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Environmental and energy performances optimization of a neighborhood in Tehran, via IMM® methodology

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Abstract*— Due to the fact that urbanization, as a dominating global development process, has been reached a dramatic measure, series of questions have been arisen about its environmental impacts. The urbanization soaring rate, which its impetus has been provided by unprecedented population growth, has had serious of direct consequences such as inconceivable and unbalanced consumption of natural resources and global warming rate acceleration. In such a dramatic circumstances how urban planning and governance could contribute to climate mitigation and emissions reduction? How urban vulnerability and urban resilience should be managed? Again, how urban transformation should be propelled in order to address these challenges. To demonstrate that sustainability and environmental efficiency is an urban issue this paper shows the application of IMM® (Integrated Modification Methodology) on Shahrak-e Golestan, a newly settled neighborhood located in District 22 of Tehran. Forming this neighborhood for accommodating a part of city's growing population is a well representative of the common developing manners in Tehran, therefore the transformed model resulted from the study could be considered as a model for further developments of the other districts.

***Index Terms*— Complex Adaptive System, Environment, Integrated Modification Methodology, Sustainable urban design.**

I. INTRODUCTION

The main goal of this article is to demonstrate the role that IMM® methodology can play to implement the environmental performances of a city regarded as a Complex Adaptive System (CAS) [1].

A Complex System performs by integration of the all the constituents as a whole and minor change could alter the course of the entire system utterly. So in accordance with this methodology the whole CAS can be transformed acting locally on selected "critical points" able to start structural changes of the System [2]. The chaotic behavior of the CAS creates an inchoate state, from which that city starts its transformation. Iran's capital acts through the definition of a specific local intervention areas, and this marks the start of a chain reaction able to transform the structure of the CAS. Actually the system's components are strongly connected, almost to all of the other components, so that simple local changes in their structures can influence the subsystems and the architecture of the ligands, transforming the structure of the System. Hence investigate the physical arrangement of the system through a dismantling process become essential. The CAS is firstly dismantled into four main subsystems, namely: Volume, Void, Transportation, and Function, then locally trasformed and finally retrofitted and optimized. Based on individual behavior of the urban subsystems (Horizontal behavior), their mutual interaction (Vertical behavior), and energy indices, three sets of indicators are introduced and a Catalyst of transformation is selected from the mentioned subsystems [3]. The horizontal modification in the catalyst triggers the transformation. The first step of third phase, Intervention and Desing, horizontal and vertical modifications are persued.

At the last phase, Retrofitting process evaluates the CAS transformation (by means of the same indicators used at the first phase) and then a further Optimization process is the concluding but still provisional CAS operation, that configures the System in a new provisional and instable state. Hence a new threshold of an endless transformation process emerges.

II. THE INTEGRATED MODIFICATION METHODOLOGY (IMM®). A PHASING PROCESS

The IMM® is a multi-stage, iterative process, applied to urban complex systems, for improving its environmental performances, which comprises different but full integrated phases. The methodology is based on a multi-stage

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process composed by different but full integrated four phases, respectively:

- Phase 1. Investigation/Analysis
- Phase 3. Modification, called First level of Superimposition (F.L.S.),
- Phase 4. Optimisation Phase, named Second Level of Superimposition (S.L.S.).

The following table shows the articulation of the interconnected phases with their each single purpose as well as how to apply them.

1	1a	Horizontal Investigation	Dismantling the system to investigate	Investigation/ Analysis	Observation & Measurement
	1b	Vertical investigation	The actual value of Key Categories		
	1c	Actual performance of the system based on 10 indicators		Data Collection	
2	2a	Detection of the transformation's *Catalyst*		Assumption and Interpretation/ Hypothesis	Formulation
	2b	Assumption of the 10 IMM® Ordering principles		Assumption	
3	3a	Horizontal Modification	The *catalyst* drives the local transformation; changing the structure of the layers/Ligands	Modification	Intervention & Design
	3b	Vertical Modification	Local transformation acts globally, changing the entire system's configuration		
4	4a	Performance of the new CAS based on 10 indicators		Contextual Evaluation	Retrofitting
	4b	Local modification/optimization of new CAS physical components or subsystems, such as: Voids, Built spaces, Functions, and Transportations.		Local Design	Optimization
	4c	Universal indicators		Comparison	

Table 1: Different phases of the IMM®

III. TEHERAN DEMONSTRATIVE PRACTICE

Tehran, Iran's capital is one of the biggest world's agglomeration with more than 12 millions inhabitants and a population growing rate of 2,6% per year [4]. The annual survey by the Economist Intelligence Union of the world's 140 major metropolises and least liveable cities in 2013 ranked the Iran's capital at the number 131, as one of the less liveable and most polluted cities in the world.

The first place in energy intensity, the second place in gasoline balance requirement, the third in domestic energy consumption as well as the second highest energy index in the world countries, simply illustrate the low environmental performances of this megalopolis, and makes the city as one of the most formidable antagonists in climate mitigation and environmental quality of the region as well.

Hence the Iran's capital low environmental performances together with its rapid unintentional development, makes pressing the needs to activate sustainable actions. But it makes this megacity an extraordinary study case to test IMM® methodology. The research selected the Shahrak-e Golestan neighborhood, located in 22nd district, in the northwest part of the city due to its own various characteristics, such as common building typologies and its morphology; moreover, the spatial analysis has revealed that the chosen district is expressing one of the highest urban growth and densification rate in respect to the other Tehran's districts [5].

The research wished demonstrate how the transformation of an intermediate scale could play role of a catalyst to initiate a chain reaction, able to transforms the entire structure of the city seen as a CAS [6].

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IV. IMM® APPLIED TO SHAHRAK-E GOLESTAN NEIGHBOURHOOD: INVESTIGATION PHASE

A. Horizontal Investigation of the Shahrak-e Golestan neighborhood

As the first step of the Investigation phase, the role of the Horizontal Investigation is to provide individual visions of the urban subsystems by disassembling the CAS into its subsystems (Volume, Void, Function, and Transportation). In other words, in this phase the CAS is being investigated through a set of categories and indicators in order to understand the architecture the CAS configuration (morphology) as well as the socio-cultural space (Typology) and therefore the artificiality of the space (Technology) [7]. The purpose of developing District 22 of Tehran was to meet partially the urgent need of providing residential spaces for the citizens. This background has direct effects on the morphological [8], typological, and technological aspects of the whole region and also, on Shahrak-e Golestan as a young neighborhood. Due to its greed-based design with standardized blocks shapes and rather uniform height of the buildings (three story buildings), the volume layer is almost similar all over the site. The urban voids in this neighborhood are limited to uniform closed yards of the residential buildings and a low number of green areas, which are mostly undefined in function. For the under development context of the region, the site is empty from some of the vital urban activities and the existing functions are distributed in a dispersed way. The main activity center of Tehran is remote from Shahrak-e Golestan, and there is no well-organized public transportation connection to it. This gives a rather suburban characteristic to the neighborhood and makes a car-depended transportation layer there. Furthermore, lack of well-circulated inner public transportation provides nothing but a poor internal connectivity. In the Horizontal Investigation phase, a try of translating the situation explained above into the numbers has been carried out, and in order to do that some simple formulas has been used. The table below shows the suggested procedure of system dismantling, and the actual values resulted from the related formula for investigating every single layer.

Layer	Description	Formula	Value
Volume	Built volume density, Dwelling density, Human density	$Vl = V_{built} / Area$	3.60
Void	Open space/area	$Vd = V_{open} / Area$	1.86
Function	Job density, Number of legal entities in the intervention area	$Fn = J_{number} / Area$	2E-4
Transportation	Number of carried out urban trips (daily)	Ntr	57,178

Table 2 Procedure for the Shahrak-e Golestan system's dismantling.

B. Vertical Investigation of the Shahrak-e Golestan neighborhood

The second step of the Investigation phase, named Vertical investigation is a survey of the comprehensive configuration of the CAS. Main goal of this phase is to understand the architecture of the ligands and the interrelation of the system components as well as to evaluate the actual performance of the CAS (urban context at present state) by utilizing selected KCs and Indicators. In this phase the correlations between the different subsystems are described by the following key categories: Porosity, Proximity, Diversity, Interface, Accessibility and Efficiency. The KC's have been investigated as followos:

- Porosity has been determined thanks to the built up density. This indicator is easily understandable, and is directly related to the porosity's component layers (volume and void). The majority of built up spaces in Shahrak-e Golestan belongs to residential section. Typical residential buildings here are three story buildings in which 40% of their occupied area is private yards (considered as urban void) [9].

- Proximity is related to the number of functions, which are accessible in a walkable distance. [10]. It could be evaluated by considering one particular function as the center of a walkable circle, counting the other functions and repeating this process for the other rest of the function. The mean number of functions in walkable distances is presented as Proximity's indicator. In Shahrak-e Golestan, because of the uneven dispersal pattern of functions, it has been decided that the standard deviation also be indicated alongside the mean number. Here, a low mean number of functions with a rather little standard deviation demonstrate that not only the overall proximity is low but also there are no specific functional centers in that context. For its under development situation, some vast areas of Shahrak-e Golestan, like its western part, are almost empty from functions, and because of its monotonous context, urban activities are limited to small units distributed in an unorganized way all over the area. It is difficult to find an

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axis or a center of functional concentration, however surrounding area of boulevard Kaj in the center seems to be more proximate than the rest of areas. The numbers of functions in walkable areas fluctuate between 2 (in various areas) and 10 (in center).

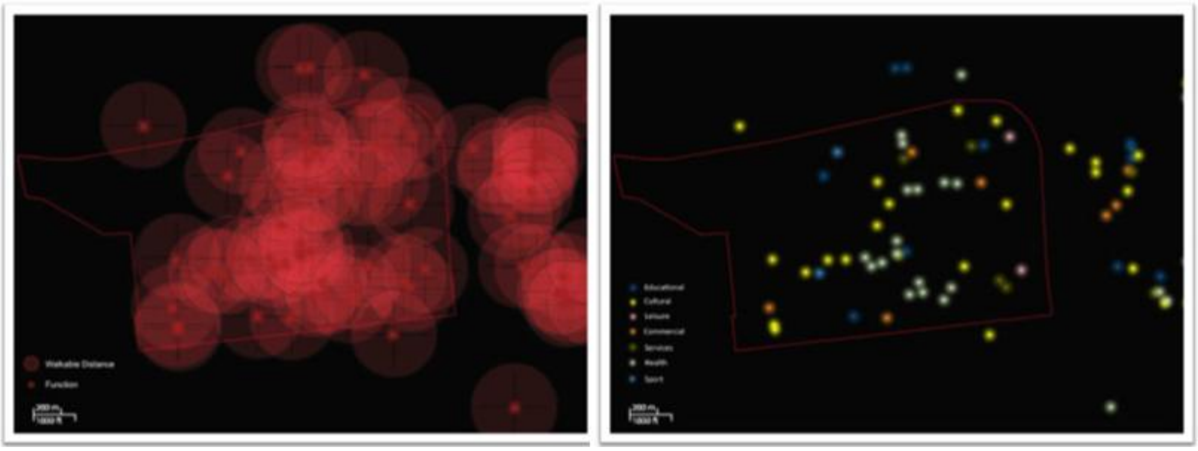

Fig. 1 Left: Proximity in Shahrak-e Golestan, as walkable distance has been considered a radius of 250m; Right: Diversity of the area according to the service types and to the quality of services

- Diversity is expected to show the level of probability of different functions in predetermined area. Diversity is directly related to the quantity and the typology of functions, and naturally, different interpretations of typology assign different meanings to this KC. For calculating the diversity a modified Simpson index [11] is hired here. For achieving a better answer, calculation of the modified Simpson index could be repeated for various types of categories. One alternative way to categorizing the functions could be regarded to the quality that they add to city. In this way, necessary activities like educational and job providing functions can be classified in one group, and optional activities like cafes, restaurants and leisure activities come together in another group. The pattern of assembling necessary and optional activities around each other shows the level of activity and traces how lives the area is, and the result of Simpson index here, describes the Diversity from that point of view. Other systematic, cultural and contextual types of categories can be added, and with analyzing and comparing the result of calculation for all of them the vision of Diversity will be clear and clearer.

The formula for calculating the Diversity (Key category) is based:

$$D_1 = \frac{C}{C-1}\left[1 - \sum_{i=1}^{C}\left(\frac{n_i}{N}\right)^2\right]$$

D1: Modified Simpson Index
C: Number of Categories
n: Number of Functions in Each Particular Category
N: Total Number of Functions

Functions are grouped in two typologies from two different points of view, which were mentioned above: urban key functions, and quality. In urban key function typology, functions are simply categorized according to their types of service (commercial, educational, services etc.). On the other hand, the quality typology is a little complicated. It consists of necessary and optional activities, and necessary activities themselves, are divided into necessary functions which are regularly must be done (e.g. school and sports activities), and occasional activities which are also necessary (e.g. banking and activities related to health care). The existence of a suitable number of optional activities alongside the necessary ones would mingle the social life and raise the quality of public spaces. Considering the largeness of the area, the number of existing functions is extremely low, and in this situation of course the concept of Diversity is affected highly by the matter of quantity. Through this overall weakness there are some realms which even suffer more: whilst there is no data on existence of show theatres, music halls, live public spaces and places for any other interactive cultural activities, the cultural and leisure activities are limited only to a low number of restaurant, libraries and mosques. This brings a very poor quality of the optional activities in the site and consequently makes a monotonous atmosphere. In the service section also, the low quantity of related functions causes a high level of dependency to the other parts of Tehran.

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Function	Service Category	Quality Category	Number
Shopping Center	Commercial	Necessary Occasional	4
Bank	Services	Necessary Occasional	4
Post Office	Services	Necessary Occasional	0
Police Office	Services	Necessary Occasional	1
Hospital	Health Care	Necessary Occasional	0
Clinic	Health Care	Necessary Occasional	9
Pharmacy	Health Care	Necessary Occasional	7
School	Educational	Necessary Regular	4
Library	Cultural	Optional	2
Restaurant	Leisure	Optional	2
Gym	Sport	Necessary Regular	2
Mosque	Cultural	Optional	11

Table 3. Existing function and their categories in each typology

The educational and sport activities are experiencing the same weakness, and the low number of job producing function gives the feeling of just a large dormitory to the employed residents.

The modified Simpson index for the both typologies is indicated below:

D1 (S) = 0.78

D1 (Q) = 0.59

Regardless of overall low quantity of functions, the calculation suggests that the area is less diverse in urban quality. The main reason for this result is the lack of appropriate number of optional activities in comparison to the other functions existing in other categories.

- Interface roots the interaction of void and transportation layers [12]. It is directly involved in movability between building blocks, and therefore, its index is expected to address the level of movability. Here, the effective voids are streets, and they could be interpreted as the veins, which are hosting the pedestrian and car, free flow. So the indicator of Interface must evaluate the quality of this flow. An acceptable method for evaluating the interface could be calculating the Mean Depth for the street network. The depth of a unit space is the number of units that a trip-maker on average needs to cross to reach all other units in a system. The value of specific depth denotes the number of units the trip-maker needs to cross to reach all units of that depth. Using this process of quantification of unit connections determines how one unit space (urban void) is connected to all the others.

$$MD \quad \frac{\sum d.n}{k \quad 1}$$

D: Mean Depth[i]

d: Depth

n: number of unit spaces at a specific depth

k: total unit spaces that comprise the system

- Accessibility is related to the ease of reaching to destinations and it is directly depended on time factor [13]. The value of accessibility is affected by transportation, technology and streets network's quality as well as the quantity of desirable destinations. The indicator of Accessibility should build a symbiotic relationship between all these features. Therefore the time factor (which is related to available technology's types) and number of destination should be highlighted in the formula. In IMM®, accessibility is defined as the number of jobs reachable in 20 minutes using public transportation. Considering the structure of public transportation nodes, average velocity and the time intervals between arrival of the vehicles the largest area in which every point is accessible to all others within in 20 minutes could be selected, and it will be called the Accessibility Core hereafter. Here the formula for calculating the accessibility is introduced as:

$$Acc \quad N_j \frac{A_c}{A_t}$$

Nj: number of available jobs in accessible core

Ac: area of accessible core

At: total area under study

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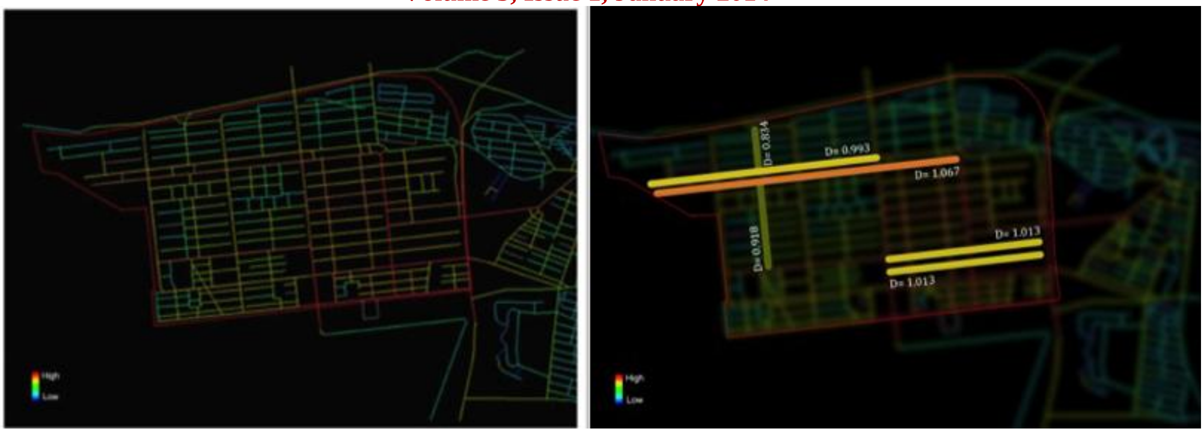

Fig. 2 Interface; Here the result of Mean Depth analysis in Shahrak-e Golestan. The warmer the color indicates the higher of mean depth for the link: (the analysis is carried out using the software "Dephtmap" developed by Space Syntax team in University College London).

In this case study the only available technology is urban bus. The accessibility core is calculated based on the average velocity of buses (17 km/h) and their arrival time intervals (10 minutes for each station). Around each node a radius of 150m of walkability is considered, and the geometric constrains gives the final shape to the accessibility area. The area of accessible core calculated as 1,539,527 m, whilst the total area of the site is 4,853,549 m. The total job numbers in Shahrak-e Golestan is estimated to be 620, and it is expected that 358 of them are located in the accessible core. So the accessibility in this area calculated as:
Acc = 358*(1,539,527/4,853,549) = 113.56

- Efficiency is directly depended on entire urban transportation's system and it could be evaluated by a classical ratio between supply and demands in the public transportation sector [14].

$$E_f = \frac{N_p}{N_t}$$

Np: Number of trips in public transportation
Nt: Total number of trips

Indeed, the public transportation is extremely poor in Shahrak-e Golestan. It is limited merely to a little number of buses and a weak network. Moreover, its location made this area highly depended on motorized transportation and private cars. In this situation there is no expectation of a high level of efficiency in this context. The estimated values of public and private transportation and the calculation of efficiency are brought below:
Np = 1,715 (Daily)
Nt = 55,468 (Daily)
Ef = 0.03

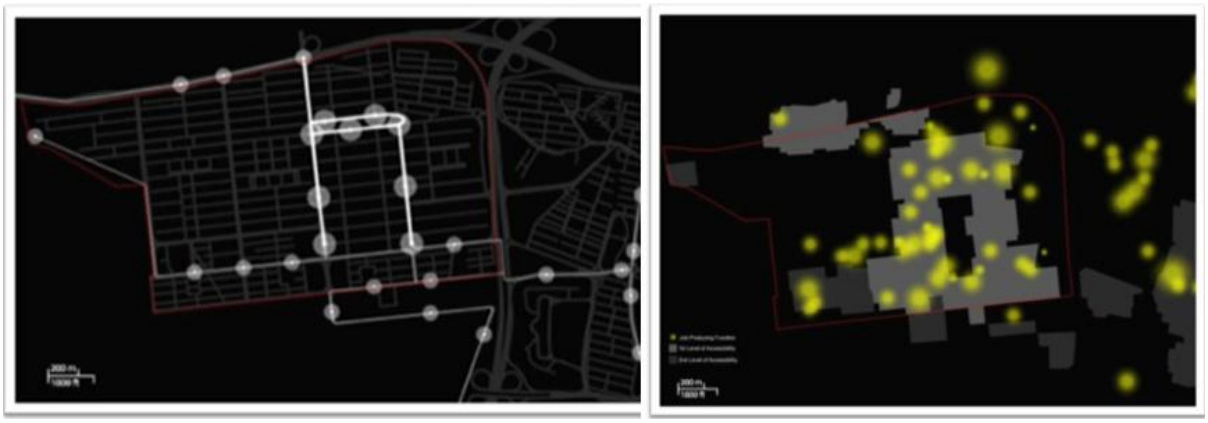

Fig.3 Left: Efficiency map; Right Accessibility map of the area.

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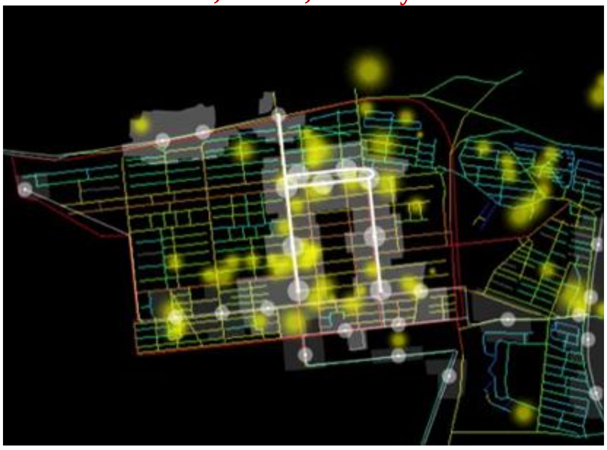

Fig.4 Vertical analysis related to the Mentioned key Categories. The image highlights the weakness of the western part of the site in terms of Accessibility and Efficiency.

The Vertical investigation investigated the architecture of the links, showing how the system's components (Voids, Built spaces, Functions, Transportations) are interrelated between them. The following table describes the characteristics and performance of the existing CAS trough the analysis of the architecture of the subsystems correlation.

KC	Indicator	Value
Porosity	Built Density	1.2
Proximity	Mean Number	5.41
	Standard Deviation	2.28
Diversity	Simpson Index (Services)	0.78
	Simpson Index (Quality)	0.59
Interface	Mean Depth	0.973
Accessibility	Number of jobs accessible in 20min	114
Efficiency	Public transportation tips/Total Trips	0.03

Table 4. Vertical Investigation. The first level of superimposition (FLS) creates the measurable KCs.

C. Actual Environmental performances of the Shahrak-e Golestan neighbourhood: Data Collection

In this step, 10 Indicators has been used for evaluate the actual environmental characteristic and performances [15] of the actual neighborhood seen as a CAS. The same indicators will be used in the Retrofitting process, which is necessary for the final evaluation of the system performance after the transformation design process. It is important to emphasize that the 10 Indicators are also connected with a series of design principles, named DOP (Design Ordering Principles), tools used to arrange later the structure of the CAS. They are respectively.

Ground Use	Urban Built Density	∑Floor/Ground level Surface	1.20
	Compactness Factor	C = Surface/ (Volume) ^ (2/3)	64.12
Energy	Gas Consumption/Capita	m^3	3,230
	Electricity Consumption/Capita	KWh/Year per Capita	655
Walkabilty	KF in walkable distance	Average Number	5.41
	Car-free Streets	Km	-
Use of Space	Residents/Activities	C = residents/Activities	1,191.30
Open Spaces	Ratio of Green/Open Spaces	T = T(green)/T(total)	0.10

	Parks/Hectare	N/Ha	0.01
	Paved Public Spaces	N & Ha	-
Transportation	Private Transp. Energy use/Person	Petrol Consumption/Capita (L)	617
	Public Transportation Boarding	Number per Year/Person	0.003
	Length of Biking Roads	Km per Capita	-
Mobility Interchange	Kinds of Public Tr.	Number of Systems	1 (Bus)
	Number of Parking	N	-
	Number of Interchange Hubs	N	-
Food	Urban Farm Production	Kg/Capita	-
	Plots for Cultivation	Ha	-

Table 5. Indicators with their formula show the actual environmental performances of the Shahrak-e Golestan neighborhood. The same indicators will be used in the CAS Retrofitting process necessary for the final evaluation of the system performance, after the transformation design process.

V. IMM® APPLIED TO SHAHRAK-E GOLESTAN NEIGHBOURHOOD: FORMULATION PHASE

A. *Detecting of the Transformation's Catalyst*

The main purpose of the Hypothesis phase is to detect the transformation catalyst, thanks to the KCs and their associated Indicators. As discussed, the malfunctioning of the KC boosts the modification process. In this phase, the Key categories, with the consideration of the interventions' goal, are evaluated and compared with the rest of the urban fabric; thus, the intervention process could be initiated with the modification of the malfunctioning system. Considering the result of the investigation phase (horizontal and vertical), it easily appears that the major malfunctioning relates to the features those are dealing with Function and Transportation layers. Obviously, weakness of one of these two layers leads to the failing of the other, as the powerfulness of one of them develops the one. Here, in Shahrak-e Golestan, lack of defined functional centers actually emptied the area from the urban nodes, and consequently no powerful transportation node has been created. This tremendously affects the transportation circulation inside the site in a way that even the vital need of inner connectivity is almost not being felt. Shortage of job producing functions and key urban activities made Shahrak-e Golestan to be extremely depended to the other parts of Tehran in a situation that the poor public transportation is hardly able to meet even a small part of the needs. The remote location of the Shahrak-e Golestan from the Tehran's functional centers adds to seriousness of the problem. The only public transportation service available inside the area is a limited number of buses while the nearest subway station is located 7 km outside the site. Although Function layer could be a proper catalyst too, Transportation layer has been chosen as the main catalyst. This selection is supported by a holistic consideration with the goal of initiating a transportation flow to create inner circulation, and enrich the transportation links in order to develop the global connection [16]. By selecting the function layer as the catalyst on the other hand, the role of surrounding areas in the feature development would be minimized. However, in the transformation process, it is obvious that the function layer comes immediately after the transportation layer and their integration gives the meaning to the design: transportation nodes will be located at the most needed or the abandoned places and the functional nodes grow in their surroundings. The connection needed between the functions define the links, and this transformation initiates.

As it explained, in the transformation process the catalyst layer takes the initiative, and all the decisions on the intervention will be taken by considering its actual performance and its potency of improvement. The individual and the mutual relationship of layers have been analyzed in the investigation phase and the catalyst layer (Transportation) has been chosen accordingly. Now it is time to decide about the level of intervention in different location of the site. In order to do so, the Key Categories in which the Transportation layer is involved, are considered simultaneously and the weaknesses and opportunities of them are analyzed. This Key Categories in this project are: Interface, Accessibility, and Efficiency.

The western area of Shahrak-e Golestan neighborhood can be considered almost empty from function and public transportation. As function and transportation produce the urban metabolism by feeding each other, the lack of one of them weakens the other one, and the latter is exactly the case of our case study. On the other hand, the axial

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analysis shows that while almost all the east west oriented streets have poor values of mean depth, two of them, which are the 8^{th} and 9^{th} streets, have distinguishable power. This opportunity can be seized by making a powerful axis out of these two for which the transportation nodes and functional centers will be assembled around. If we resemble the context as a leaf, this axis could be interpreted as the midrib and the north-south oriented streets could be considered as the veins. Therefore, this strategy will scheme the level of intervention in different parts and the dispersal pattern of the urban features.

B. Design Ordering Principles (DOP)

DOPs [17] are certain design principles coming in the second step of the formulation phase. They are tools used for arranging the structure of the CAS with the role of driving the transformation toward a more sustainable form. Each one of them is defined in a way to improve the efficiency of the behavior of the subsystems, and the overlapping of all of them sketches the backbone of the master plan. The DOPs' role into the design process is significant for addressing the consequence of the Investigation/Analysis Phase. It is really important to note that the DOPs are associated with the 10 Indicators previously used for the estimation of the actual Energy performance of the CAS (Data Collection) as well as for the CAS Retrofitting process. The Design Ordering Principles applied in the Shahrak-e Golestan neighborhood transformation are, respectively:

- Balance the ground use.

This DOP is based on the efficiency that the compactness brings to urban areas [18]. Higher density and relative shorter distances characterize urban compactness. Accordingly, this principle highlights the fact that development should not just be denser but more compact. Many advantages arise particularly from the compact form of the city, such as reduction in need of motorized transportation, less transportation cost, and lower thermal loss in buildings. In this project, the goal of increasing compactness will be achieving through designing buildings with higher densities and certain geometry of blocks, which promotes well connectivity and provides a better integration with open spaces. The average urban density of Shahrak-e Golestan is 1.2, and the average density of the new buildings is expected to be more than 60% higher. In order to minimize the undeveloped land, there will be a special attention to the western part of the site.

- Fostering the local energy efficiency

This DOP [19] is rooted in the holistic approach toward the energy efficiency, and its purpose is to introduce buildings as components of community energy system. Its basic orders are listed here and the effect of applying this principle on the design decisions will be completely discussed in the architecture part. This principle can be achieved optimizing the relationship between building form and heat loss as well as natural ventilation, as well as optimizing the relationship between the building shape and energy production (solar gain, natural ventilation). But also the evaluation of the solar potential of the project area has been considered.

- Promote walkability

Regardless of numerous social benefits, promoting walkability extremely improves the city behavior in terms of energy efficiency [20]. It decreases the demanded energy in transportation section by reducing the unnecessary traffic and generally, the need of drive. Functions in walkable cities are usually better oriented and the high level of integration between them provides better connectivity, hence supports Compactness. The level of integration between open spaces and walkable transportation links is also much higher. For this project, the idea is to promote walkability while the original interface is maintained. In other words, no major link will be added to the context, but certain streets will become car-free, and will make a walkable network. This transformation, of course, takes place in a process that may last for years. To select the car-free streets some principles were taken into consideration:

Firstly Size. Actually Car-free links should not be selected from the wide streets. Unfortunately, majority of streets in Shahrak-e Golestan are relatively wide. Therefore some of the selected streets are rather larger than normal walkable avenues. This problem could be solved in some level by providing small spaces in large ones (e.g. dividing the streets into sections by means of rows of trees, urban furniture, or small urban activities)

Secondly Connectivity: Car-free links should not interfere in connectivity. For this reason the adjacent links to a walkable street remain open to motorized transportation. Finally the integration with open spaces; actually car-free links are tried to be selected in a way that provide maximum integration with existing open spaces and the areas

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which have the potential to be defined as strong open spaces in future. This will raise the chance of creation of powerful public spaces in the site.

- Fostering mixed used spaces

Mixed-use development surely is a matter of sustainability [21]. It reduces the need of travel by increasing the level of self-efficacy in smaller scales. In mixed-use neighborhoods, jobs and other vital urban functions are more accessible and transportation modes are usually following a targeted pattern. Walking flows are created between the mixed-use blocks, social life is promoted and live public spaces emerge. By involving volume, void and function layers directly, mixed-use development plays a key role in transformation of Shahrak-e Golestan. It is decided that almost all the new construction in the site to be mixed uses buildings. The main parts of the physical feature of the project will be shaped by this approach, and thanks to the investigation phase, appropriate sizes and functions will be assigned to the new blocks.

Fig. 5. Left: Mixed-use building in Shahrak-e Golestan; Right: The new Green Network activates the metabolism of the System

- Create connected green open spaces and protect urban biodiversity

The main purpose of this design principle is to define strong connections between city and countryside through the green corridors [22]. The aim is to promote the implementation of an integrated open and public green system for fostering the urban metabolism. A well-designed green network could also help reducing the temperature by affecting Urban Heat Island and this could be a very positive contribution to the sustainable strategy, especially during the warm season. A serious need of green spaces is being felt in the current situation of Shahrak-e Golestan. Not only the extent of the existing green is very low, but also there is no hierarchy and connection between them. In such situation, the green spaces are acting like abandoned voids with an unknown identity. Accordingly, in order to meet the current needs, a vast continues green axis had been considered in the design. This axis has the role of a green fountain branched out with a number of green connections and occasionally meet some green islands. The resulting system is supposed to produce a green network. Considering the surrounding areas in different parts, various functionalities could be defined to the green spaces. Public spaces, sport fields and in small scale urban farms could be defined in different areas. Certain streets would play the role of the green connectors. These streets mostly would be selected from the walkable streets between the greens, and will be designed with strong rows of trees in order to represent green links visually as well as functionally [23].

- Cycling and reinforcing public transportation

The main aim of this DOP is to reduce the dominance of the private cars and to increase the use of more sustainable forms of transportation [24]. A high quality bicycle network alongside walking and a supportive public transportation elevate the general connectivity, and extremely raise the efficiency of the transportation system. Existence of cycling station beside other transportation nodes not only increase the level of inter-modality, but also add quality to the area and provide new public infrastructure nodes as magnets for the urban development. Moreover, entry of cycling into transportation modes can positively affect the lifestyle of the citizens. It encourages the social bonding, and most obviously, promotes a very healthy behavior. The motorized free streets are of course good containers for bicycle traffic, but cycling circulation should also be extended through the other links. Introduction of bicycle lanes cause a reduction in quantity of car lanes in the most congested areas, and this increase the accessibility for cycling mode while equilibrates the traffic flow in the whole area. For this reason, alongside the motorized free links bicycle paths are added to a number of streets of Shahrak-e Golestan in order to create a cycling network. Selection of street for the cycling purpose must be carried out in a manner that supplies

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a continuous multi-directional network and provides maximum accessibility for bicycle users. Certain bicycle paths could be defined in the streets beside the car lanes, or the paved pedestrian path could be extended to provide a proper width for cycling alongside the walkways. Bike sharing nodes are also introduced to Shahrak-e Golestan. It has been tried for their locations to be selected in a way that helps to give a good covering area and make inter-modal and good integrated public transportation nodes.

Fig. 6. Left: The proposed new cycling network of Shahrak-e Golestan; Right: the new bus system.

- Change from multimodality to inter-modality concept

Changing to Inter-modal forms of transportation is a significant contribution to the urban sustainability [25]. The most important effect of this strategy is the moderation of private car usage resulted by introduction of wider range of choices between different transportation modes. Replacing the private cars with more energy efficient forms of transportation brings environmental and social benefits. The car pollution will be reduced, traffic jams will occur less, and social interaction will be increased through the using of public transportation. Inter-modality raises the level of urban complexity. For the citizens, this concept is being felt in the transportation nodes more than any other places: Different nodes which suggest various forms of travel to the desired destinations, which themselves are inter-modal origins for other destinations. Accordingly, the turning point of this project is to empower the existing transportation nodes and define new inter-modal nodes. For this reason the introduced walking and cycling network is reinforced by the bus system. New bus stations are added in certain locations in order to cover the less accessible areas and to create inter-modal transportation nodes.

The following step is to define the links between these nodes. The bus system that exists now in Shahrak-e Golestan provides mere connection to the western part of the city, which can be considered very poor. The new bus lines therefore should make a good inside circulation in order to provide a better internal accessibility while producing a better connectivity to the rest of the city. Regardless of private cars, now there are three types of transportation: walking, cycling, and buses. By the over lapping of the station and nodes of each type, different transportation hubs with different level of inter-modality are created.

- Convert the City in a food producer

This DOP has the aim of providing more land for green space towards urban and peri-urban agriculture implementation [26]. In addition to produce some extent of citizen's daily needed food, urban farms could positively affect the urban sustainability by reducing energy consumption and pollution associated to transportation, lowering the UHI effect, reducing storm water run-off, and improving air quality. As it has been shown before, some part of the designed green lands could be devoted for limited food production. On top of the new buildings, green roofs could be designed and they can contribute to the urban farm too. Green roofs provide many benefits such as reducing heat island effect as well as energy demand for heating and cooling. There is also an agricultural area close to the eastern part of Shahrak-e Golestan. Its production could be transported directly to the site and be sold in a local market.

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Fig. 7 Left: The new hierarchy of transportation nodes in terms of inter modality; Right: Strategies could be decided to transport food from eastern agricultural land to the site

- Prevent the negative impact of waste

The main aim of this principle is to integrate in a more sustainable way the micro- urban utilities as well as the making the treating and recycling water and waste process possible on site, avoiding transportation and distribution costs and implementing the efficiency of the system [27]. A simple though useful strategy for small-scale waste management is the waste separation. Different types of waste should be separated in residential units, buildings and neighborhoods. The easiest separation could be distinguishing between organic waste, recyclable waste, and hazardous waste. After separation, each of these types go through their own treatment mechanism. Organic waste is converted to soil, recyclable waste is collected in recyclable centers, and hazardous waste is annihilated in specific centers. It is important that this policy is taken in a synergetic manner, which means that residents should separate the waste in their home, and a compatible separation system should exist in building blocks and neighborhoods.

- Implement water management

Beside the waste management, policies could be taken to minimize wastewater and implement water management [28]. In the building scales, the use of eco-friendly installations (washing machines and dishwashers, low flush toilets and air mixer taps) could reduce the consumption level up to 25%. Green roofs also could play the role of local storm water management. Certain technologies could be used in the green roofs to collect the rainwater, delay it and evaporate it. In the neighborhood scale too, specific canals could be designed for collecting the storm water and conduct it to the Chitgar Lake. The domestic wastewater goes to the Tehran's water treatment center and the treated water will be used in agricultural section

VI. IMM® APPLIED TO SHAHRAK-E GOLESTAN NEIGHBOURHOOD: MODIFICATION PHASE

The third step of the IMM® is called F.L.S. and corresponds to the First level of Superimposition. This is a specific design phase, which applies to a multi-layer and multi-disciplinary approach. Thanks to a driver (Catalyst) a local modification (Horizontal modification) marks the starting point of a chain reaction (Vertical modification) towards the global transformation of the CAS. Actually due to the fact that CAS is composed of four subsystems, we consider its state as a superposition of products of the subsystems' states. Once the subsystems interact, their states are no longer independent. In urban term this phase is oriented to the local modification (neighborhoods/local nodes) with the aim of global transformation achievement. According to IMM®, in this phase, the project works horizontally (modifying the local subsystems individually) and vertically (modifying the other subsystems and the architecture of their connections). Folding and superimposing the selected layers collaboratively, in a way in which the transformation of each layer changes the other one's structure/performance and characteristic, is the key factor of the main system transformation. At the end of the transformation, a new structure of the system will emerge once all of the superimposed layers meet each other and they integrate together simultaneously and collaboratively; as a consequence, a new morphology will have emerged and new will occurred as well as different performance.

The main outcomes of this phase are, respectively:

- The design/project of the chosen catalyst layer, in order to achieve a local modification that will be transmitted to process to the reactants layers.
- To drive the local transformation towards a structural transformation of the CAS.
- Preliminary evaluation of the transformation.

As it was explained, the transformation is initiated with Horizontal Modification which is the local modification of the Catalyst layer, and is being proceed with Vertical Modification in which the other the urban layers will be

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formed in compatibility with the mentioned horizontal movement. The local modification as designed perturbation of a system causes a series of effects that lead to macroscopic consequences starting up a chain reaction, which can transform structurally the CAS. Actually, IMM® considers CAS not depending only from the individual components but there are some interactions between them, which create emergent patterns as well as specific characteristic and different performances of the CAS. The Vertical modification is a chain reaction of the system propelled by the project. The aim of this step is to make possible the propagation of local changes towards the distant parts of the system as a consequence of connectivity, and making this propagation cause of a global change. The Vertical modification is driven by the response of the reactants layers catalyzed by a selected layer (catalyst), which modifies the architecture of the ligands activating the reaction, which transform the structure of the System. Actually the system's components are strongly connected, almost to all of the other components, so that simple local changes in their structures can influence the other subsystems in such a way that the same CAS results affected. Like in a chemical conversion the Catalyst layer catalyzed the other reactants adjusting the architecture of their joints and transforming structurally the System (CAS). The general design concepts of this project have been discussed in the assumption phase. In this section, the role of Catalyst (Transportation layer), and the applying sequence of Design Ordering Principles in the transformation process will be argued. Since the Transportation Layer has been elected as the catalyst, strengthening the structure of transportation and its related aspects are coming to the first level of priority. As the trigger of transformation, the transportation system should be modified in a way to become able to meet the needs of current situation, and also to sketch the further development. The designed system thus should promote the use of public transportation, introduce more energy efficient forms of transportation, and provide higher level of overall accessibility. In order to do so, while the existing nodes and links are empowered with new modes of transportation, new links and nodes are generated in a way to cover the undeveloped and less accessible areas. In this project the transportation system is based on three main modes: walkable links, cycling network, and bus system. The overlapping of these modes defines the quality of transportation nodes and these nodes are the places which urban development starts from. Considering the whole context and depended on the level of accessibility of each node suitable functions are suggested around them, and this is where Function Layer is involved in the transformation process, and the project enters to Vertical Modification phase. The rank and the situation of the transportation nodes help to decide about the type, quantity and the location of urban functions. In order to modify the function layer, different kinds of urban activities should be suggested in surrounding areas of transportation nodes in a way that increase the job opportunities as well as raise the level of efficacy of the neighborhood. Placing a particular type of function on its proper vicinity to a certain node is the main objective of the modification phase in function layer. Deciding about the different features of the buildings, in which selected functions are to be placed, embodies the physical modification within the volume and void layers. Modification in the volume and void layers take place in a parallel manner. Volume of the buildings should be designed with the aim of satisfying the desired density and providing good serviceability related to the assigned functions. Voids on the other hand, should create proper connection between buildings and provide an interactive network of public spaces. Optimum solar access for the buildings and other urban areas should be resulted from the integration of these two layers.

- Transportation Layer

Accordingly, in Shahrak-e Golestan the transformation begins with the introduction of a new transportation system. A central axis of transportation has been considered for this new system and it is supposed to act like a midrib which branches into secondary links to feed the rest of areas. This axis is defined between the Otrish square (east) and Arghavan Boulevard (west) in 9th streets and 8th Streets. The structure of the new system is based on more than 17km of car-free streets and 10km additional bike path. With the aim of supporting this structure, 14 new bus stations have been suggested in different places and some of the existing stations have been strengthened with new links. The resulted network consists of links and nodes with various level of importance (regarding to their distance from the central axis). Next step is to define the needed functions around the transportation nodes.

- Function Layer

The main theme of the function layer is residential use mixed with urban key activities. The functions are to be assembled in three sections around the central axis and be reinforced by walkable vertical axes. The western section is the Qaem neighborhood, which is the area between Arghavan and Hashemzadeh boulevards. Beside residential use, offices would be concentrated here around the main axis. The Sarvestan neighborhood is the central section, which is located between Hashemzadeh Boulevard and Zeinali Boulevard. Because of its central location, destination based functions would be arranged here to support its centrality. Therefore, main function around the

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central axis here would be a mixture of commercial and residential. The eastern section in the area is surrounded with Zeinali and Golha boulevards. Here more emphasis would be on residential use around the main axis while vertical axes provide other functionalities. Vertical axes in this section and in the other sections are dedicated to the mixture of residential use and small businesses and commercial activities. The car-free atmosphere of these streets stimulates a smooth movement for shopping and flowing between public spaces. Based on the current needs and radius of service, educational, cultural, health care and leisure activities would be located around the context.

- Volume and Void Layers
A linear open green space is suggested in on the main axis. This green space would be extended through the residential blocks in the eastern section in order to create a powerful network of public spaces with the Kowkab and Baghrah parks. The buildings blocks would be located in surrounding the created and existing voids and their volume would be decided in a way to provide the desired density. Overall, the buildings around the main axis would have higher volume rather than the others. After the intervention, it is expected that the total number of daily trips increase about 25%, and 920 new job opportunities would be produced. The volume of the new construction would be about 2,200,000m3 whilst 6,737m new green spaces would be introduced to the area.

Layer	Description	Formula	Value	growth
Volume	Built volume density, Dwelling density, Human density	Vl = Vbuilt / Area	7.75	115%
Void	Open space/area	Vd = Vopen / Area	2.75	48%
Function	Job density, Number of legal entities in the intervention area	Fn = Jnumber / Area	8.9E-04	345%
Transportation	Number of carried out urban trips (daily)	Ntr	71,473	25%

Table 6. Shahrak-e Golestan new system's dismantling for a preliminary evaluation

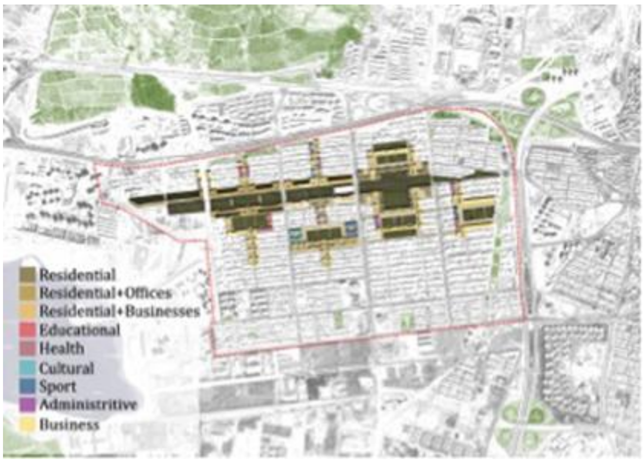

Fig. 8 General scheme of the Neighborhood master plan.

VII. RETROFITTING AND OPTIMIZATION PHASE

A. Retrofitting

After the transformation, the project enters into the retrofitting phase [30]. This phase starts with evaluating the performance of the new design by means of comparison between the neighborhood's behavior before and after the intervention. In order to carry out dimensional measurements and make possible such comparison, indicative tools are required. So the 10 Indicators already used are still help for making the comparison possible and then to drive the process toward an optimization phase in order to lead the complex system transformation in a correct way. Because the energy consumption in building section is highly related to the construction methods and energy class of the buildings, for the indicators related to this subject the average ranking of Tehran is repeated again. In food

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production part too, although the new design raise the expectation of improvement, because of the complexity of prediction no number has indicated. Although the raised density and 80% growth in the area of green spaces point out a huge physical transformation, the most remarkable features of this table are those, which are related to Transportation, and Function layers. Besides of being a prototype in Tehran, the introduction of car-free streets, bike path and inter-modal public transportation system would completely change the quality and related quantities of transportation layer in this site. This change would definitely brisk the activities and businesses and transform the functional behavior of the neighborhood too. According to the suggested planning, the average number of key functions in walkable distances could raise by more than two times, and the ratio between the numbers of residents and activities would gain less than half of its value in existing situation. This would elevate the self-efficacy in Shahrak-e Golestan, and in some extent would reduce the number of trips to the outside of the neighborhood. Beside the population growth associated with the increase in neighborhood's density and the attraction made by new functions inside the context the new values of almost all the indicators suggest that there would be less usage of private cars and more energy efficient forms of transportation.

			Before	After
Ground Use	Urban Built Density	∑Floor/Groun level Surface	1.2	1.44
	Compactness Factor	C = Surface/ (Volume) ^ (2/3)	64	30.65
	Building/Hectare	N/Ha	Not Specified	Not Specified
Energy	Gas Consumption/Capita	m³	3,230	3,230
	Electricity Consumption/Capita	KWh/Year per Capita	655	655
Walkabilty	KF in walkable distance	Average Number	5.41	11.57
	Car-free Streets	Km	-	17.70
Use of Space	Residents/Activities	C = residents/Activities	1,191.30	576.84
Open Spaces	Ratio of Green/Open Spaces	T = T(green)/T(total)	0.10	0.18
	Parks/Hectare	N/Ha	0.01	0.01
	Paved Public Spaces	N & Ha	-	Not Specified
Transportation	Private Tr. Energy use/Person	Petrol Consumption/Capita (Lit)	617	617
	Pub. Tr. Boarding	Number per Year/Person	0. 03	0.08
	Length of Biking Roads	Km per Capita	-	27.62
Mobility Interchange	Kinds of Public Tr.	Number of Systems	1	2.00
	Num of Parkings	N	-	-
	Num of Interchange Hubs	N	-	4
Food	Urban Farm Production	Kg/Capita	-	Not Specified
	Plots for Cultivation	Ha	-	Not Specified

Table 7. Indicators with their formula show the environmental performances of the Shahrak-e Golestan neighborhood before and after the transformation design process. The comparison with the actual neighborhood's performances drives the process toward a further optimization phase.

B. Optimization

After the retrofitting process the last phase named S.L.S. is driven by the Key categories for achieving the conclusive optimization of the CAS. KCs are morphological, typological and technological features -determinatives- expressed by the superimposition, or symbiotic integration, of CAS subsystems (Inner layers). KCs are applied in the investigation phase for analyzing the urban context and its performance before the design intervention, as well as in the final as evaluation phase after the intervention. Here, the key categories are, respectively: Porosity, Proximity, Diversity, Interface, Accessibility and Efficiency, like the follows, express the new superimposition, or symbiotic integration:

- Porosity. The volume added to context resulted by the intervention is estimated to be 2,784,921m^3. This volume provides 738,893 m^2 of additional building area for various uses. Hence, the urban density shows an 20% improvement.

- Proximity. The 48% increase in job opportunities which is mentioned before, which is a minimal assumption based on raising the number of activities by nearly 148%. Depended on their location, this extent of growth in number of function could bring major changes in Proximity index. The following image is the visual analysis of proximity based on the proposed master plan. In the master plan 68 new functions are predicted. Although most of them are assembled around the main axis, it has been tried to reach an equal dispersal of functions in the rest of the area. In the image, it is vividly shown that the western part of the site, which, in actual situation is almost empty from functions, now enjoys almost the same level of proximity as the other areas in context. Comparing with the actual situation the average number of activities in walkable circles all around the site is raised by 113%, which can be considered as a tremendous change in the overall Proximity. The growth in standard deviation which is almost two times, on the other hand, is the result of the centralized approach in planning and shows that the functions are assembled in some places (around the main axis), and dispersed in the other areas.

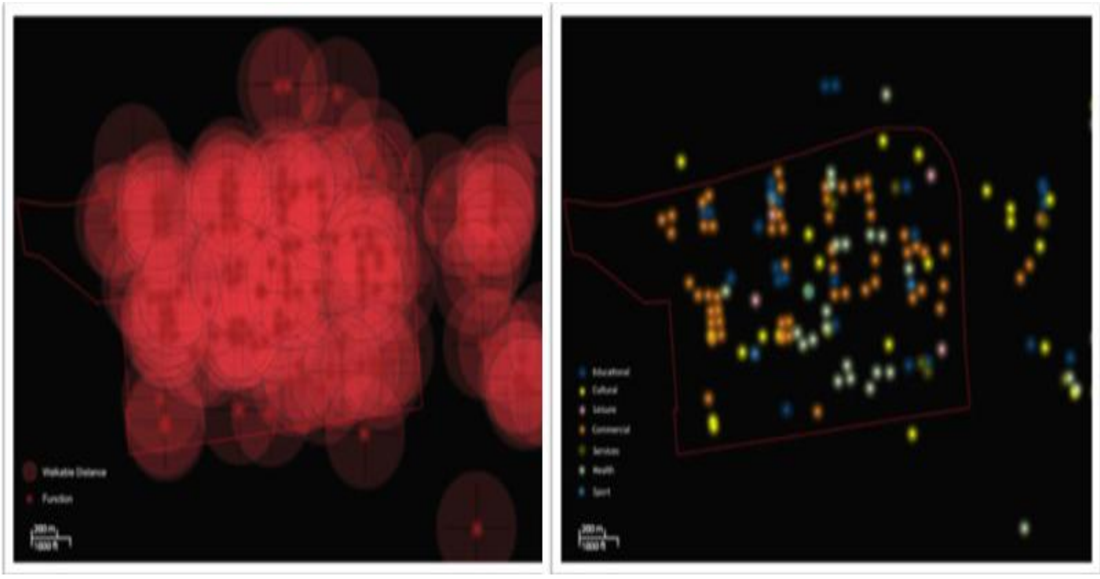

Fig. 9 Left: The Proximity map of the ne CAS; Right: The new Diversity from Urban Functions

- Diversity. In the master plan, for the suggested activities certain types of function have been considered. This will change the Diversity of the functions in the area. The most highlight change would be in the number of commercial centers, which will be increased from 4 to 53. Obviously most of the commercial units will be located in the vicinity of the central axis. Activities related to urban services also will experience a raise in number from 5 to 13. In the images below the expected situation of the site in terms of diversity of functions are shown. According to the explanation of the diversity's concept in our project functions have been categorized from two different points of view: from urban functions point of view, and from urban quality point of view. Comparing with the actual situation, the modified Simpson Index as the indicator of Diversity shows that placement of different functions in the master plan would be rather closer to an equal distribution in both cases. From the urban services point of view D1 would be equal to 0.84, and from urban quality point of view it would be equal to 0.62. These values in the existing situation are 0.78 and 0.59 respectively.

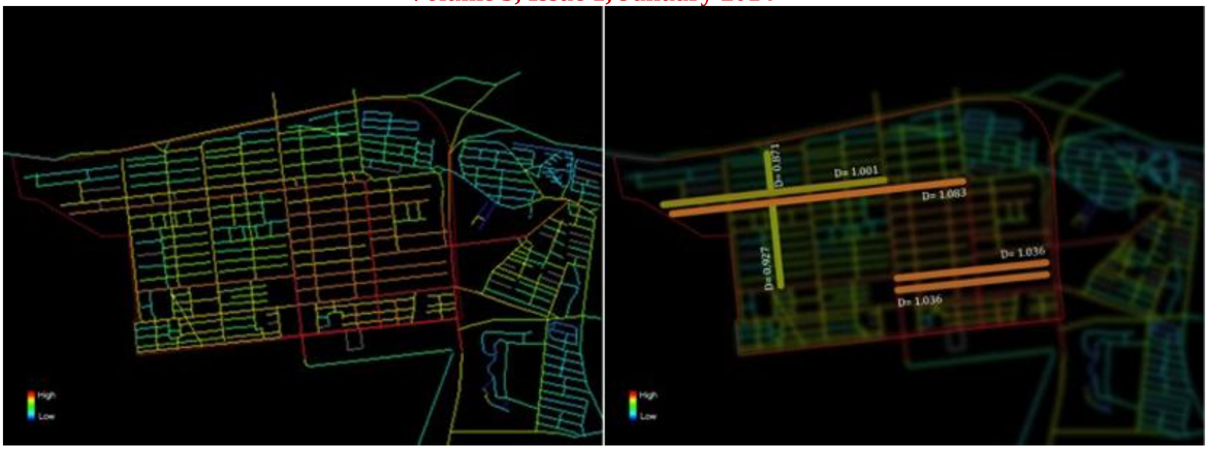

Fig. 10. For comparison sake, new Mean Depth values of the links which have been elected in the analysis part.

- Interface. In the master plan there are no major changes in the physical interface of the streets. The only change would be the continuity of vertical walkable links all over their sections. In the actual situation these streets are interrupted with the central axis and parks, but regard to their new definition in the master plan (being free from motorized traffic) they can be assumed continues. This continuity is maintained with crosswalks in the 8th and 9th streets in the central axis. The vertical walkable links are Banafsheh St. and Golfam St. in the eastern section, Sarvestan St. and Qaem St. in central section and western section respectively. Mean Depth analysis for the master plan is illustrated in the image below. The analysis is carried out via the software “UCL Depthmap”. Although the mentioned changes can be considered as a minor switch in definition of links, it changes the value of Mean Depth in so many streets. There is a slight increase in the value of Mean Depth in all the selected links, which shows that the overall pedestrian accessibility has been elevated.

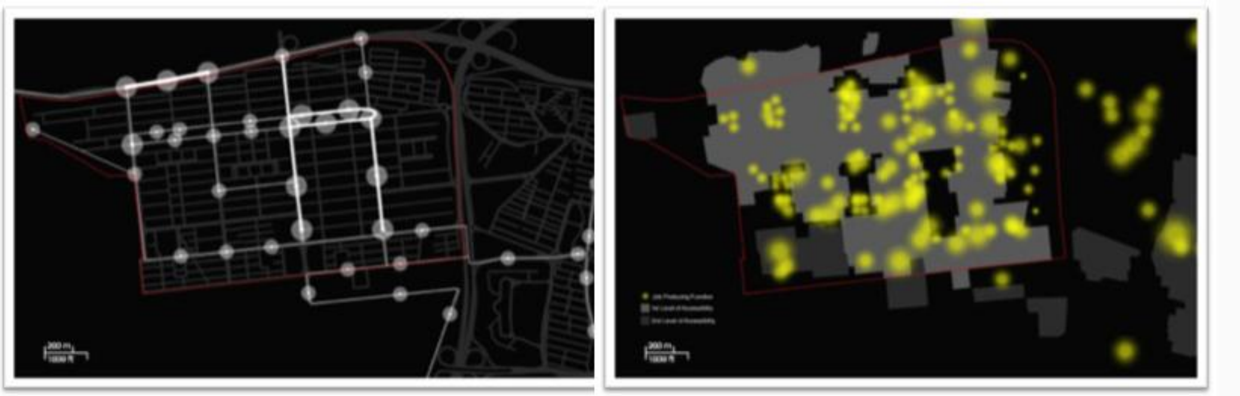

Fig. 11 Left: The hierarchy of public transportation in the transformed CAS; Right: The new Accessibility map, as the integration of Function and transportation. The map shows an improved value for reaching destinations.

- Accessibility. To promote accessibility is necessary to increase the number of jobs in the context, as well as to enlarge the accessible core area. Both strategies are taken in the planning. While placing the new functions would produce nearly 300 new job opportunities, thanks to enhancing the public transportation the area of the Accessibility Core would become to almost 3591626 m^2. This area is more than two times larger than what it is in the actual situation. Hence, the indicator of Accessibility for the proposed master plan is calculated as:

$$Acc = 934*(3,591,626/4,853,549) = 691.16$$

Comparing to the existing situation, the Accessibility has more than five times growth in this particular index. This major improvement is indeed one of the highlights of this project.

- Efficiency. It is assumed that by increasing the density, the population of Shahrak-e Golestan would raise by 20%. The total number of urban trips associated with this population growth is estimated to be 25% higher than its

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number in the existing situation. This means that around 71,473 trips would be originated from and designated in Shahrak-e Golestan daily. According to rough estimations (based on average contribution of public transportation nodes in Tehran's traffic) the new transportation system would carry out 5,718 trips out of the total trips, which is an 8.7% contribution. Correspondingly the indicator of efficiency is calculated as below. This value is 166% higher than the efficiency in the actual situation, and remarks a significant improvement.

$$E_f \quad \frac{N_p}{N_t} = \frac{5718}{62755} \quad 0.08$$

KC	Indicator	Value	Improvement
Porosity	Built Density	1.44	20%
Proximity	Mean Number	11.57	114%
	Standard Deviation	4.03	77%
Diversity	Simpson Index (Services)	0.84	8%
	Simpson Index (Quality)	0.62	5%
Interface	Mean Depth	0.992	2%
Accessibility	Number of jobs accessible in 20min	691.16	506%
Efficiency	Public transportation tips/Total Trips	0.08	167%

Table 8. Optimization Table of the Shahrak-e Golestan neighborhood after the transformation design process

VIII. CONCLUSIONS

The Tehran's case shows how the IMM® proceeds and transforms an existing urban context from its actual morphology into a more sustainable one. Thanks to the IMM®, including its modification process and integration of layers, a new urban form emerges as a still provisional CAS, that configures itself as a new threshold of an endless transformation's process. In Shahrak-e Golestan the intervention via IMM® methodology illustrates a sharp decline in total energy consumption despite the site's densification increment rate. So, whilst its urban density is expected to be increased around 60%, highly car-depended neighborhood with poor public transportation Shahrak-e Golestan neighborhood would experience a two times growth in public transportation usage. Other energy indices also will be improved by more than 50% in average. The presented case study demonstrates trough the use of an integrated, multi-scale and multi-layer approach that the compactness of urban settlement forms related with increases in settlement density, mixed uses and by integration of space and supported by a collective hierarchical and highly integrated infrastructure, can generate a settlement model environmentally sustainable in the long period. Nowadays cities are playing a critical role in the reliability, affordability and environmental sustainability of their energy supply. This article was developed as a pattern for cities that want to tackle this challenge, providing them an implementing sustainable strategy based on an innovative methodology.

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