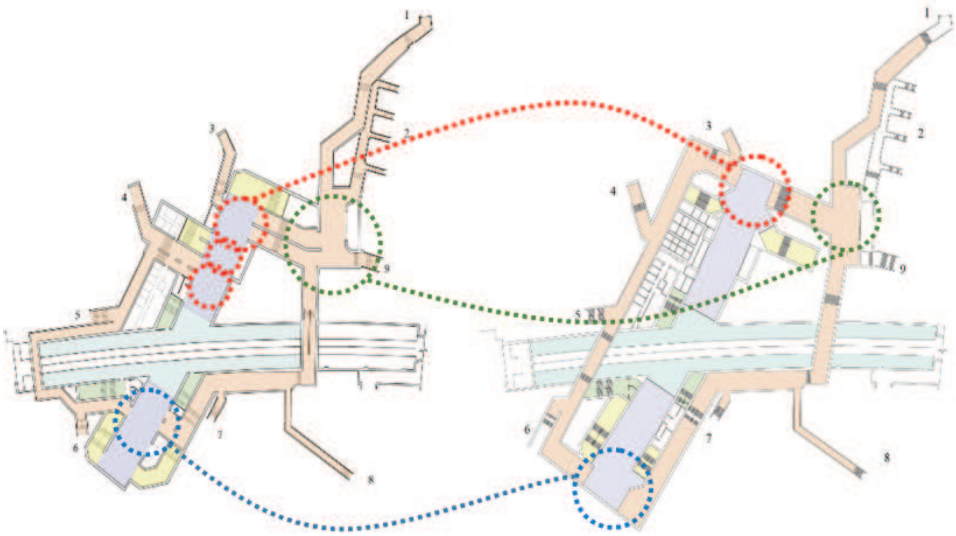

Fig. 9 Left, the original design. Right, the remodeled scenario.

7.1 Remodeled scenario analysis

In the following text we will follow the same steps of the original version analysis, starting with determining intelligibility degree through axial analysis then turning to VGA analysis, but in this scenario it will be sufficient to focus on Visual control graph helping to study then new characteristics.

7.2 Intelligibility of Ramsis station

As shown of the following graph there is a high degree of similarity between the integration and connectivity, which affected the value of R-square that represents the intelligibility of the system to be fairly high, with an R square of 0.82, which means that from single spaces it is possible to easily obtain a guide to the overall system. This could be interpreted as the building is easy to navigate and the wayfinding task should be easy to perform.

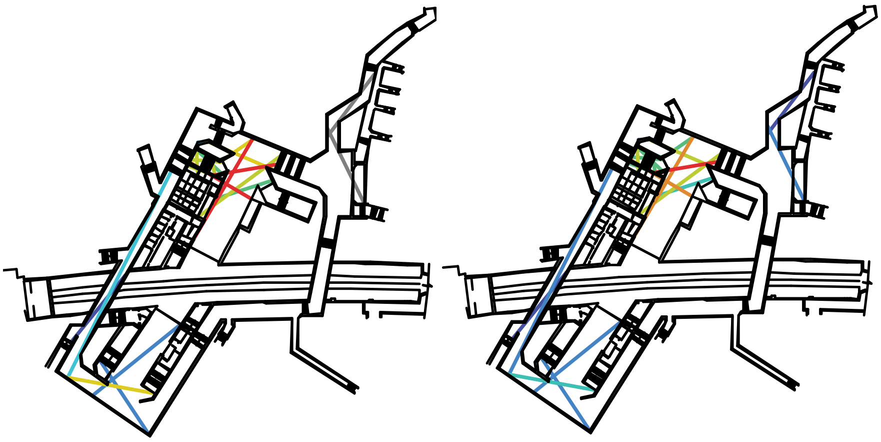

Fig. 10 Left, the axial integration HH graph. Right, the axial connectivity graph

Fig. 11 Scatter plot of the correlation between axial integration and connectivity (R^2=0.82).

7.3 Characteristics of remodeled scenario

VGA visual control graph could clarify the reasons for the high degree of intelligibility fig.12. By examining the visibility distributing in the new scenarios, a trend is discovered - the visibility of the three main critical zones improved dramatically along with increasing the width of the visual field, similarity degree and the straightening of the plan which enhanced visual access and ease of wayfinding. Hence, by following the users flow, it was clear that users converge at one pause for each hall with no overlapping or opposite flow of line 2 users, in addition to separating passenger of the occasional movement of the route crossers which enhances reducing overcrowding flow capacities, and therefore, it is transformed into a normal building which people can understand and memorize, that is to say, gains a legible spatial system.

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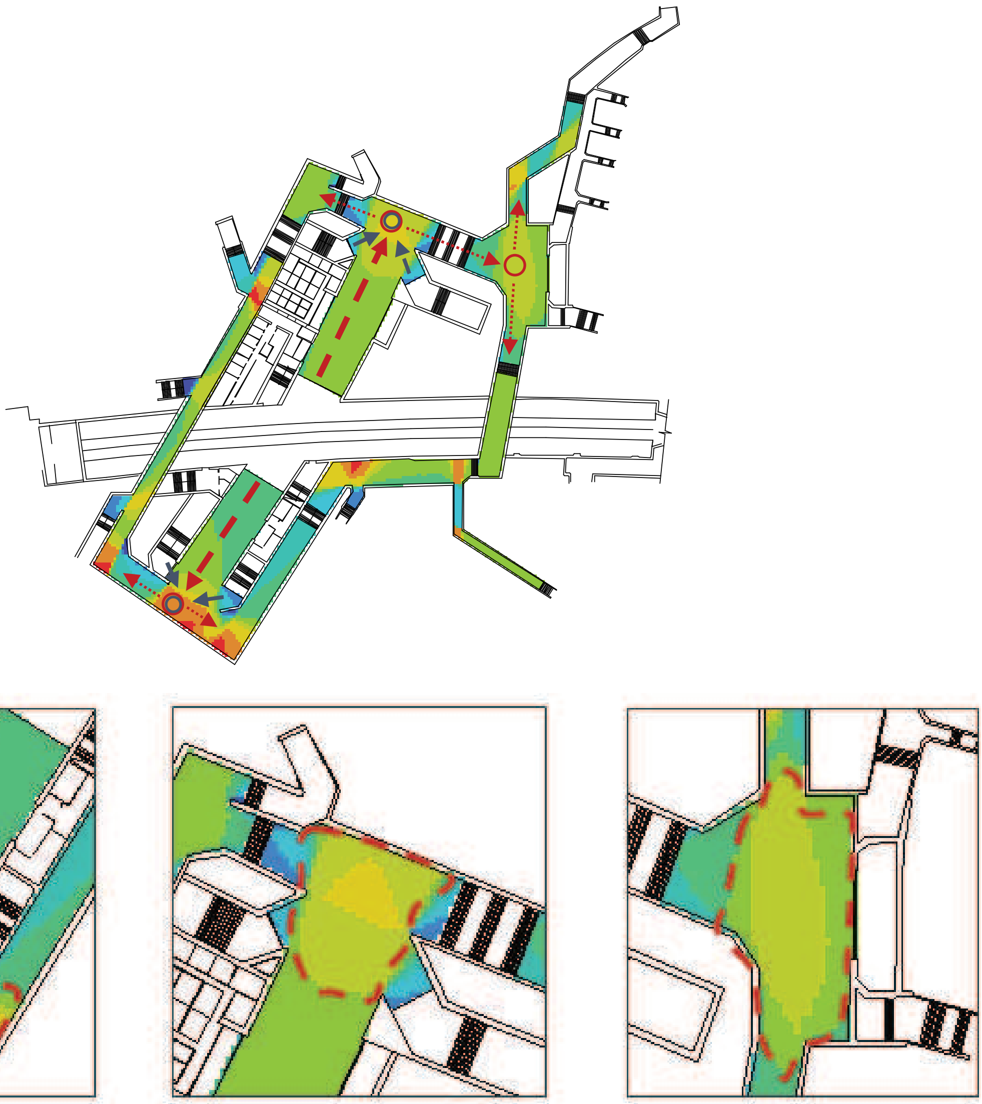

Fig. 12 Movements pattern and critical pauses characteristics

8 CONCLUSION AND DISCUSSION

In this study, J-Graph was utilized to analyse the spatial configuration of three large-scale underground reciprocal stations in greater Cairo: Attaba station, Tahrir and Ramsis stations. The operational design of these stations were analyzed based on interviews with the operational office in charge of each facility. Ramsis station was found to have the lowest integration, and its layout and circulation were designed from the viewpoint of spatial configuration. The degree of wayfinding quality was analyzed through space syntax technique. The following are design guidelines for invigorating underground reciprocal stations.

- Design process

This paper gives a thorough explanation for the production of spatial complexity for a special building. This effort is in line with many other studies aiming at providing an objective, quantitative approach to validly predicting wayfinding performance during the early planning stages of a building (Werner & Schindler, 2004). First of all, there is a need for an integrated design process which takes into account the quantification of the diverse passengers experiencess and their perception as the center of planning indoor pedestrian. Thus, the complexity model of a large-scale underground reciprocal stations appears to be closely related to the production of critical zones which could identify as pauses that discontinues the sequence of movements, which is normally present, in case of increased possibilities paths, and creating difficulties of mental map representation.

- Circulation plan

In a large-scale underground space, a circulation system should be formed from the user perspective to improve wayfinding. First, users movements could be controlled and directed through decreasing critical zones with respect to its characteristics of wide visual field. Second, confirming the importance of increasing visual access and symmetry degree, and decreasing number of turns and distance to the target. Third, as proposed by this study two main types of paths could be identified, the sequential paths which could guide users flow, and multi possibilities paths which enhance space interactively. Thus, in such a functional buildings sequential paths have the priority on the multi possibilities paths.

- Spatial configuration plan

To activate a large scale space, a main axis of activation is required. It is also important to form a main core to concentrate the flow of floating users. First, Consensus value of axial integration and connectivity is the main anchor to achieve a clear suitable configuration. Second, structure elements should be designed with respect to the spatial configuration to avoid production of additional paths affecting users flow, if necessary to place an element in a route. It's also preferred to be set in the middle, as a way to not affect visual field. Third, the spatial configuration of routes and its role in directing movements affect users flow more than caring about routes width. Fourth, avoiding overlapping passenger flow could be reached without affecting stations functional relationships. Finally, the singage system is not always the suitable solution to enhance wayfinding especially in case of users illiteracy, thus the importance of configuration reveal to have the priority.

- Site plan

Well connecting of urban context with indoor environments is a challenge to balance ease access of arriving and out departing users, as proposed. Providing various access is not the anchor of balance especially for departing, but it's mainly depending on the ease of reaching destinations by confirming the importance of increasing visual access and symmetry degree, and decreasing number of turns and distance to the target. Therefore, the designers may be able to cope with the spatial complexity with higher controllability by these efforts that contributes improving the efficiency of pedestrians flow. The enhancement of the indoor environment which affects the densities of movement on the urban scale, thus, avoiding adding more movements patterns to the expected planning over these stations.

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