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Criteria for Sustainable Planting Design Applications in Landscape Architecture Projects Under Arid Conditions

Abstract—Planting design is an important part of all Landscape Architecture projects (LAs). It needs new criteria in order to make it more sustainable. When arid conditions are dominant, these criteria will be more difficult. These limiting factors of harsh environment and aridity, such as high temperature and evaporation, low rainfall, poor and sandy soil, are largely diverse in many levels concerning water, soil, and climate. Thus they clearly appear in designing and impeding sustainable LAs. The planting design in LAs is governed by three major factors which are: plant species, water availability, and the control soil property and climate conditions. However, the designer can adjust and customize these designs aiming at satisfying sustainability principles by carefully selecting plant materials from native or exotic plants and dealing with new practices effectively within the landscape, such as managing water supplies, irrigation methods, plant water requirement (PWR), modifying soil properties to be more efficient, appropriate to hold water, and developing the planting design techniques to restrain aridity conditions. This study adopted field and environmental analyses of real projects to reach new criteria for planting design in LAs that are able, by increasing the functional and environmental compatibility to achieve sustainability under aridity conditions.

Keywords: planting design, Landscape Architecture, plant material, arid regions, sustainability, exotic plant, and native plant.

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1. Introduction

The environmental challenges that modern cities are facing, particularly in the arid conditions, are increasing dramatically and the green areas contribute to reducing their impact through designing environmentally sustainable Landscape Architecture projects (LAs). Applying the principles of sustainability in these projects is one of the most important ways to reach environmental projects that are suitable for the harsh conditions prevailing in the arid regions.

Sustainability is defined as the continuous effort to meet the needs of the present generation without compromising the ability of future generations to meet their needs [1]. The theory of sustainable landscaping, in general, comprises all the environmental, social and economic elements [2] and it has aesthetic as well as economic advantages [3]. Sustainable landscape planting can be defined

also as that which minimizes energy or physical resource inputs (water, fertilizers, pesticides, etc.) in stock production, plant establishment and vegetation management, which is locally appropriate (in terms of species selection and source) and maintains ecological integrity [3].

Successful and sustainable landscape planting design under arid conditions faces many challenges such as plants species, soil and water levels.

Therefore, Landscape Architecture (LA) designs must be able to overcome these challenges, and perhaps plant designs are the ones that can address the environmental problems correctly [4] and they should have relatively low-maintenance costs, be as sustainable as possible, taxonomically diverse, demonstrate marked seasonal change, and support as much wildlife as possible [5].

LA was introduced to the Middle East region by modern architecture, as elsewhere in the developing

world, and therefore was highly influenced by Western ideas of space [6]. In the Middle East today, there are strong tensions between global and local aspirations in landscape architectural projects. Modernism has led to design approaches that were detached from the local context, while some adopting approaches inspired by Western models with only little adaptation [7]. Most of the urban landscapes that are inspired by western landscape designs are primarily focusing on aesthetics factors [2].

Plant material is one of the major components used by LAPs. It contains all types of plants (trees, shrubs, ground covers, climbers, etc.) used in planting design. Three functions of planting design are utilized in LAPs [4,8]: (1) architectural functions (creation of space, screening, privacy control), (2) environmental functions and climate control (modifying air temperatures, cleaning the air and reducing pollution, retaining moisture in the soil, fencing and windbreaks, providing shadow, sand dunes stabilization, preventing erosion and loss of soil and providing habitat for birds and animals aiming for wildlife conservation and supporting), and (3) visual or aesthetic functions (complementary, unifier, emphasize, acknowledger, softener, view enframement).

In the arid region, harsh conditions are dominant. The rainfall is low and usually received as thunderstorms causing floods [9]. Descending air tends to get warmer, which decreases its relative humidity and increases its “dryness” [10]. Humidity in the air is higher and dew is a valuable addition to the total volume of water available. Temperature and radiation extremes are still a common feature [9]. Most arid lands lie in the tropics and therefore, receive substantial inputs of solar radiation energy, which can be expended on heating the environment, wind generation, or be utilized for evaporation [10].

Large parts of the arid region are covered by light textured sandy soils. The geological conditions and the arid climate lead to poor soil development [11] and to a loose and rocky land surface and the evaporation increases the salinity. The surface topography of the earth, including plains, slopes, flatlands and valleys, is clearly reflected in the behavior of water flowing on the surface as well as on the soil and their properties [9]. Whenever possible, landscape architects should strive to work with the existing situation because the results are likely to be more sustainable than if soils were transported or manufactured soils [12]. However, it

is necessary to improve the physical properties of soil to get the optimum plant growth.

The water resources in the area are very scarce which reflect in the type of water used in agricultural practices which consume large amounts of fresh water.

The plant materials used in the design become exotic species in LA projects which is unable to resist the prevailing conditions in the arid region especially in countries like KSA [13], UAE [2] and Oman [14]. Exotic plant species need high maintenance and need substantial support systems to keep them alive. Moreover, these exotic plants are mostly introduced from the temperate and semi-temperate regions to the arid environment and have high water irrigation requirements [2].

Novice and professional Landscapers are now turning to native landscaping practices in order to reduce maintenance and promote plant and wildlife conservation [15]. Selecting species from a natural habitat that is closely matched to the landscape site is the key to success [3]. Native plants species usually include species that are found to occur in distinct natural places without the aid of humans, and that have adapted to local climate conditions (high temperature, drought, salinity, high wind velocity) leading to the high efficiency of water consumption, minimization of maintenance time and cost [3]. Hence it has economic value in some cases, especially when used in urban areas. They have provided new design features with their flowers, leaves, plant forms and colors and will eventually become a distinctive feature of LAPs in these regions [9]. Using native plants will reduce not only water requirement but also the maintenance, fertilizer and pesticide cost of any landscape project [2].

The main objective of irrigation in LAPs is to add sufficient water to the plant to ensure its health and good appearance [16]. Nevertheless, it is difficult to determine the amount and time of irrigation because there are many other factors that depend on it, such as soil type, root system size and depth, plant density and water quality as well as other critical factors such as temperature, humidity and wind [17]. For that, plant materials in LA are often given more water than their actual requirement to compensate maintain the environmental site conditions and preserve the aesthetic appearance for the species [18]. Several methods were applied for the estimation of plant water requirement (PWR) of the plant in LA; some of these methods have a clear-cut set of rules while others depend on

the personal experience [18]. Although, watering resources are scarce, the landscaping sector solely consumes one-third of the total water supply of the green sector in UAE, this trend is highly expected to increase, especially with the urbanization and the sharp population growth in the country [19].

The soil provides a structural base to the plants and allows the root system (the foundation of the plant) to spread and get a stronghold. Plants normally have a higher concentration of roots close to the soil surface and the density is decreased with the depth [11]. The available water holding capacity, which is the water retained by an initially saturated soil against the force of gravity, for a few typical soil types in the arid region are very low [11].

The main objective of this research is to investigate and analyze the planting of LAs in different Gulf cities to produce high performing and successful sustainable practices which are able to increase the functional and environmental compatibility to achieve sustainability criteria under the arid and semi-arid conditions.

2. Materials and Methods

Field survey and observations were recorded on the LAs in six different Gulf cities during the period 2014-2018. Numbers of plant design structures were analyzed in order to determine patterns of relationship between them and the environment in terms of altitude and the characteristics of the climate.

The plant structures and environmental analysis for several LAs in the study area were analyzed. This includes the plant species and usage, ability to resist drought, adaptation for environmental conditions, and suitability for use in arid and semi-arid conditions. Soil properties and characteristics, irrigation systems and water quantities were also studied. The climate data were collected for all studied Gulf cities. On another hand, this study focused on the plant selection in these projects as it the main part of successful sustainability in the planting design projects. The types of plant (trees, shrubs, ground cover or grass), drought resistant species, and native species were recorded and analyzed. The plants were classified according to drought resistance into five groups (resistant, tolerant, mild tolerant to drought, non-tolerant, water-demand) [18]. Soil types and properties, irrigation systems, water quality and quantity to several studied projects are not available. Hence, the data were collected from the cities' municipalities and their websites.

3. Study Area

The study area has covered five cities in KSA and UAE. In each city, one or two projects were selected to cover one neighborhood or the whole city (Table 1). All cities in this study are located in the arid region except the Taif area which is located in the semi-arid region and these belonged to either the Saharo-Arabian or the Sudano- Zambian geographical regions [20].

Table 1: The LA projects names, codes, location and the total area of the studied projects.

LA projects names	Projects code	Location	Total area m ²
Al Ain-Abu Dhabi road	P1	Abu Dhabi, UAE	2,450,000
Umm Emarat park	P2	Abu Dhabi, UAE	305000
Mirdif park	P3	Dubai, UAE	15,660
Al Mamzar Park	P4	Dubai, UAE	800,000
Al-Jahali park	P5	Al-Ain, UAE	250000
P.Mohamd	P6	Al Madinah, KSA	73,500
K.Fahed	P7	Al Madinah, KSA	736,500
Salam Park	P8	Riyadh, KSA	287,650
Al-Hajar park	P9	Riyadh, KSA	28,100
Oliah park	P10	Riyadh, KSA	35,000
Al-Khuzama garden	P11	Riyadh, KSA	21,700
Mohammed bin Qasim park	P12	Riyadh, KSA	67,500
Alruddaf park	P13	Taif, KAS	565,000
Jeddah Corniche N	P14	Jeddah, KSA	700,000
Al-haramayn district	P15	Jeddah, KSA	1,260,000
Majd park	P16	Jeddah, KSA	238,600

The climate data show that the maximum temperatures are greater than 34.4°C and it reached to 49.3°C in Abu Dhabi and Al-Ain while the minimum temperatures are less than 5.6°C (except for Jeddah 18.1°C). The annual precipitation ranges

between 60-160 mm/year and the relative humidity ranges between 11-65% while the maximum wind velocity exceeds 50 km/h in all examined stations (Table 2).

Table 2: The climate stations data and their altitude for the studied cities.

Climate stations	Jeddah	Taif	Riyadh	Al Madinah	Dubai	Abu Dhabi	Al-Ain
Altitude (m asl.)	16	1452	613	635	19	27	265
Max temperature (°C)	38.8	35.3	44.4	34.4	48.8	49.3	49.3
Mean temperature (°C)	28.2	22.8	26.2	28.4	27.8	27.7	28.8
Min temperature (°C)	18.1	8.4	7.7	11.6	7.4	5.4	5.6
Precipitation (mm/year)	54	165	115	65	86	62	62
Relative humidity (mean %)	54-67	24-61	11-52	12-39	49-65	48-68	30-63
Wind velocity (km/h)	118.5	124	101.8	111.2	72	66.7	87
Period (year)	35	35	10	27	35	35	22

Source: The General Authority of Meteorology and Environmental Protection in KSA and the National Centre of Meteorology and Seismology in UAE.

4. Results

The results of this study show that several projects in this study area have succeeded in achieving sustainability of planting design applications, whereas many of them are still suffering from a clear deficiency of these applications, which causes a lot of difficulties in environmental conditions and increases the costs of establishing and maintaining projects.

The results show that the number of plants species that were used in each project were hugely varied. The highest numbers were recorded in P4, P5, P13

and P14 (44, 47, 40 and 57 species, respectively) and the lowest records were in P1 and P12 (3 and 7 species, respectively). In fact, the tree layer was the most dominated in all the projects, while the turf grass area represents between 45-70% in the area of the project except for P1, P9 and P15. The palms were used in 11 projects sharing other trees to make effective shading and to cover the soil, but the shrubs (succulents, and pseudo-palms) were just used in small beds as an individual sample (Table 3).

Table 3: Description of planting materials, soil and water in the studied LAs in this study.

Projects code	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
Total No. of species	3	34	27	44	47	13	16	21	14	28	12	7	40	57	17	14
Plant type ¹ (trees&Palm)%	1	16	12	22	18	8	10	14	6	15	6	5	12	24	7	8
Plant type (shrubs)%	2	13	7	11	18	3	2	6	7	5	6	1	11	24	7	4
Plant type (ground cover)%	0	5	7	10	11	2	3	1	1	7	0	0	16	8	2	1
Plant type (Grass)%	0	30	25	20	70	0	2	45	0	65	0	20	30	15	5	-
Exotic T&VHDR2 species	0	35	6	11	17	7	9	9	7	12	6	4	9	12	7	6
Exotic MDR species ³	0	12	7	12	14	4	4	8	4	8	4	1	7	17	5	4
Exotic L&VLDR ⁴ species	0	8	10	12	16	0	1	1	1	6	2	0	13	19	3	1
Native species	3	7	3	8	8	2	1	3	2	1	1	1	10	8	1	2
Plant-soil cover ⁵	1	m	m	h	h	h	m	m	h	m	h	h	l	m	m	l
Irrigation system ⁶	D	S,D, B	S,D	S,D, B	S,D, B	D,B	S,D, B	S,D, B	D,B	S,D, B	D,B	S,D, B	S,D, B	S,D, B	S,D, B	S,D, B

The major turf grass¹ in the projects is *Cynodon dactylon*.²Exotic T&VHDR: Exotic tolerant and very drought resistant species. ³MDR moderate drought resistant. ⁴L&VLDR low and very low drought resistant. ⁵Plant soil cover (High coverage (h), Medium coverage (m), Low coverage (l)). ⁶Irrigation system (Sprinkler (S), Drip (D), Bubbler (B)).

The total number of species recorded in all studied projects was 114 species. The number of species

which was classified as tolerant and very high drought-resistant plants were presented by 33

species and the number of native species was just 13 species, *Ziziphus spina-christi* and *Dodonaea viscosa* were the most popular native species used in the projects while *Bougainvillea spectabilis*,

Conocarpus lancifolius and *Prosopis juliflora* were the most used as the exotic drought-resistant species (Table 4).

Table 4: The plant lists of native and tolerant and very drought resistant species and their percentages were used in the study projects.

Native plants	%	Exotic tolerant and very drought resistant plants	%
<i>Adenium obesum</i> (Forssk.) Roem. & Schult.	31	<i>Acacia nilotica</i> (L.) Delile	13
<i>Aloe vera</i> (L.) Burm.f.	25	<i>Agave americana</i> L.	50
<i>Atriplex halimus</i> L.	13	<i>Agave americana</i> var. <i>variegata</i> Hook.	13
<i>Dodonaea viscosa</i> Jacq.	50	<i>Albizia lebbek</i> (L.) Benth.	50
<i>Hyphaene thebaica</i> (L.) Mart.	6	<i>Azadirachta indica</i> A.Juss.	31
<i>Lantana camara</i> L.	25	<i>Bougainvillea spectabilis</i> Wild.	88
<i>Leptadenia pyrotechnica</i> (Forssk.) Decne.	6	<i>Coccoloba uvifera</i> L.	13
<i>Nerium oleander</i> L.	19	<i>Conocarpus lancifolius</i> Engl.	88
<i>Salvadora persica</i> L.	13	<i>Cordia myxa</i> L.	13
<i>Tamarix aphylla</i> (L.) H.Karst.	19	<i>Leucaena leucocephala</i> (Lam.) de Wit	31
<i>Ziziphus spina-christi</i> (L.) Willd.	50	<i>Leucophyllum frutescens</i> (Berland.) I.M. Johnst.	31
		<i>Moringa oleifera</i> Lam.	13
		<i>Parkinsonia aculeata</i> L.	25
		<i>Pennisetum divisum</i> (Forssk. ex J.F.Gmel.) Henrard	13
		<i>Pithecellobium dulce</i> (Roxb.) Benth.	13
		<i>Prosopis juliflora</i> (Sw.) DC.	44
		<i>Thespesia populnea</i> (L.) Sol. ex Corrêa	19
		<i>Washingtonia filifera</i> (Linden ex André) H.Wendl.	63
		<i>Washingtonia robusta</i> H.Wendl.	25
		<i>Yucca aloifolia</i> L.	38

The certain irrigation system was used in all projects. The sprinkler irrigation system was used with grass while the drip and bubbler irrigations were applied for the other plant species. The soil in all projects was modified by different levels by adding soil conditioner (organic matter and peat-moss and compost).

The analysis of the planting in landscape architecture criteria in the current projects showed that they could be classified into four types as follows:

1) Traditional practice: These practices were applied in a previous period when the projects were trying to introduce new species into the sites especially trees such as *Azadirachta indica*, *Conocarpus lancifolius*, *Eucalyptus camaldulensis*, *Prosopis juliflora* as the main aim was to increase the shade. In fact, no landscape planting design principles were recognized in that projects and these species were present in current projects as remnants of planting from the previous period. This type was recorded in projects P8 and P12.

2) Planting design in LA: It was used widely in a good number of the studied projects (P2, P3, P5, P8, P13, and P14). The principles of planting design were applied in LA, but the projects were aiming for an aesthetic visualization.

3) Limited sustainability: It was also documented in various projects (P1, P6, P7, P9, P11, and P12). Designers were trying to apply the principles of sustainability in LA plant design, especially when the plant selection was concerned in drought-resistant plants and native plants which reflect on the quantity of used water, the cost, and maintenance. These projects still suffer from several difficulties, thus not able to reach a high level of sustainability.

4) Sustainable planting design: These types of projects are the ones that we are looking for in the future when the LAs have applied sustainability criteria in design ideas, planting materials, services, and practices.

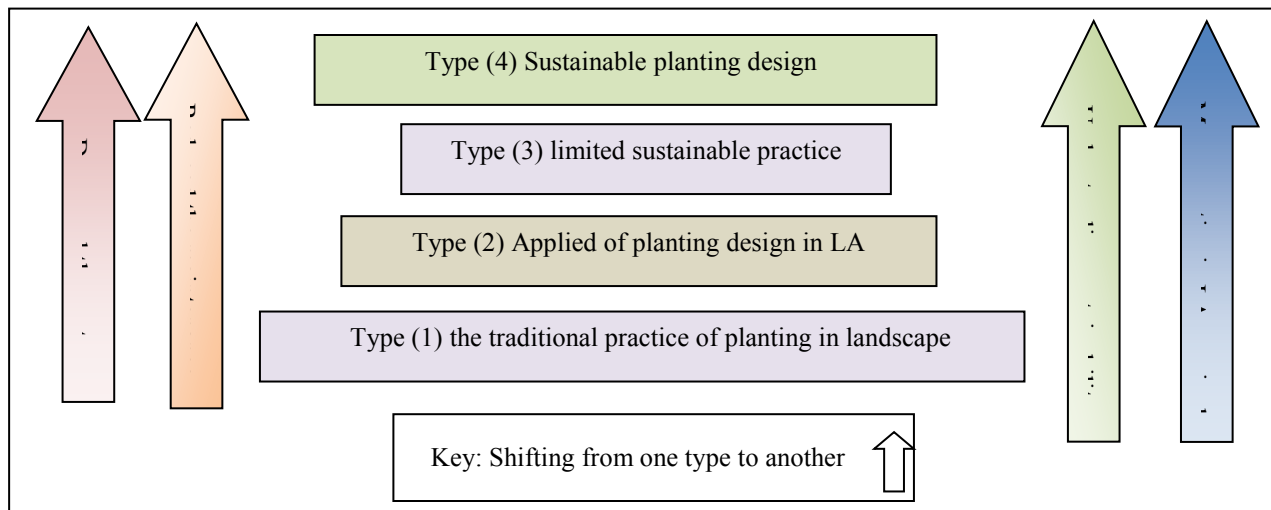


Figure 1: Types of planting design practices that were applied in the studied projects and the practice for shifting from one type to another.

5. Discussion

New applications in sustainable plant design in LA still appear at local and global levels. The climate change will increase temperature and that will directly affect the evapotranspiration value which in turn will increase the demand for water significantly [21]. For that reason, if we are looking for maximizing benefits, reducing maintenance, minimizing costs and reaching successful sustainable LA under arid conditions it is necessary to review the criteria of planting design and selection and management of plants. Principles of successful and sustainable planting design under arid conditions depend on criteria of plants, soil, water, and maintenance.

The field analysis of the studied LAs in this research shows that many applications can be suggested to achieve this goal. Hence, all the criteria proposed in this study such as plants selection, limiting turf grass area, efficient irrigation, soil improvement, mulching and proper maintenance were presented in Table 5.

The exotic drought-resistant species were used widely in planting until now because they were produced widely in the local nurseries and the experience of using them is available. However, the better alternative of exotic plants for the arid region is the native species. In fact, the limited availability of the native plants in the nurseries, lack of experience of their use and scientific research on propagation techniques will generate real problems for LA projects; therefore specific propagation guidelines would be extremely valuable for

nurseries and other green industry professionals [24].

The process of increasing the ability to retain water in the wet zone as long as possible and reducing water drainage is very important. It contributes to conserve the irrigation water, reduce the washing of nutrients and keep the plants in good health.

The soil in the arid areas is poor, coarse structure and weak to preserve the water. It is very important to improve the soil properties to get the best plant growth. Landscape architects can effectively manage soils on their project sites by restoring the site soils through various amendments, importing native soils to the project site, and by specifying the use of manufactured soils [12]. Soil conditioners materials (peat moss, compost, and organic matter) are the best way to improve the physical soil properties in most LAs. They increase the soil's ability to retain water by holding water 5-15 times in volume. Therefore, Landscape architects should add up such materials to the soil in arid and semi-arid areas to achieve several benefits that include reducing losses through drainage or evaporation, conserving irrigation water, improving soil structure to control excessive drainage of irrigation water, increasing ventilation, and soil cohesion. The sandy loam, loam, and silt loam textures are normally selected as some of the best soil textures for a wide variety of landscape plants [12].

For increasing the efficiency of irrigation water in planting design, we must ensure that the surface of the soil is covered by multilayer of shading plants. In practice, the combination of a tree and shrub layer of cultivated species with an under-planting of

indigenous perennials has proven valuable [3]. The ground cover plants or other mulch materials such as gravel will contribute to the preservation of soil water. One of the critical issues with design planting is the recognition that it is always the least drought tolerant species that determine the irrigation regime [3] for that, hydro-zone must be created to group the plants depending on their water requirements.

The concepts of sustainability technique or methodology are still unclear for many gardeners and stockholders need more clarification to adopt them. Therefore, education and scientific research and experience will increase their awareness and

their demand to apply these concepts to produce optimal results.

In spite of the importance of the processes that can be applied to plant design, which is related to the basic elements of the plant, soil and irrigating water, there are other important procedures related to the relations between these elements and the impact of each other. A good understanding of ecology and phytosociology of the natural vegetation is required for new sustainable planting design ideas which will reduce the impact on the environment and conserve the wildlife [25], and consider longevity, competitive behavior and minimal maintenance [3].

Table 5: The recommended criteria for sustainable planting design in LA in the arid region.

Key of criteria	Description issues	reference
Plants		
Appropriate plant selection	Use of native species, drought-resistant exotic species.	[22], [23]
Planting to be in the appropriate place	Use the plants for the right site that is, high PWR plants at the lowest point, and low PWR plants at the highest point.	[23]
Multilayer planting	Use high trees and date palm (Native trees) to cover the land, generate shading and provide suitable habitat wildlife. Few numbers of plants can cover a wide area from the landscape. Trees perform all of these functions for very low cost over their lifetime. Short and medium shrubs rows cover a large area of landscape with low quantity of water	[23]
Reduce using the turf grass	Less turf, use ground cover and other materials in lieu of turf.	[22], [3]
Functional compatibility between species	Used drought resistant ground cover to create space and use of appropriate grass species to suit the conditions	[23]
Aesthetic compatibility in the design	Achieving aesthetic compatibility between species	[3]
Propagation plant	A plant (trees and shrubs) propagated by seed is capable to tolerate the arid region condition.	
Soil		
described soil	the soil areas should be described in detail explaining (soil layer, and drainage layer, soil physical, organic compost, chemical (electrical conductivity, PH), and biological characteristics)	[12], [23]
Soil amendments	Add conditioners to improve the soil texture and aggregation, soil absorption and drainage.	[12]
Cover the soil surface	Use appropriate mulches to minimize evaporation.	
Water		
Efficient irrigation	Give the plant the correct PWR, create hydro-zones, irrigate the wetted zone	
Irrigation Applications	Direct through providing water for the root zone, irrigation at night. Use a controlled drip and sprinkler irrigation system	[23]
water resource	Reduce potable water use for landscape irrigation but use recycled gray water	[22]
Maintenance and practices		
Appropriate Maintenance	Reduce the usage of herbicides, pest control and chemical fertilizers. Selected pruning should be applied	[23], [12]

6. Conclusion

Many cities in the dry regions are trying to reach sustainability in LAs. However, the concepts of sustainability are still unclear and need criteria clarification. Principles of a successful and

sustainable planting design under arid conditions depend on special criteria of using plants, soil, water, and maintenance. This study aimed to reach new criteria for planting in LAs, by increasing the functional and environmental compatibility in order

to achieve sustainability under aridity conditions. The results showed that numbers of LAs have been able to implement sustainable design approaches by using shading trees and drought-resistant plants and providing highly controlled irrigation systems. While many other projects have not been able to apply sustainability criteria in planting designs, this is clearly illustrated by using large areas of turf grass, depending on plants with high water requirement, and a low number of drought-resistant species and native species. In fact, using native species in LAs is a prerequisite for the next phase, but the current reality does not provide what it takes to use.

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