A strategy for an integrated ecological and urban landscape development: the urban natural network

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Based on the new trends of urban structure development, an important switch in planning strategy has occurred in several countries in thinking about the relationship between ecological and urban development. In both fields of interest a tendency for network thinking is emerging. The purpose of this study is to present a theoretical and methodological approach to natural network planning in and around high densely populated urban areas, with special emphasis to arid environments. The approach used in this paper is based on the premise that a network approach should serve as the skeletal framework of a comprehensive landscape planning scheme. The application of the framework to the city of Alexandria, Egypt, revealed that locating open and derelict spaces using satellite imagery provides a useful technique for developing natural network systems. In order to reconnect fragmented landscapes, a conceptual system of nodes and interconnected corridors is proposed. It is assumed that this study should be followed by additional comprehensive investigations in order to examine the validity of the proposed network elements, to test its ecological significance, and to carry out a detailed inventory of available open spaces characteristics.

تشهد مجالات التخطيط الحضري والإقليمي تقدما نحو الاهتمام الأكثر بالأبعاد البيئية في التصميم من ناحية أنها لا توفر فقط الحماية والحفاظ على النسق الايكولوجى للطبيعة، ولكن توفر أيضا وضعا اكثر ملاءمة داخل المناطق الحضرية لإقامة الإنسان. تعتمد المفاهيم البيئية فى التخطيط على تقديم مفهوم التصميم الايكولوجى للمناطق والمواقع المختلفة داخل المدينة والاهتمام بتصميم شبكات من المناطق المفتوحة مترابطة ومتداخلة مع الشبكات الأخرى، مثل شبكات الطرق مثلا. هذه الشبكات يمكنها أن توفر بعدا إضافيا للاستدامة والتواصل بين الطبيعة وبين مناطق النشاطات الاقتصادية والاجتماعية داخل وحول التجمعات العمرانية. يهتم هذا البحث بدراسة الأسس النظرية والعملية لمفهوم التخطيط الشبكي للمناطق الطبيعية، ويفترض أنه يمكن تطبيق هذا المفهوم داخل وحول التجمعات العمرانية التى تحتوى على كثافات سكانية عالية وبخاصة فى المناطق الحارة الجافة عن طريق الاستفادة المثلى بالمناطق المفتوحة والمناطق المهملة داخل المدينة وتحقيق الترابط بينها. ويوضح التطبيق على الجزء الغربى من مدينة الإسكندرية وباستخدام نظم الاستشعار عن بعد أنه يمكن من خلال الاستفادة من جميع المناطق المفتوحة والمهملة فى بعض المناطق تكوين شبكة من العناصر الطبيعية يمكنها أن تساهم فى الحفاظ على النسق الايكولوجى للإقليم بالإضافة إلى تحقيق وظائف اقتصادية واجتماعية أساسية للمجتمعات العمرانية داخل المدينة.

Keywords: Natural networks, Greenways, Landscape planning, Arid urban

1. Background

The process of urbanization and the capacity of city systems to manage and absorb the growing population pressures are causing great risks to city environments and the well being of the people. As mentioned by Hough [1], the modern city is shaped by a technology whose goals are strictly economic rather than social or environmental. This has contributed to a great extent to a misuse of urban and rural natural and manmade resources.

As a consequence, Agenda 21 (The UN Conference on Environment and Development held in Rio in 1992, adopted Agenda 21 as a policy plan outlining the actions to be taken by governments to achieve sustainable development) acknowledges the outcome of the poor living conditions in urban and semi-urban areas as destroying the lives of people, their health, and their social and moral values. Moreover, it admits that urban growth in cities is associated with destructive effects on the physical environment and the resource needed for sustainable development [2]. Agenda 21 calls for "an environmental interventions in the urban environment" and includes, "promoting human resources development and capacity building for human settlement" as one of its main objectives. The

declaration of Rio as well as other United Nations Conferences on Human Settlements increased the awareness among governments and institutions on the importance of new planning strategies involving multi-functional landscapes that integrate city and nature. In some towns and cities, new landscape planning programs based on ecological approaches have been developed for the restoration and amelioration of the urban quality of life.

1.1. New trends in urban and regional planning

Conventionally, overcrowded cities were viewed as areas void of natural values and consequently unworthy of any ecological planning measures. Several studies carried out by [3] have shown that this is rarely the case: in London, over 1800 species of plants and 200 birds were recorded. This means that there are good reasons for natural planning in cities, not only for wildlife conservation, but to provide places where people can experience nature. Goode [4] comments: "If we were to utilize ecological knowledge in the design and management of urban spaces, then considerably greater provision could be made for nature, at the same time catering for people's enjoyment of nature within urban surroundings".

1.2. Historical background

Ecological concepts and principles have been considered in landscape planning since the 60's by McHarg [5], Lyle [6], Zube [7] and others. As understanding of urban ecology grew through the 20th century, most of what was applied was initiated in the field of landscape and urban planning on the insights of Ebenezer Howard, who first proposed the concept of new garden cities at the end of the 19th century (1898) (Zube [7]). Howard's settlements could be conceived as urban units of limited size, surrounded by greenbelts that included most of the essential life-support functions of the urban landscape such as farms, pastures, and forests. The original greenbelt idea as described in Ebenezer Howard's London Plan was a wide strip of rural land, 5 miles or more deep, that defines the limits of the urban area and serves a protective role in guarding the rural hinterlands, delineating both city and nature, fig. 1 (Howard [8]).

However, today, urban units cannot be envisioned as discrete cities separated by greenbelts. As a result of growing technology and economy, new communication and transportation means were conceived for faster and efficient movement of information, people and goods. The isolated town no longer exists. Complex urban networks on a regional – or even continental – level took their places. Lyle [9] comments: "Thus garden cities become garden communities, and greenbelts become green networks, encompassing the communities and weaving them together. In the green networks are the processes that support life". The evolution of the urban and regional land use structure can be further explained in fig. 2: (a) the pre-industrial structure: separate communities are clearly defined by outer boundaries that distinguish what is urban from what is rural, (b) the garden city structure, the greenbelt works as functioning mean to connect people to the surrounding nature, settlements are still separated, and (c) the emerging urban structure, as a result of the information and transportation era, the region, continent, or globe could be conceived as a set of multiple networks, the most prominent are the urban and ecological (natural) networks.

Based on the new trends of urban structure development, an important switch in planning strategy has occurred in several countries in thinking about the relationship between ecological and urban development. In both fields of interest a tendency for network thinking is emerging. The question as imposed by Vrijlandt [10] is whether thinking in network analogies makes it possible to find a better way of dealing with the spatial conflicts between these different kinds of patterns for planning purposes.

To sum up, the study is built on the following assumptions:
The environmental quality in our cities is deteriorating, and needs to be restored for several reasons: (a) enhance biological

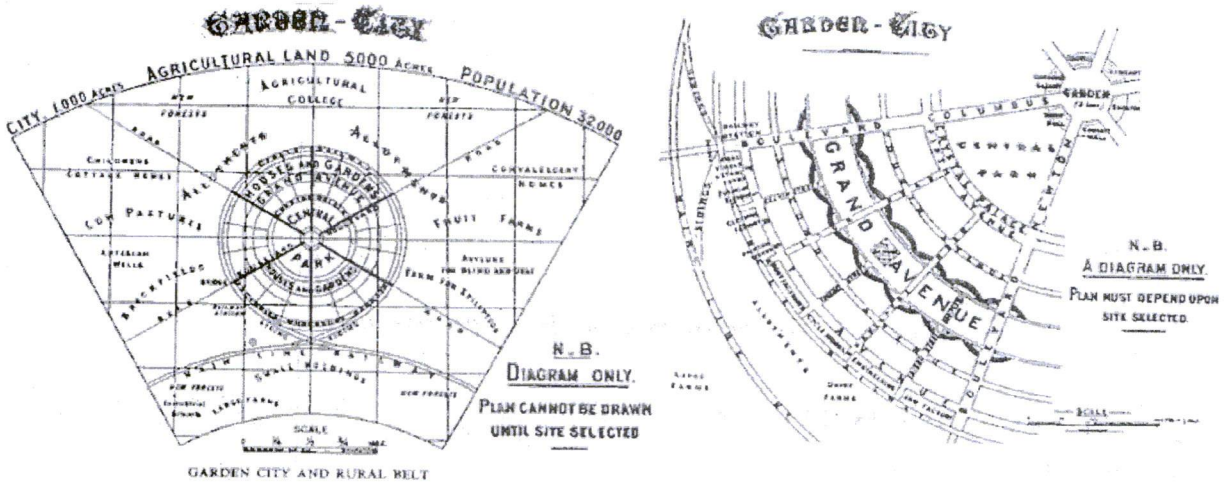


Fig. 1. Howard's schemes for the garden city.

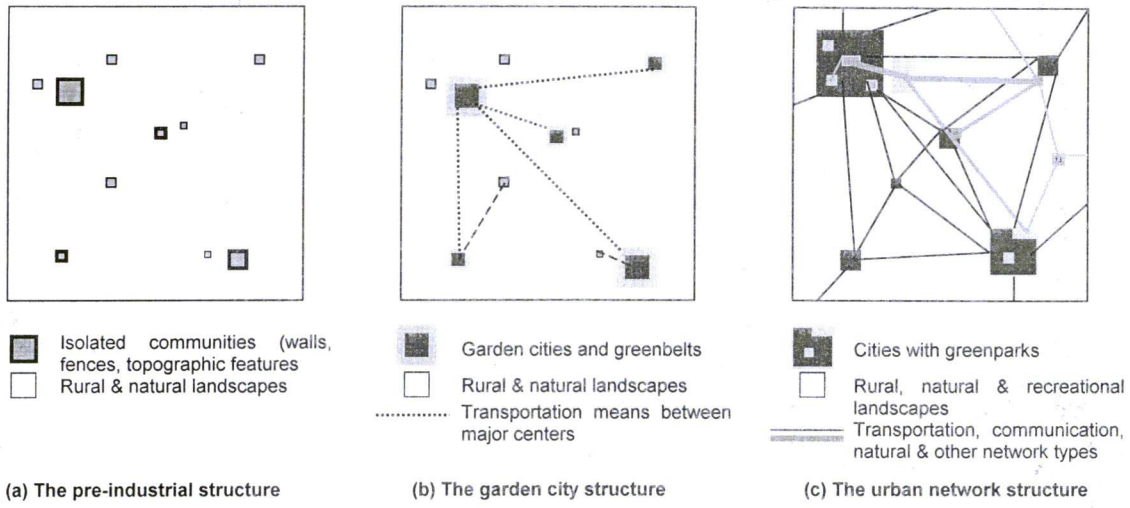


Fig. 2. Conceptual presentation of the evolution of urban and regional land use structure.

diversity and conserve natural resources, (b) reduce environmental pollution, (c) develop of natural areas in cities as an educational resource for new generations, (d) Increase the recreational opportunities for city residents, (e) create an esthetic quality and sense of community, and (f) gain economic benefits as a result of possible increasing property values, tourism development, and employment and commercial opportunities.

2. The restoration of environmental quality within urban structure is dependent to a great extent on the intuitive planning and design of the available open spaces, that include existing parks, streets, squares, waterways, as well as institutional grounds, converted derelict lands, and residential open spaces and courts.

3. Within the landscape ecological planning framework of the city, thinking in network analogies could be proved to be useful in weaving both the existing manmade and proposed natural elements in a harmonious and unified structure.

The purpose of this study is to present a theoretical and methodological approach to natural network planning in our existing cities, that better accounts for the conservation of present resources and the conscious reuse of open spaces within the urban

structure. The approach used in this paper is based on the premise that a network approach should serve as the skeletal framework of a comprehensive landscape planning scheme. The paper draws from the knowledge bases of landscape ecology, network theory, and landscape planning. The specific objectives of the study are: (a) to review the literature on ecology and planning that relates to the design of urban natural networks, (b) to apply this information in the development of an ecological framework for the planning and design of urban open spaces, (c) to illustrate the applicability of the framework through a case study example, and (d) to generalize potential applications of the framework for planning and designing of urban open spaces as a scheme to be adopted by planners in order to ameliorate the living environment within cities.

2. Literature review

The field of urban and regional planning has witnessed in the past years the introduction of many innovative approaches, tools, and techniques that have transformed the profession. Recently, landscape planners have begun to incorporate the principles of landscape and urban ecology into design and planning proposals. In order to provide a common foundation, it was considered useful to describe some important concepts and terms applied in this study, and seen by practicing planners as newly introduced to the profession.

2.1. Landscape ecology

Landscape ecology is a science that emphasizes the interrelationships between people and nature. Its goal is to seek a more sustainable landscape condition in which the needs of the present are met without compromising future requirements of man and nature from existing resources. This challenge for sustainable landscapes has inspired a dialogue between ecologists and planner within the discipline of landscape ecology (Ahern [11]). According to Cook [12], one of the most relevant contributions that landscape ecology makes to landscape planning is the use of spatial concepts as fundamental principles. Landscape planners are experienced in working with ideas relating to structure, function and change. Landscape ecology demonstrates how these characteristics are linked and establishes a scientific framework for the planning procedure. A thorough explanation about Landscape ecology, its foundation, principles, and applications can be found in Forman and Godron [13] and Naveh and Lieberman [14].

2.2. Ecological networks

One of the most important aims for landscape ecologists is to maintain integrity and continuity in landscapes, in order to achieve the required functional flows and movements of the natural elements of the ecosystem. Ecological networks provide great efficiency in functioning of ecosystems, as well as preserving the integrity of adjacent land uses. With a goal of maintaining ecological integrity, a range of ecological and social benefits accrues. From an ecological perspective, biological diversity and integrity of hydrological systems can be enhanced. Habitat and conduits for species migration can be accommodated. Most importantly, these systems can be self-sustaining requiring limited infusion of external resources to achieve its benefits. Social benefits in the form of recreation, aesthetics, education, cultural/ historical significance, land use buffers, and human health can also be achieved [12].

On the other hand, the dramatic increase in human population and intensification of commercial and residential development break the natural areas into smaller pieces, resulting in new *"fragmented"* spatial patterns. According to Collinge [15], the primary ecological consequences of nature fragmentation are (1) loss of native plant and animal species, (2) invasion of exotic species, (3) increased soil erosion, and (4) decreased water quality. Respectively, landscape fragmentation will also have a direct effect on the human social and economic environments. Ecological networks can then be used in order to stitch together fragmented pattern in urban landscapes.

2.2.1. Elements of a natural network: patches and corridors

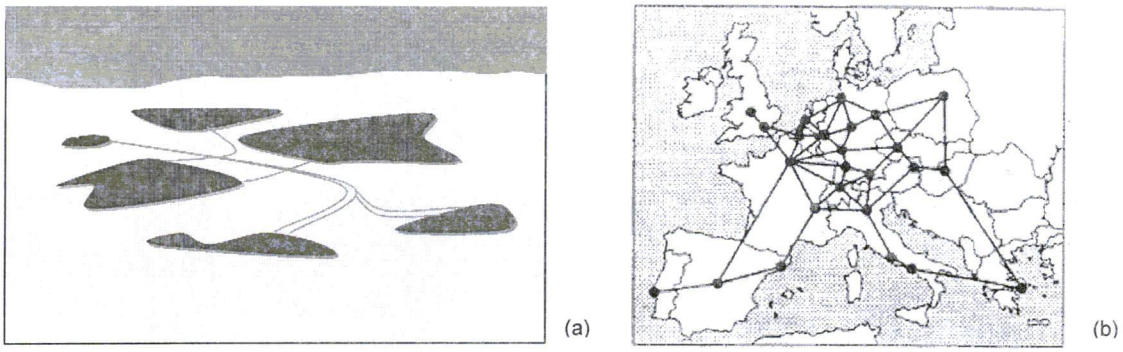
Landscape connections play an important role in ecological dynamics within and between natural areas. Various landscape elements found within an urban context can be classified as patches and corridors. The preservation of naturally vegetated corridors among isolated natural areas is predicted by Collinge [15] to moderate the negative effects of nature fragmentation by maintaining landscape connectivity. In the context of ecological studies, the term *"corridor"* refers to a linear landscape element composed of natural vegetation, which links clusters, or *"patches"* of similar natural elements (fig. 3).

2.2.2. Different concepts embracing the network

As a result of the great variations in landscape characteristics and pattern of spatial and land use distribution within cities, several concepts embracing the natural network theory emerged. Although the theoretical background depends mainly on patch and corridor plans, the application of such concept in urban contexts rise the need for a multipurpose urban ecological network. The multipurpose focus demands that the planning process be multidisciplinary and with a high level of public involvement. This is for several reasons. First, there is a need to reconcile the requirements of nature protection with the needs of city inhabitants. Secondly, cities and regions differ from one another in terms of size, pattern, climate, pollution, density of buildings, degree of degradation of natural elements, and land use.

In Europe, plans and pilot projects have been implemented in several countries, such as Poland, Netherlands, and England. These plans are often known as ecological infrastructure, green structure, or ecological network plans fig.3-b. It relies heavily on the spatial theory and the interest on ecological elements and protection areas rather than on human needs. It is supposed that human interventions have a negative effect on the natural ecosystem. In North America, a concept initiated by land use planning is known as greenways. Greenways tend to be multipurpose plans based on combinations of spatially compatible uses [11]. Fabos [16] describes greenways as corridors of various widths, linked together in a network in much the same way as networks of highways and railroads have been linked. The major difference is that nature's super infrastructure – the greenway - is pre-existent.

The majority of greenways fall into one of three major categories, that are increasingly overlapping in comprehensive greenways systems or networks: (a) greenways of ecological significant corridors and natural systems to maintain biodiversity and to provide for wildlife migration and appropriate



(a) (b)

Fig. 3-a. Elements of a natural network: patches and corridors, b. regional urban networks replace the former separate towns in Europe [12].

nature studies, (b) recreational greenways, including trails and routes having scenic quality as they pass through diverse and visually significant landscapes, and (c) greenways with historical heritage and cultural values to attract tourists and to provide recreational, educational, scenic and economic benefits, as well as high-quality housing environments at greenway edges.

The above definitions present some key characteristics of natural networks: First, the spatial configuration of natural networks is primarily linear. Second, linkage is a key characteristic that defines and relates it to the larger landscape context. Finally, natural networks are multifunctional, based on an assumed spatial and functional compatibility of certain uses (fig. 4).

2.3. Arid zones and deserts, characteristics, key elements for planning and design

In arid zones, particularly in desert regions, the idea of integrating nature into urban development is less considered by planners and decision-makers. Golany [17] considers that the researches on urban and regional planning in desert areas are minimal. In desert and arid environments, sustainability issues are more compelling because of the scarcity of natural resources. This is why it is vital to carefully manage and protect existing non-renewable resources in order to create a livable environment. In planning of natural networks, a different set of additional principles is targeted to dry landscapes.

The management of water resources presents one of the most important principles to be considered. Climatic extreme in arid lands and the minimal rainfall are the main reason for the shortage in water resources. Water losses from evaporation and infiltration contribute significantly to the ephemeral nature of stream flow, lake formation, and vegetation. Several problems are directly related to the unique nature of precipitation in arid zones such as: intense erosion, land slides delivering large quantities of silt to major streams, and large amount of runoff in a short time. In designing open spaces, the following points should be fulfilled: (a) the natural drainage systems of the site should be

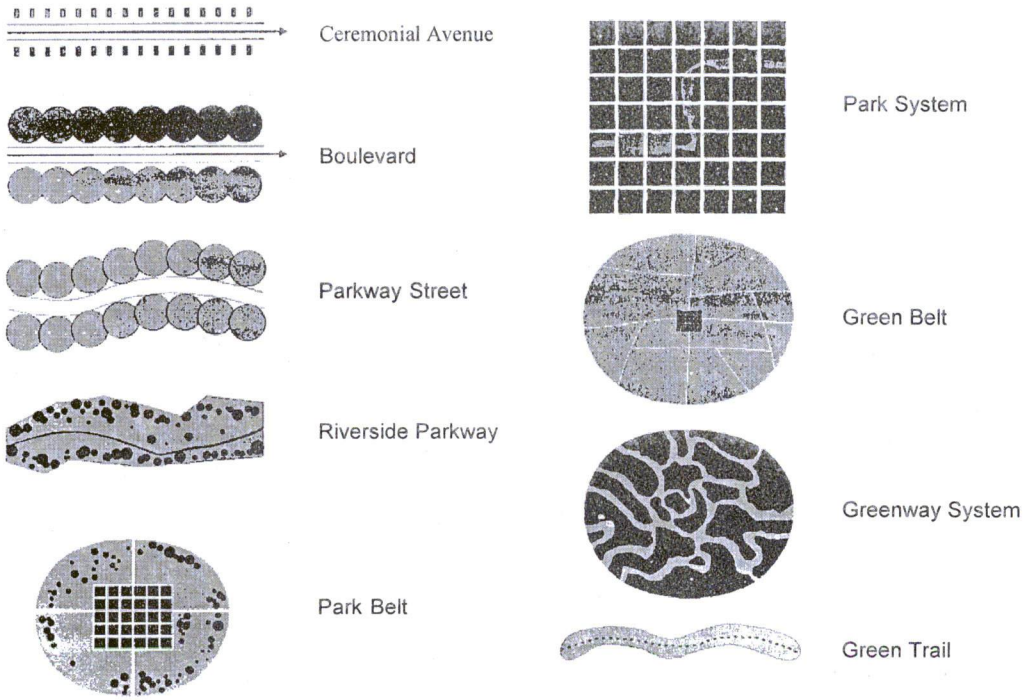


Fig. 4. Different types of natural network elements and concepts, having a history of at least 3,000 years [18].

enhanced to function during the extreme periods of rainfall, (b) construction of surface areas requires an investment for natural systems of drainage to accommodate the rapid runoff, (c) minimizing the amount of water evaporation and controlling the rate of water runoff requires the use of indigenous species of vegetative cover, and (d) taking appropriate measure to protect the quality and quantity of existing water resources such as water bodies, rivers, and ground water.

A good value to integrate both natural and transportation networks in desert environment is represented by roads; they are usually of more local significance in dry landscapes. Roadsides watered by runoff from paved and surrounding surfaces often have dense vegetation that attracts wildlife, and little-used road networks represent one of the best examples of a network through which species move and connect to other areas.

Wind and exposed surfaces are also ecologically highly significant in desert environment. The various designs and arrangements of windbreaks have diverse effects on wind speed. This in turn strongly affects evapotranspiration, plant production, soil stability, and soil accumulation patterns. The effects of wind, as well as the high mean duration of sunshine can be altered by the arrangement of spatial built and natural elements and the amelioration of the vegetation cover [19]. In short, water, wind, moving soil, and sparse vegetation are the key elements to be considered in planning and managing natural networks in most dry landscapes.

2.4. Functions of natural networks in cities

The definition of natural network functions and objectives is especially important in arid and desert urban environment because of its multifunctional nature and strategic approach. The wide variety of open space characteristics (function, scale, surface materials, and location) implies that compromises in goal achievement will take place. This means that all functions cannot be achieved within one space. In order to identify the context in which a natural network will function within the urban areas, it is necessary to identify the various ecological and human factors regarded as necessary for the success of a multifunctional planning strategy. The functions here are classified into two categories: ecological and socioeconomic functions.

2.4.1. Ecological functions

One of the main objectives in the development of natural networks is to maintain both species diversity and ecological processes. This is not always entirely possible in disturbed environments of the cities, especially those characterized by low natural vegetation. Based on the discussion in the previous section, this can be overcome in arid urban areas by considering some important biophysical functions such as [20]:

- *Hydrology:* In arid environment, water availability is a life support crucial factor. Urban areas usually witness the disturbance in natural water circulation, mainly due to covering of open space surfaces with impermeable material (asphalt, concrete), and the resulting increased runoff precipitation water, wasted through evaporation or sewage system. For this reason, natural networks inside arid urban should participate in ameliorating water natural cycle by providing ground recharge zones, and adequate vegetation cover to eliminate excessive runoff precipitation.
- *Climate*: A well-vegetated valley in an urban context can make a significant contribution to micro-climate improvement. The 'urban heat island' can be partially mitigated through preservation of existing vegetation and extensive new plantings. On the micro scale, vegetation in hot arid zones provides shade, wind and soil erosion protection, and cooling through evaporation. A network should be based on extensive areas of air regeneration usually located in suburbia and areas enabling relatively free inflow of fresh air into a city and outflow of polluted air from it.
- Biota: Biological diversity has been used to describe the variety of flora and fauna, the ecological functions they perform, and the generic diversity they contain. When establishing objectives for biological diversity, species composition becomes critical, and indigenous, rare, and endangered species

should be given high priority. As previously discussed, an important factor playing a role in the functioning of urban nature is the fragmentation of natural areas. This may be considered unimportant from the point of view of human needs, as it does not directly influence living conditions. However, it is a serious threat to the existence of sustainable environment. In cities, green spaces are small, so the effects of fragmentation are strong and the degree of isolation of patches is high due to the presence of roads, buildings and other infrastructure. The role of natural network is to ensure links between individual open spaces and the provision of an extensive network system that may be used by various species.

- Many other reasons of planning of natural networks deals with the usefulness of plants in erosion control, waste management, noise abatement, and pollution control.

2.4.2. Socioeconomic functions

Socioeconomic objectives of natural networks can be divided into general categories such as connecting with nature, enhancing aesthetic values, among other health related and economic benefits:

- *Maximize recreation and tourist opportunities:* Some of the most important socioeconomic functions of natural networks is to provide multi-use recreation areas and amenities and increase the general public's exposure to the natural environment, especially along linear corridors through rural and urban landscapes. It is worthy to mention that both planning for recreational and protection objectives are conflicting in nature. Recreational activities have to be categorized as passive, active, as well as defining the density of recreational development depending on the carrying capacity of the natural network and the objectives of ecological protection.
- *Reshaping the urban spatial pattern:* One of the socioeconomic goals of natural networks in cities is the restructuring of the spatial relationships between city elements and features this can be achieved by a) Controlling and directing urban expansion, b) providing people with access to open spaces close to where they live, c) providing most attractive and ideal residential environments, through physical and visual access to the edges and peripheries of natural networks, and d) linking together urban and rural spaces.
- *Historical heritage and cultural values:* the third socioeconomic function of natural network planning is to protect and restore historical and cultural heritage. It is easy to see how historic heritage values are assigned to natural networks. This is because most cultural features are near rivers and along shorelines, which have been during history major transportation routes.

In summary, natural networks in an arid urban structure has to fulfill a range of ecological and socioeconomic functions. A durable system has to be established in order to support basic ecological functions, protect key natural and cultural resources and permit other uses that do not impair landscape sustainability, with the overall goal to provide a livable environment within the city.

3. Guidelines for a natural network structure in arid urban areas

Based on the previous review on natural networks concepts, characteristics, functions, and elements, the purpose of this part is to establish the required guidelines for exploring opportunities and planning of new natural networks in arid urban environment. The proposed structure is based on the framework proposed by Dawson [21], Ndubisi and others [22] and Baschak and Brown [23]. It is adapted for use in arid high density cities, characterized by sparse vegetation cover and limited water availability, and aims at providing a systematic procedure that facilitates: (a) the enhancement of natural environment, (b) the management of available city spaces, including derelict and disturbed landscape, and (c) the linkage of present and potential natural areas within urban settings and fringes.

The application of the framework requires that each of the network elements and design principles, previously mentioned, be considered in detail. The approach taken here consists of three main phases that include the following steps (fig. 5): (1) goal establishment, (2) resource inventory and analysis, (3)

selection of the natural network elements and priorities, (4) implementation and management, and (5) assessment and feedback. Goal establishment defines the overall goal and detailed objectives of the network planning both in ecologic and socio-economic dimensions, and provides the basis for the resource inventory. The inventory defines various available open spaces in urban areas and includes open spaces, derelict and disturbed areas, water corridors and bodies, transportation networks, and areas of natural and historical values. Resource analysis concentrates on the study hierarchy, connectivity, and condition of selected areas both in regional and detailed scales. The inventory and analysis is facilitated by analyzing and classifying satellite data, which provide a good source for detecting available open spaces. Potential spaces identified through resource analysis are further investigated during the final natural network and priorities selection process by a combination of field investigation and additional data research on ecological significant areas and the materials of the network elements. Crucial factors for arid urban environments such as the hydrological system and the availability of water, wind and soil erosion, vegetation type, amount and quality should be analyzed in this stage. The final produced maps represent natural network elements and hierarchy, the final system of connecting greenways. The maps and analysis also form a work program for the future, and an inventory for managing networks, and mechanisms through which local authorities can consider natural networks in future planning.

4. Opportunities for natural network planning in the city of Alexandria

Following the steps mentioned in the first phase of the above described guidelines, regional analyses were conducted in order to evaluate the spatial opportunities within and around the western part of the city of Alexandria, Egypt.

4.1. Study area and technique description

The study site is located in the western part of the city of Alexandria, Egypt. It is bounded from the north by the Mediterranean sea, from south by agricultural fields and lake Mariut, and extends westwards to ElAmereiah, ElAgamy, and Mariut suburban areas. The area includes the city center, the old Turkish historical town, the eastern and western harbours, and the airport. Although the selected study area is a high densely populated area (The study area includes some of the most populated areas in Egypt. The Ministry of Planning [24] recorded a density of 132 500 person/km^2 in ElGomrok. The average density in the urbanized section of the study area is about 40 000 person/Km^2), it includes a variety of water bodies such as (1) the East and West harbors, (2) Western Beaches, (3) Mahmoudiah Canal, and (4) Lake Mariut, as well as different types of open spaces such as (1) current transportation networks, (2) derelict lands especially around the port and railway, (3) open unused western fringes, (4) agricultural lands, (5) cemeteries, and (6) Shallalat park and other green spaces.

A scene from the French satellite SPOT was used to conduct this preliminary study and to detect the different available open spaces. The imagery belongs to the multispectral sensor (3 bands), with a resolution of 20 x 20 m. The analysis of the remote sensed data was conducted using the Idrisi software and by pursuing the following steps:

- Create a false color composite image from the three data bands in order to visually assess land cover characteristics of the study area (fig. 6-a). Red colored features represents vegetated areas, grayish features are mainly urban agglomerations, and disturbed lands are presented in light gray to white color grades. The image also shows the main road network and major water bodies.
- Interpret of data using an unsupervised classification and cluster analysis techniques to distinguish between different reflectance values across the set of bands. Two types of clustered images were created. First, a broad clustering of 6 classes was used to get general groups from the bands, then, a fine clustering

of 14 classes was generated to get the final classified image fig. 6-b. Prior knowledge and field survey of ground information was necessary to assist in the interpretation.

- From the previous analysis, 9 different types of open spaces were defined: the sea, derelict and vacant land, disturbed and polluted areas, four levels of green areas, and 2 types of water bodies. Fig. 7 represents the types and amount of open spaces compared to the built-up urban areas in the whole study area as well as in a selected highly populated urban setting.

The following sections introduce the proposed typical analysis required to delineate elements of a natural network in the study area or similar case studies.

4.2. Resource inventory and analysis

4.2.1. Elements of the urban natural network

Network selection begins with an inventory and description of the existing and potential resources. These are classified as 'landscape elements' according to their characteristics. The aim of this analysis is to propose from the available open spaces a set of core areas (patches) and ecological (natural) corridors

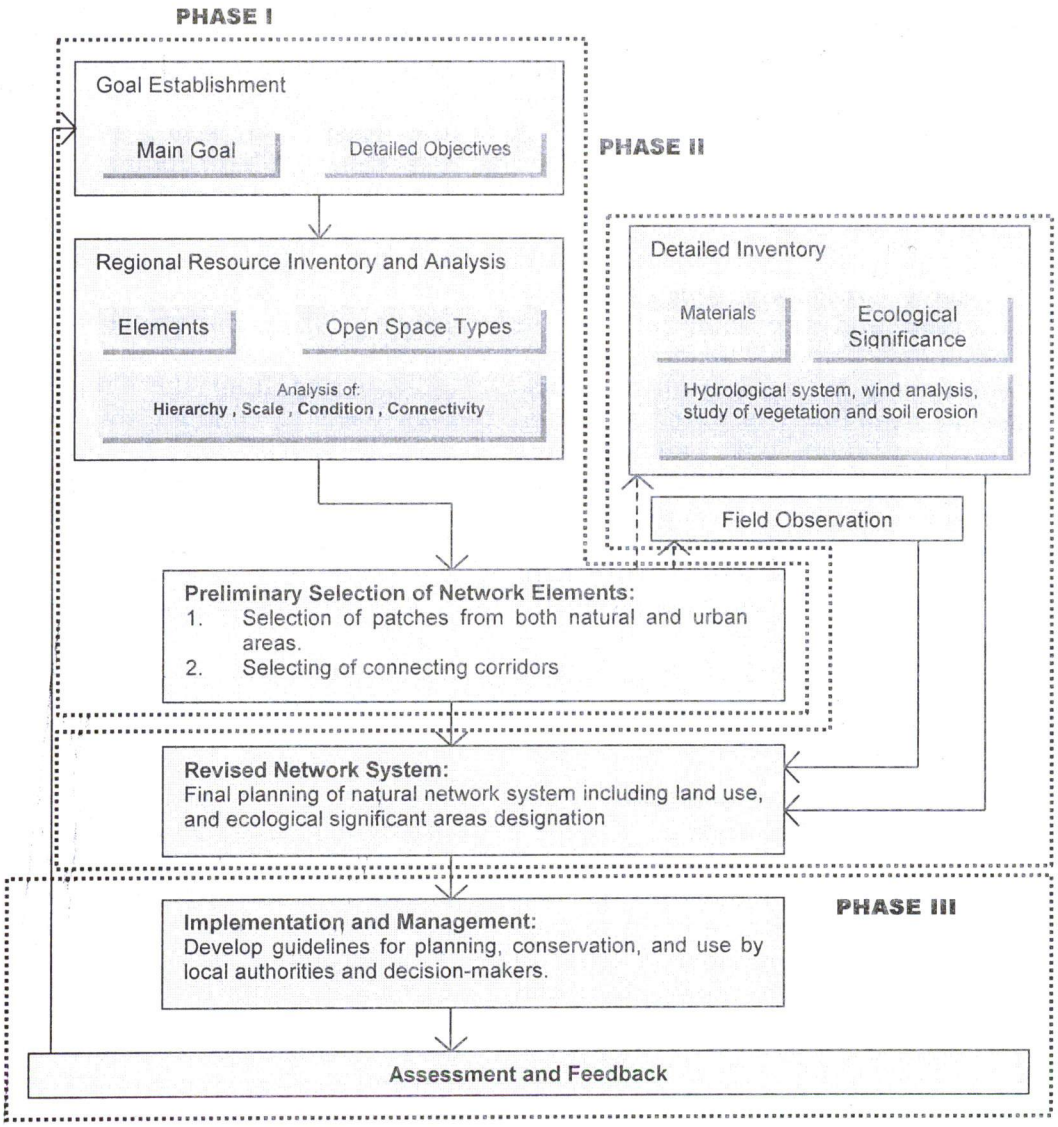
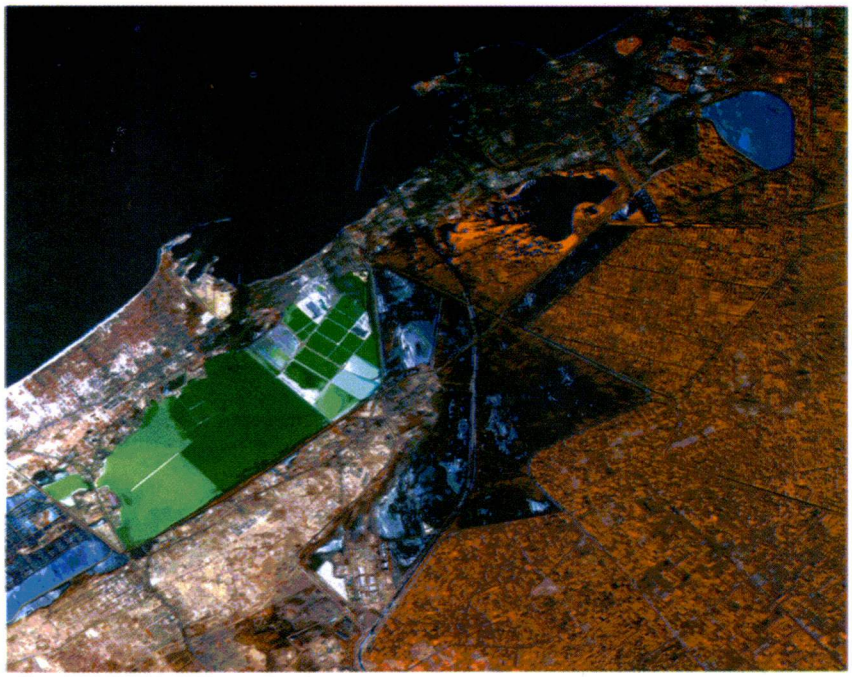


Fig. 5. A framework for planning a natural network structure in arid urban areas.

(a)



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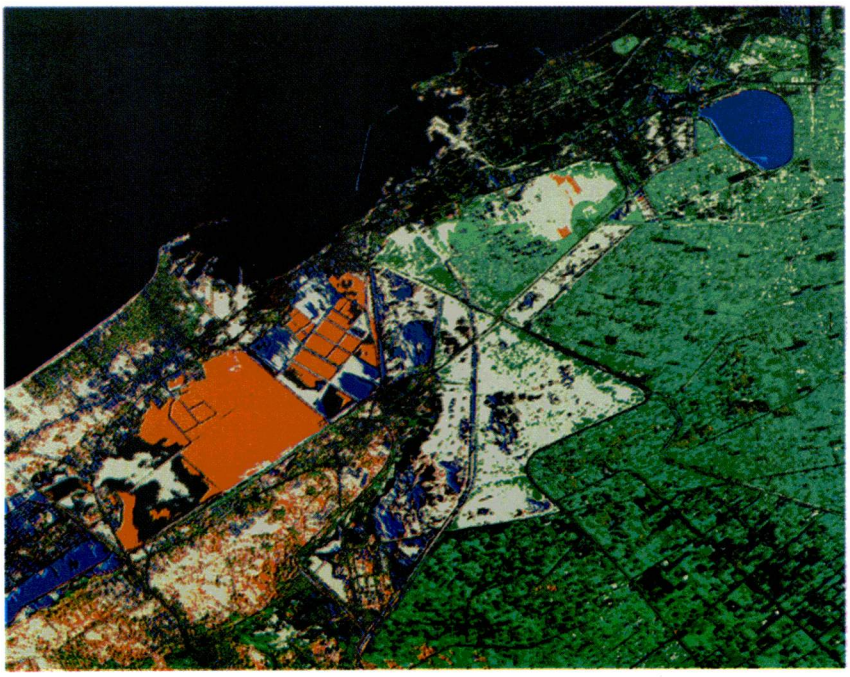

Fig. 6 Case study: the western part of the city of Alexandria, (a) the false color composite (vegetation, green areas, and irrigated fields are presented in red, (b) classification of open and built-up spaces.

Amount of open spaces: in the study area			in urban areas only	
Legend	Area (Hectare)	%	Area (Hectare)	%
Mediterranean Sea	5678432	22.46		
Water Body - Deep	636768	2.52	55056	1.97
Water Body - Shallow	708352	2.80	117984	4.22
Green Healthy (3)	745936	2.95	10496	0.38
Green (2)	3233120	12.79	119440	4.27
Green Poor (1)	2748080	10.87	124576	4.45
Disturbed Green	1152816	4.56	215840	7.72
Vacant - Derelict	3851792	15.24	373488	13.35
Disturbed-Polluted	1728688	6.84	85824	3.07
Urban (1)	1385728	5.48	444176	15.88
Urban (2)	3409696	13.49	1250080	44.69
Total Study Area	25279408	100	2796960	100

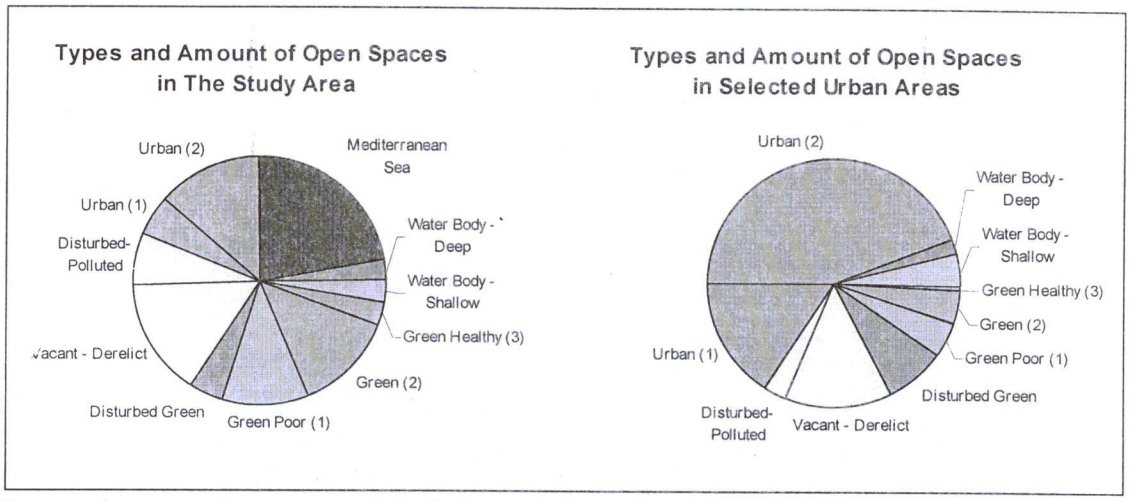

Fig. 7. Types and amount of open spaces in both the study area and in a selected urban highly populated area within the city of Alexandria.

connected to one another and also connected to other natural networks of different scales and objectives. The system sustainability is supported by buffer zones that work at eliminating or minimizing external urban related effects (fig. 8). This can be achieve by the appropriate use of various types of open spaces such as large parks, residential and public squares, private gardens, roads, alleys, and pedestrian walkways. The above mentioned natural network elements are described in the following sections.

4.2.1.1. Core Areas (patches) Since a natural network in cities needs to meet the requirements of both ecological and socioeconomic functions mentioned earlier, describing the types and location of patches cannot follow the methods applied in natural landscapes. In the case of the latter, the main criteria for defining core areas are a degree of naturalness and richness of species [15, 21, 25]. In urban context, open spaces available for core design are limited. Core areas in urban context should be those areas that fulfill the role of shaping climate, hydrological and socioeconomic functions in adjoining terrain. Core areas can range from conservation zones with little or no human disturbance, especially in suburbs (e.g. wetland), to active recreation grounds and entertainment areas. Several opportunities for a core design can be found in different forms in the cities.

The core areas can include spaces with, besides the function for nature, an agriculture or fisheries functions. Also included are water catchment regions, recreational regions, sea defense regions, and military reserved open areas. With less degree, some industrial yards, harbors, urban residential spaces, and piazzas could be developed as a part of the natural network of the city.

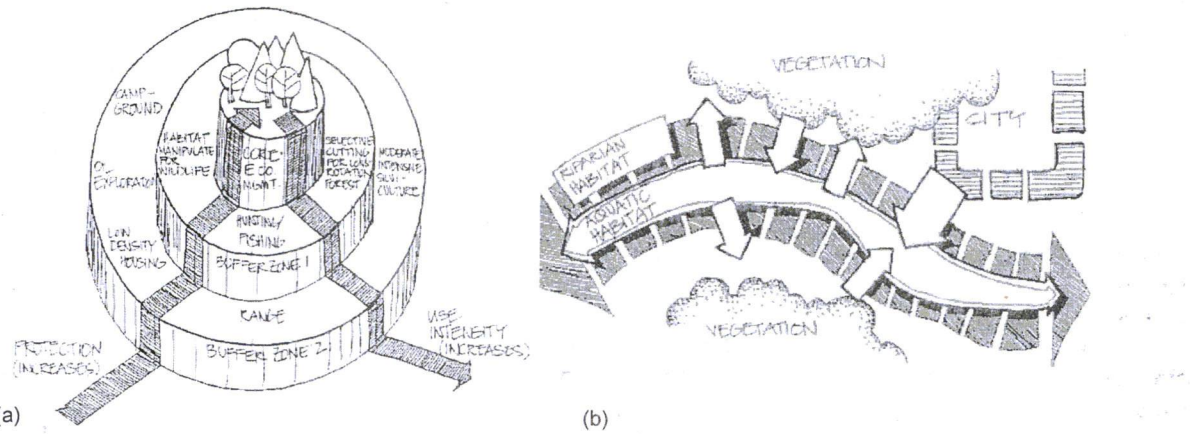

Fig. 8. Elements of a natural network: (a) patches or core areas, and (b) linear features or corridors [23] .

In fig. 9, several types of patches are detected within the study area. Typically, large patches are located westward and southward on the urban fringes (agricultural land, open areas, and Lake Mariut). Mostly important, the analysis of the remotely sensed data shows that it is possible to provide open areas within the city's fabric: small patches of parks, cemeteries, historical sites, and derelict land are distributed unevenly within the urban fabric.

4.2.1.2.Ecological (natural) corridors: The main connection between core areas can be formed through corridors of sufficient length and width, and enough variations in ecological elements. In natural areas outside the urban context, this can be achieved by combining it with existing watercourses, wetlands, main drain systems, and rural roads. To design such corridors, barriers must be removed between the natural network elements in order to achieve the integrity of the natural system. Within the city, ecological corridors can be created through the re-designing of existing strips of land along linear features such as roads, waterways, and railways.

Forman and Godron [13] recognized three types of corridors, on which existing and proposed linear spaces within urban areas can be classified: line corridors, strip corridors, and stream corridors. The distinction between line and strip corridors depends on the width, which affects the degree of naturalness of the corridor and the habitat function. Generally line natural corridors can be provided inside cities from existing road networks, residential paths, railways, promenades and walkways. Usually line corridors represent the minimal resources to achieve the accepted degree of naturalness required in the city. Strip corridors are formed from wider spaces that can be featured by large arterials, parkways, boulevards, transmission lines and highways, which are confined by a right of way wide enough to support a natural diversity (fig. 10). These links, have several characteristics that will determine the opportunities for alternative functions Hough, [26]: (a) they provide physical and biological links through the city to the surrounding countryside, (b) for the most part they have little active use, being regarded in many cities as 'waste land', and (c) public access is in many cases restricted for reasons of security and ownership.

According to Forman and Godron [13] the minimum recommended width for line corridors is 9m, for strip corridors, 61m. Stream corridors are characterized by the presence of a linear water features, such as rivers, canals, and stream ways. Turner [27] suggests that urban water features should be converted into blueways, by opening access of its banks to the public. However, other areas should be closed off to humans, so that wildlife habitats can develop.

Natural corridors are limited in the study area. Nevertheless it is possible to include other linear feature into the natural network system. Available linear resources are

presented in fig. 10, the most prominent are the Mahmoudia canal, the waterfront, and the transportation network (main roads, highways, and railways).

4.2.2. Network typology

Although the network was defined into its main components, there is a possible large amount of diversity in terms of the typology of its elements. The value and utility of these typologies lies in their potential to facilitate the planning and design of the system. Natural network structure in arid urban areas may vary according to scale, density of development, and types of surface materials. The typological values that will be discussed are: scale, hierarchy, connectivity, components, and materials. These elements should be involved in both the first and second phases of the proposed framework (fig. 5).

4.2.3. Value of scale, hierarchy and and connectivity

The challenge for sustainable landscapes has inspired a dialogue between ecologists and landscape planners suggesting that future landscapes should be spatially structured by a network of "patches and corridors" with the following design criteria [19] (fig. 11):

Maintain few large patches of natural vegetation, as well as wide corridors especially along major watercourses. If a network is to function effectively, the scale and hierarchy of its elements are important to discuss. According to Baschak [20] there are at least three scales of patches and corridors within a network to be considered: (a) a *community* is an area less than a few hectares (site scale), (b) a *series of communities* (local scale), and (c) a large geographic *region* (regional scale). In urban context it is advised that planner should provide hierarchical networks of open and natural spaces in site, local, and regional scales using patches and corridors.

- Maintain connectivity between the network elements at different scales, not only to facilitate migration of species, but also to provide unpaved natural interface for urban dwellers. People can then experience the process of natural ecology either on water corridors, or even on a desert environment. They can observe the good and bad aspects of how human activities interact with the environment, be it pollution or natural restoration projects. In addition to learning about nature, opportunities to interpret local culture and history emerge, as urban rivers, canals, and rail lines, which constitute some elements of the proposed network, are parts of cities history [28].

4.2.4. Components and materials

The quality of a natural network in urban areas is directly affected by the type of materials involved in shaping its spaces. The non paved urban spaces, mainly vegetation covered, can be an important resource for handling the hydrological cycle, and improving the micro-climate. In contrast, impervious surfaces of city streets and paved spaces and the stone and concrete of building surfaces have negative effect on the quality of the environment, specifically in:

- Storing and conducting heat much faster than soil or vegetated surfaces. The city temperatures get warmer than the areas outside. Furthermore, the much greater aerodynamic roughness of built-up areas has the effect of slowing down prevailing winds and diminishes the cooling power of wind in summer.
- Lowering the permeability of water infiltration surfaces. As a result, the ground water storage system is affected. Moreover, the amount of rainwater runoff increases. It is estimated that, in urban areas that are completely paved or roofed, the water runoff constitute 85 percent of the precipitation [29], causing erosion, low water quality, and excessive evaporation.

This can be overcome by taking the following precautions while designing urban landscapes:

- Even within very built up urban areas the mainly paved spaces between buildings can be designed to include green elements and previous pavement, important locally for air quality, temperature and wildlife.
- Local rain water retention and infiltration has positive environmental implications especially in areas with scarce water resources.

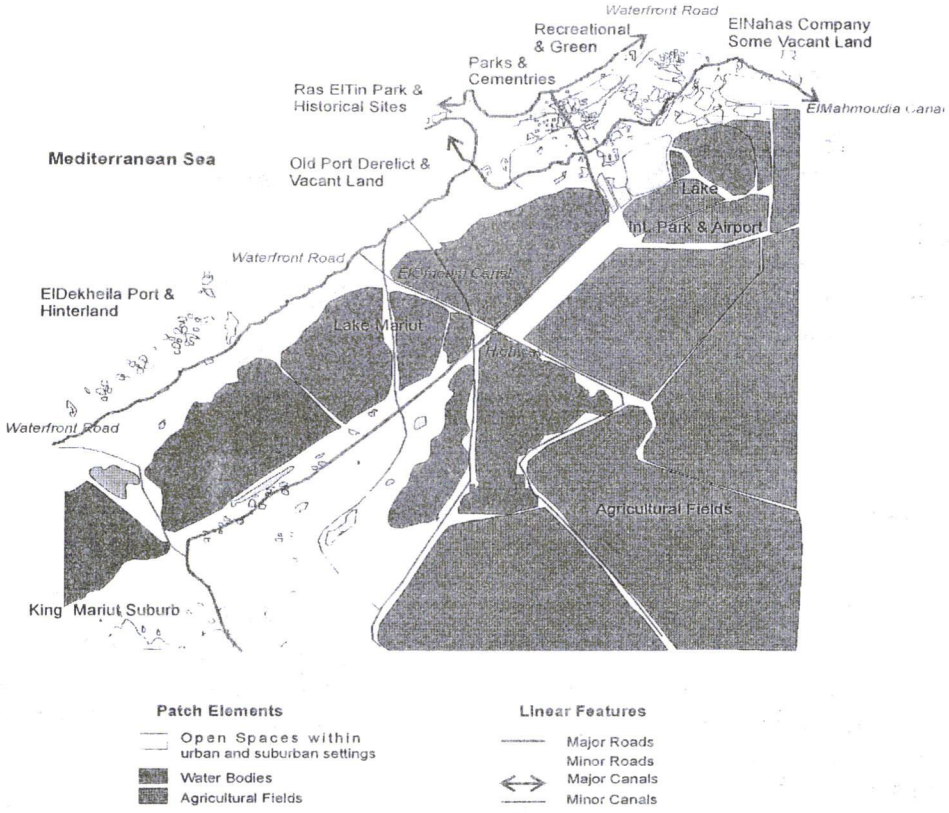

Fig. 9. Available patches and corridors (linear features) of open spaces in the study area.

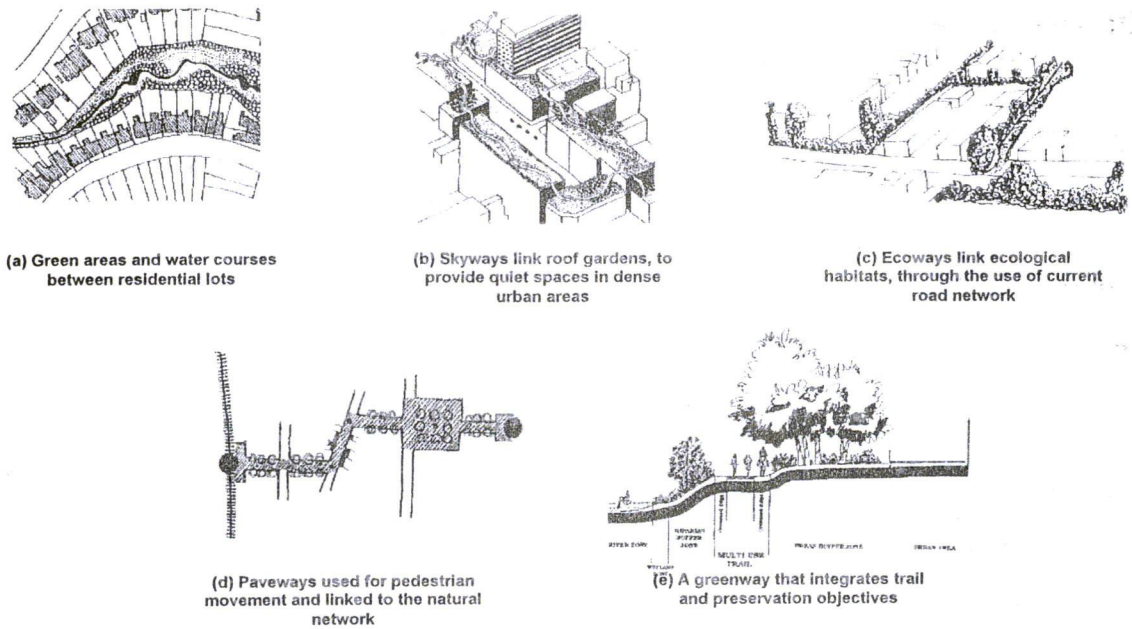

Fig. 10. Several solutions for the use of available urban linear features within a natural network system, (a.-d.) Turner [27], e. [28].

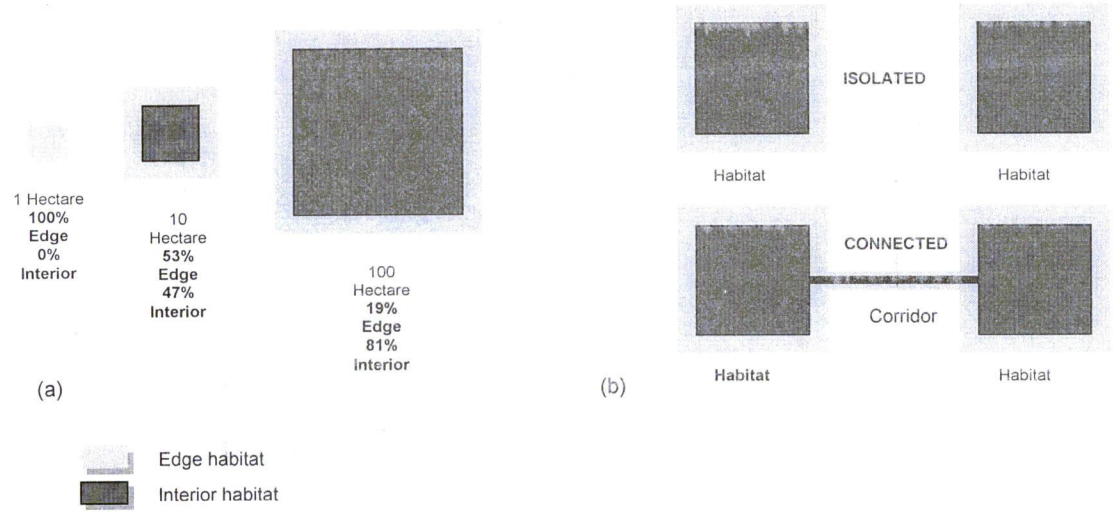

Fig. 11-a. Relationship between habitat fragment size and edge effects. As fragment size increases, the relative proportion of edge habitat decreases, and interior habitat increase, b. Diagrammatic presentation of the value of integrity and connectivity between patches [15].

- On the other hand, buildings need not act as complete ecological blockages in the development of network systems. In heavily built-up areas an increase in wildlife habitat can be achieved by the use of roof gardens, climbing plants on walls, the use of window boxes and so on.

5. Discussion and conclusions

The primary emphasis of this paper is to demonstrate the available opportunities in developing natural and green network systems in urban arid environments. It addresses three natural network related objectives: to provide a definition and review, to propose guidelines and typology, and to apply the guidelines to a selected case study. The central thesis presented is that natural network concept offers a promising strategy for planning sustainable environment in and around highly populated cities in an arid environment.

Natural networks provide ecological, recreational, and cultural benefits. It is assumed that it is possible, in low vegetated urban areas, to build the network by detecting and using all available open spaces. This can vary from large parks and water bodies to smaller derelict or unused spaces. Transportation networks and alleys could also assist in supporting linear connectivity between those spaces. In designing the network, it is also important to consider typological features such as hierarchy, scale, and materials. If natural networks are to support the concept of sustainable land use, they must also include social and cultural goals, not only those of environmental protection. Multiple use is central to the natural network concept. They must integrate historic, cultural, aesthetic, and recreational goals.

The application of the framework to the city of Alexandria, Egypt, revealed that locating open and derelict spaces using satellite imagery provides a useful technique for developing natural network systems. In order to reconnect fragmented landscapes, a conceptual system of nodes and interconnected corridors is proposed (fig. 12). Nodes (patches) are of different sizes, typically smaller within the city's urban fabric as a result of the limited space availability. An hierarchical distribution of nodes related to their size and location is also proposed. Smaller nodes are designed to be in close proximity to each other, while larger ones could be more distant, as far as they are connected by appropriate corridors. Large areas of agricultural lands and water bodies surrounding the city are of great importance in mitigating the negative effects of high population density, pollution, and small amount of available open spaces within the

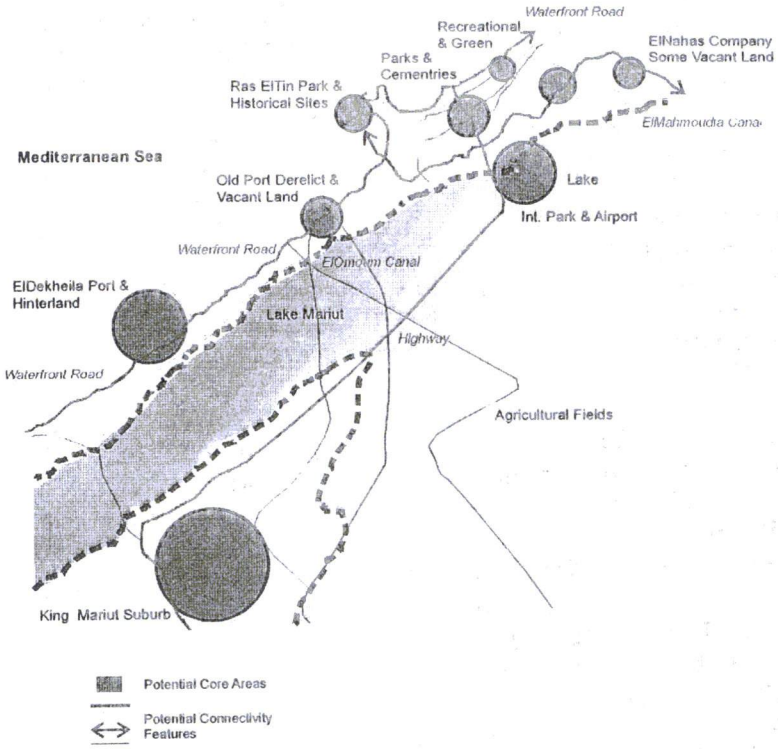

Fig. 12. Proposed nodes and interconnected corridors in the study area. The large zone (green) includes the lake and agricultural fields, and should be preserved to alleviate the effects of pollution, hot weather, and to provide a visual and physical contact for the over-crowded population of the city with open natural spaces.

city fabric. The second element of the natural network, the corridors, is designed from available wet and dry linear features to achieve the system integrity. The most prominent ones are the canals, railway, and several road types and classes. It is recommended that a degree of 'naturalness' should be considered for the proposed corridors. Both proposed nodes and patches should conform to the natural network functions and criteria described in sections 2 and 4. This study should be followed by additional comprehensive investigations in order to examine the validity of the proposed network elements, to test its ecological significance, and to carry out a detailed inventory of available open spaces characteristics.

In future developments, natural networks should be considered as an essential planning element from the first design phases. This can assist in providing healthy and enjoyable environment for the city inhabitants as well as conserving the nature.

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