Investigation of Urban Form and Environmental Performances via IMM methodology: The case of Tehran, Iran.

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Abstract
Nowadays the correlation between urban developments and environmental stewardship is crystal clear. Subsequently, how should one implement practical methods to tackle urban growth and environmental issues simultaneously is the main headline. How should integrate urbanization and the issue of saving natural resources? How can design strategies contribute to climate mitigation and emission reduction? Is the urban form correlated with these issues? And eventually, how can the urban transformation be performed, retrofitted and monitored in order to achieve a more sustainable result?

A strictly sectorial approach could result in neglecting mutual dependencies of these demands. On the opposite an integrated approach can help to sharpen a better comprehension of the different performances of different urban assessment. IMM® is a multi-stage, iterative process, applied to urban complex systems, for improving the metabolism of the city as well as its energy performance. Due to the facts that most future growth in urban areas will occur in developing countries and its relative few megacities, where will live 5% of earth population the paper wish to present a case study of a megacity, Tehran.

Keywords: Integrated Modification Methodology (IMM), Morphology, Energy consumption, Environmental performances, Complex Adaptive System.

1. Introduction to IMM and the role of megacities.

According to IMM® theory, the city, is not solely a mere aggregation of disconnected energy consumers and the total energy consumption of the city is different from the sum of the whole building’s consumption. “The whole is more than the sum of its parts”. [1]

The main goal of this article is to establish the relationships between urban morphology and energy consumption, providing some new basic design principles to re-shape urban assessment, as well as designing new better energy performnig and more sustainable cities.

It is essential to emphasize that IMM® theory considers the city as a complex adaptive system. A Complex System (CS) is an arrangement of interconnected heterogeneous elements that, as a whole, shows one or more performances, and the final result of the whole system is utterly different from every individual constituent’s performance. in the other hand, the Complex Adaptive System (CAS) is a particular case of the complex system with the specific ability to learn from prior occurrences. System’s agents adapt themselves to improve their performance, in a response to new internal and external constraints.

“The paper’s briefly discusses about IMM process, and particularly some of Key Categories utilized in the process, via a case study in the megacity of Tehran, Iran.” [2].
Additionally it is important to emphasize that at any particular scale, the Complex Adaptive System (CAS) is a sub-system of a upper-system. Hence cross-scale effects are of great significance in the dynamics of CASs and a Multi-scale approach is essential to understand the behavior of the complex systems. In other words the transformation of an intermediate scale play in IMM the role of a catalyst to initiate a chain reaction able to transform the entire structure of a CAS, whatever is the system's magnitude.

Figure 1: Megacities with 5, 8 and 10 million inhabitants in the year 2015. Source: Kraas.

Due to this assumption and to the facts that most future growth in urban areas will occur in few megacities, where 5% of the population will live in the coming years. The megacities’ energy consumption as well as greenhouse gas emissions are anticipated to rise by 10 percent or more a year [3]. We consider that megacities be seen as an important subject to investigate the relationship between morphology and energy consumption.

Authors present how a megacity, seen as a CAS, can be operated in order to optimize its environmental performances. The Tehran’s case study shows the role that morphology can play and how can be possible to change a CAS through the local scale modifications.

The term “mega-cities” was defined for metropolitan agglomerations, which concentrate more than 10 millions of inhabitants. The 20 “Mega-cities” represent a population of around 300 millions of residents, generate 18% of global GDP and 10% of global carbon emissions and contributes to 19% of electricity consumption [4].

Megacities cannot be considered just large size cities; they consist of a complex unit of production for consumption, a large labor market, a specific system of power and extreme social and cultural differentiation and physically speaking they are enormous and changing, expanding beyond city boundaries into dynamic regional entities.

“One of the features of Megacities is that they are polycentric, which means they do not have a single center, but rather that the same urban extension includes different areas capable of attracting economic, social, and political activity. Megacities are structured around different centers” [5]. Megacities are excellent example of CAS composed by many sub-systems working as CAS. Megacities are physical entities made by interacting and interconnected CASs
acting in a non-linear way, an over-changing morphological structure not solely including quantities of units and interactions, but also uncertainties, in determinations and random phenomena.

According to L. Bourdeau-Lepage and J. Huriot, the new urban revolution, started in the second half of the XXth century, is going to challenge the relationship between the size and economic role of cities. This revolution is mainly characterized by two divergent phenomena. They believe that in the last decade have witnessed unprecedented megacities emergence, mostly located in less developed countries. [6]. “In 1950, only two cities in the world exceeded the 10 million inhabitants, New York and London. In 2005, 20 megacities regroup 292 millions inhabitants. (...) on the other side, the globalization generates a new urban organization where a few number of cities concentrate a disproportionate part of economic power, they are global cities. Now megacities and global cities are partly diverging. Actually, numerous megacities have emerged and a large number of them did not gain any global economic dimension or global function”. [6] This paper present the case study of Tehran investigated in its sub-system interaction and transformed through IMM® methodology, with the aims to transform its morphological structure, seen as a CAS, into a more sustainable, energy efficient one.

2. The case of Tehran.

In terms of morphology and energy consumption, one of the most interesting megacities in the world is Tehran. Tehran is largest city in Western Asia, and with a population around 14 million in its metropolitan area, has the 24th place amongst the most populous megacities in the world. Being a developing country, Iran has some of the most dramatic international rankings in energy consumption. Iran has the highest Energy Intensity among the world’s countries, and is second in Energy Development Index. [7]

With having the world’s fastest growth rate in natural gas consumption [8] currently Iran is the 3rd natural gas consumer in the world [9]. Fuel consumption is very intense too, as the country
New Urban form and Environmental performances, via IMM methodology: The Tehran case.

As the Iran’s largest city, Tehran is responsible for having the biggest share of country’s energy consumption, which puts Iran in the above-mentioned critical situation. Tehran contributes to over than 22% of the whole country’s fuel consumption [11], near 14% of natural gas consumption [12], and more than 10% electricity consumption. [13]

The urbanization pattern in Tehran is also very particular, and the urban morphologies within it are strongly tied up to its development history. With regard to global-scale, Tehran has passed the different levels of evolution from a castle-city to a modern and huge metropolis very quickly (in less than 2 centuries). The history of Tehran consists of several periods of intense and hasty urban development trends in which the city devoured its suburban elements many times, and again reclaimed more of them outside its newly established borders. The urbanization growth especially in the recent 50 years left a tortuous morphological legacy for Tehran. The main elements of its urban infrastructure have been formed only in 20 years (between 1956 and 1976), when the population of Tehran has increased nearly 3 times (from 1.5 million to 4.5 million). [14] As a result of this unnatural rate of development, accidental and inharmonious morphologies began to grow in every corner of the city.

Moreover, as Iran’s capital city, Tehran has experienced two particular phenomenons in its recent 35 years which also contributed to its strange growth, and led to new morphological forms: 1979’s revolution, and 8 years of war against Iraq (1980 – 1988). The first changed the social and political infrastructure of the city and by imposing new systems of validation extremely tried to fight with the former development patterns, while the latter dramatically increased the rate of immigration to Tehran and has forced the city to react to the newly demands dramatically.

The high volume of construction resulted from economic development in the recent years also is rapidly putting a vivid trace on the city’s form and is changing its view in an extraordinary manner. In figure 3 the urban growth of Tehran during its history is illustrated.

With the complex morphological inheritance from its history, Tehran is still subjected to urbanization, and patterns of its energy consumption are changing and twisting even more quickly than before.
In this paper the links between urban morphology and energy consumption in Tehran is studied through analyzing energy indices and formal aspects of four neighborhoods, which belong to different periods of urbanization, hence carrying dissimilar morphologies. [15] These neighborhoods are: the rather old Narmak in east, Azadi in the center, Saadat Abaad in north-west, and Shahrak-e Golestan in the recently developed western part of the city. [16]

3. Environmental performances and morphology based on IMM® investigation process.

IMM® [17] research has demonstrated how urban morphology directly impacts on energy and carbon emissions and more in general effects the urban environmental qualities and performances. As city is an energy system by itself, the final performance of the city emerges from composition of urban constituents, the new transformed form of the city emerges from modification of it elements. Despite these heterogeneous elements perform and get modified differently, they are bonded together with certain networks and laws. Morphologically speaking a city is comprised by an enormous number of interrelated components, categorized in different Layers or ‘Sub-systems’, which through their inner arrangement and the architecture of their ligands provide a certain physical and provisional arrangement. The modification of the elements needs multi-scale intervention, and transformation macroscopic emergence of the elements modifications, one should deal with the urban elements modification holistically. Much research has been done on the urban form correlation with energy consumption of the city; however, the discordant results have left the planners and designers in utter confusion. “There is no single sustainable city form; the choice of a planning and design approach for the improvement of an existing city or city region depends entirely upon the characteristics of that city or city region and may therefore have to be different in each case”. [18]

Due to the fact that IMM® investigates on the relationships between urban morphology and energy consumption, the theory focus mostly on the ‘Subsystems’ characterized by physical characters and arrangements:

- Urban Volumes (built-up mass layer)
- Urban Voids (open spaces, streets, etc.)
- Functional (land use layer)
- Transportation and Mobility

They are structurally organized and linked together in a provisional physical structure, outlining a distinctive and specific morphology [19]. Indeed, it is the architecture of their ligands, which provides a certain physical and provisional arrangement of the CAS every time different.

Moreover the CAS [20] is also a single energy entity; accordingly with this assumption, a more efficient and sustainable urban form emerges through modification of its elements and integration of its subsystems over time. The IMM® process highlights the transformation of mid-scale areas, which is a determined area and acts as a bridge between the local scale and global scale. However, the limit of this area has to be mapped, as the intervention and project site by the designers and planners.
The main criterion to confine the intervention’s border is based on the wide-ranging contextual features, such as morphological aspects, social and functional layers. In IMM® theory the modification of CAS [21] elements, which causes the final transformation of the system, occurs in different scales.

4. The role of Key categories.

According to the essence of CAS, a mere action in one constituent of the system will produce chain reactions in others. This means that from superimposition or symbiotic integration of CAS’ subsystems another profound vision of system’s operation emerges. Therefore, the actual key of understanding the complexity of the system is to study all the one-by-one interactions, which are occurring between its components.

Considering city as a CAS, from integration of system’s basic components (Volume, Void, Function and Transportation layers), six dimensional concepts are created which are namely: Porosity, Proximity, Diversity, Interface, Accessibility, and Efficiency. In IMM® they are refered as Key Categories, and they defined as morphological, typological and technological features which the inner behavior of the urban context is analyzed with. The relationship between the Kay Categories and urban subsystems is indicantes in Table 1.

From vertical optimization of Volume and Void layers Porosity is defined. By representing spatial features of the city, this Key Category provides a wide groundwork in which various aspects of energy consumption in an urban scale could be studied. Solar gain of individual buildings and the manner of wind flow between the urban volumes can be analyzed with the help of Porosity. Moreover, the regulation between Volume and Void denotes the relationship which exists between volume density and the hierarchy of urban voids with which the compactness level of urban context could be evaluated.
Table 1: Superimposition of the layer; the first level of superimposition (FLS) creates the measurable Key categories; additionally, the second level of superimposition (SLS) defines Morphological, Typological and Technological features of the city. The city could be transformed towards a more energy efficient form, if one creates a symbiotic relation between the Key categories.

As the integration between Volume and Function layers, Proximity provides an area to study the city with regard to the locations of urban key functions. Here, neighborhoods can be assessed with respect to their vicinity to main urban activities, and the related morphological aspects can be analyzed. With studying Proximity, the pattern in which urban activities are assembled together and form morphological nodes could be understood, hence the neighborhoods could be evaluated in terms of the energy, which is consumed in order to have access to such nodes.

Diversity is the Key Category that is resulted from overlapping functional layer with urban voids, and it characterized by the variety of key functions, which may exist in a particular urban context. Diversity has a direct relationship with the Complexity, and it denotes the level of self-efficiency of a neighborhood. Besides having stronger social characteristics, the neighborhoods with higher levels of Diversity consume less energy in transportation section, thanks to mingling different types of activities around each other.

From integration between Transportation and Void, Interface [22] emerges. In terms of energy efficiency Interface is a Key Category with high level of importance because it represents the strength of the street networks, and the quality of traffic flow within them. The main role of this Key Category is to explicate how different parts of an urban context are connected to each other through streets, and how the street layout supports energy efficient modes of transportation.

Accessibility [23] is resulted from interaction between Function and Transportation, and it is a tool to study the Connectivity of an urban area. Accessibility has a direct relationship with the pattern of energy consumption in transportation section for it represents the easiness of reaching to different urban functions (mostly workplaces). By embodying time factor as its main element of evaluation, Accessibility involves many aspects of transportation layers like the available technology and the physical network of public transportation. Furthermore, by studying accessibility, the quantity and the location of urban function in neighborhoods could be assessed in terms of their capacity of producing job, and their vicinity to transportation nodes.

The integration of Volume and Transportation creates the Efficiency. With this important Key Category the adequacy of public transportation for urban areas with different compactness level, hence different population densities could be analyzed. The level of car ownership in
neighborhoods, and the quantity of fuel consumed in private transportation are also directly related to Efficiency [24].

5. Three neighborhoods in Tehran; A comparison.

Tehran is a huge consumer of fuel, and although it is almost saturated by cars, every day the number of private vehicles is increasing in its streets. Heavy traffic congestions is becoming the dominant characteristic of the city, and the government’s attempt at constructing new roads and highways has no result but over-demanding the situation of new vehicles. Based on statistics in 2006 there were around 4 million vehicles moving in the city every day. This number is estimated to be much higher now. Air pollution is an immediate consequence of the amount of fuel consumed by these vehicles, and it is tangible evidence which schemes out the intensity of energy consumption. Tehran is always being listed amongst the world’s most polluted cities, and it is estimated that each day 27 people die due to pollution related diseases. Research conducted by Tehran Municipality and Iran's Department of Environment (DOE) suggests that auto exhaust fumes are to be blamed for more than 80% of Tehran’s air pollution. Like in any other mega city, diagnosing the malfunctioning elements in Tehran’s transportation section is not a straightforward task, for traffic problems are rooted in many systems (economy, society, management, etc.). However, the aim of this paper is to study the relationship between the ordering elements of Tehran’s morphology and the level of private car ownership in its different zones by means of analyzing morphological aspects of three different neighborhoods of the city. Because of their holistic essence in concepts, IMM’s Key Categories have been used as the main analysis tool here.

The zones that the case studies have been selected from are: Narmak in eastern Tehran, Azadi in center, and Saadat Abaad located in northwest. They have been selected in a way to represent variety of urban features and morphologies.

Narmak is a rather old zone, which its residents are normally coming from the middle class. It is famous for its morphology of residential blocks that is based on large central voids. Most of the buildings in this area are between 4 and 6 stories; hence Narmak’s neighborhoods can be classified as medium dens neighborhoods. Between 52 to 61 percent of citizens of this area own private cars.

Established in more recent periods of Tehran’s history, Saadat abad is host of taller buildings and denser morphologies. People who live in Saadat Abaad normally belong to economically upper class, and 61 to 71% of them use private vehicles. This range of car ownership is one of the highest in Tehran.

Azadi zone is characterized by monotonous building blocks with average built density regulated in a greedy layout. The citizens in this zone are normally coming from working class with medium income level. The percentage of car ownership in this zone is being between 28 and 34%, which is the lowest range amongst the case studies presented here.

In selection of the neighborhoods it has been tried to include various typologies of streets in the selected areas’ vicinities, and the neighborhoods has been bordered with rather similar sizes. In the following, some of the IMM’s Key Categories are discussed for the selected neighborhoods:

5.1. Proximity.

In IMM®, Proximity is evaluated by the number of urban key functions existing in walkable distances. Although in every city key functions are defined contextually, everywhere they
normally cover certain typologies of services, health, education, commercial, leisure, and cultural activities. Walkable distance also is defined in contextual manners. However it is normally defined between 250 to 400 m. In this study, because of car dependency and the morphology of Tehran’s streets, walkable distance has been defined in its minimum value, which is 250m.

With putting all the urban key functions (regardless of their typology) as centers of walkable circles, the scheme of proximity in neighborhood scale appears. In the Figure 5 the intensity of red color created by overlapping the walkable circles denotes the level of Proximity in the mentioned neighborhoods.

![Figure 5: Proximity. (Left) Narmak, (Middle) Azadi, and (Right) Saadat Abad](image)

It is clearly noticeable that the neighborhood located in Saadat Abad suffers from the lowest Proximity amongst the selected case studies. It means that in this neighborhood the daily travels are normally longer than convenient walkable distances, and considering the high residential density of this zone, this partially justifies the high level of vehicle ownership in Saadat Abad.

The other two neighborhoods have higher Proximities. However, due to existence of central voids in Narmak in which the key functions are concentrated, the neighborhood located in this zone enjoys the highest Proximity.

### 5.2 Diversity.

In IMM®, *Diversity* refers to variety of functions existing in an urban context. Typologies matter the most in definition of this concept. Distribution manner of different functions directly affects the distances of urban trips with different purposes. In Picture 2 with regard to their typologies, urban functions are illustrated in different colors. The multiplicity of the colors denotes the Diversity level of the neighborhoods.

![Figure 6: Diversity. (Left) Narmak, (Middle) Azadi, and (Right) Saadat Abad](image)

Also in this index, Saadat Abad experiences the lowest quality. Diversity of this neighborhood is highly affected by the lowness of available activities. In that area, the number of key functions is that small that Diversity is almost losing its relevance in definition. Consequently, the residents of this neighborhood are expected to travel long distances more often to fulfill
their different daily needs, and this situation again increases the dependency of private cars in a considerable extent.

Narmak on the other hand, have the highest value of Diversity. Its hierarchic central voids actually form a network of functional nucleuses, which brings an acceptable level of self-efficacy for that area.

In Azadi, The uniformity in morphological features leaves its trace in the neighborhood’s Diversity too. The area experiences a rather similar Diversity everywhere, for the key functions are usually located at the intersections of the main streets. With respect to the other case studies, the Diversity in this area stands in the middle.

### 5.3 Efficiency.

As a concept which is defined by the integration between Volume and Transportation layers, Efficiency is dealing with the quality and quantity of transportation facilities available for certain population densities. It could be evaluated by the ratio between the number of trips operated by public transport and the total transportation demands of the study area. Existence of more transport nodes, and variety in transportation modes, eases the use of public transportation, therefore increases the efficiency.

![Figure 7: Public Transportation Network. (Left) Narmak, (Middle) Azadi, and (Right) Saadat Abad](image)

As it appears in picture 3, urban buses are the only transportation mode available in Saadat Abad. Considering the density of this neighborhood, the limited circulation of buses seems very poor and ineffective. The Value of Efficiency here is estimated to be only 0.05 here. With this context, it is not surprising that this area has the highest demand of private vehicles.

With an approximate value of 0.28, Azadi has the highest efficiency among the selected case studies. It is located close to three metro lines (lines 2, 3, and 4), which from their intersection a triangle emerges that in each of its vertices a powerful transportation hub is created (University of Imam Ali, Vali Asr, and Azadi Stations). This situation is also supported by the existence of BRT, which after Metro is the most used public transportation mode in Tehran. In Azadi the BRT lines overlap with the Metro lines, and together form a multi-modal network of transportation. Moreover, urban buses also cover some areas in vicinity of the selected neighborhood.

Narmak also benefits from close vicinity of Transportation nodes. The Metro Line 2 is crossing from its upper parts and goes to city center. One of the BRT lines of Tehran initiates there and covers the eastern part of the neighborhood. Urban buses also provide connections to surrounding neighborhoods.

However, comparing to Azadi the number of transportation nodes is less in Narmak, and the level of multimodality is also lower here. The Efficiency value is 0.24 for this area. And this partially justifies why despite of having the strongest quality in Proximity and Diversity indices, the range of car ownership in Narmak is higher than Azadi.
6. Conclusions.

“The comparison between the three case study shows that debats between higher density versus lower density is a distraction”. J.Kotkin.

It is interesting to notice that Saadat Abad’s neighbourhood has the highest density with the lower environmental performances, the higest demand of private cars use with the poorest public transportation offer. So the first observation of this comparison based on IMM methology, shows that density and even compactness are apparently not sufficient on their own to guarantee high environmental performances. In Saadat Abad higher density doesn’t minimize the car usage and more than the others two neighbourhoods it seams to be car’s dependent.

On the contrary, the highest level of proximity in Nemark’s neighbourhood is connected with the highest value of Diversity, with the consequences that the residents of this neighborhood are expected to travel shorter distances to fulfill their different daily needs, and minimizing their car dependency. Accordingly in Nemark we find the lowest average of private cars.

But if urban morphology should be more compact than just denser to shorter distances, the comparison shows that even compactness alone is not sufficient to provide the best possible performing arrangement. Actually a second conclusion comes from the second comparison between Nemark and Azadi neighbourhoods, where the lower number of transportation nodes in Narmak, as well as the lower level of multimodality compared with Azadi’s neighbourhood, justifies a higher range of car ownership in Narmak.

In conclusion the comparison between the three neighbourhoods, based on IMM shows that compactness alone without complexity and connectivity can’t provide any real optimization of the environmental and energy performances.

In particular the study cases shows that the use of private car, main responsible of the very high level of energy intensity as well as of the high pollution level in Terhan, can’t be minimize just increasing density, or even compactness.

7. References


[13] Iran’s Young Journalists club.