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Development of sustainable landscape design guidelines for a green business park using virtual reality

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ABSTRACT

Green business parks (GBPs) are attractive to employees because of their environmental and social benefits. Recently, sustainability has become an international trend that is intended to tackle climate change. Therefore, there is a persistent need for sustainable landscapes in GBPs to ensure that workplaces are productive and healthy. The main focus of this research is developing a methodology of the GBPs` landscapes, in order to guide the stakeholders in the decision-making process. Moreover, getting users` and experts` opinions using Virtual Reality (VR) techniques plays an essential role to correctly predicting how a space will perform. By considering these contexts and their significance to sustainable development in a hot-dry climate area, the study evaluates the practice of landscape design for a GBP in terms of compactness and greenness. Consequently, three different landscape design models—formal, xeriscape, and biomimicry designs—were constructed as 2D and 3D models on AutoCAD and SketchUp. Then, the three alternatives are evaluated by experts and users using VR headset and mobile devices (MDs). The main finding is merging the sustainable principles with the aesthetic appearance which satisfies the users` opinions. The essential aim of this study is creating guidelines for sustainable landscape design for the future GBPs.

1. Introduction

1.1. Background

Climate change and global warming are complex global issues with environmental, economic, and social, effects. Solving them will require globally and locally coordinated responses. One possible way forward is sustainable city planning, which decreases the negative effects of cities on the environment and climate. Consequently, a sustainable urban environment that focuses on the amelioration of the environmental conditions is fundamental. Regarding this context, it is worthy-noted to point to the landscape design, and its impact on the urban environmental balance (Coccolo, Kämpf, Mauree, & Scartezzini, 2018).

Furthermore, compact cities are one strategy for creating more efficient, livable, and sustainable cities, where careful planning is undertaken to manage expansions (Vaggione, 2013). Urban sprawl reduction, as well as promoting bicycle use and moving away from motorized transport modes, may reduce the greenhouse gases associated with urbanization and climate change. New Borg El Arab City (NBC) in Egypt is a compact city intended to reduce the congestion in Alexandria. The green spaces provide a way to maintain the livability of the city and also establish breathing spaces within the urban environment. Urban green spaces can alleviate urban warming troubles to some degree (Xiao, Dong, Yan, Yang, & Xiong, 2018). Consequently, business parks (BPs) can contribute more to the city`s environmental enhancement than can the huge office buildings in the city center. The main features of BPs are promoting more green spaces through the office buildings, as well as moving by environmentally friendly transportation like bikes (S. M. Atwa, Ibrahim, & Saleh, 2017). Subsequently, they can contribute to mitigate the climate changes. So, the business parks are considered as a promising step towards establishing new environmental resilient sustainable cities.

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1.2. Purpose

At present, Egypt is facing many challenges related to its rapidly growing cities and sustainable development. EcoCities are one way to deal with both (Antuña-Rozado, García-Navarro, Reda, & Tuominen, 2016). The current study attempts to mitigate businesses' negative effects on the local natural environment and human well-being. This study can be a part of the framework of the Eco NBC project outlined by VTT Technical Research Centre of Finland, which focuses on sustainable community and neighborhood regeneration and development. The aim of the VTT study is to contribute to the transformation of NBC into an EcoCity (Antuña-Rozado et al., 2016). The essential target of this research paper is elaborating design guidelines for landscape sustainability in an open space at a BP in NBC, which can be considered as a step toward green business parks for the new sustainable cities of Egypt. Furthermore, the research focuses on using VR technology to promote the users` participation and obtain reliable feedbacks that can help architects in the future decision-making so as to optimize designs and meet consumers' needs and preferences.

1.3. Relevance

Studies have revealed that countries' development depends on their economies; this emphasizes the necessity of adequate office buildings. After transportation and industry, buildings and public sectors are generally responsible for the most carbon emissions. It is estimated that residential and commercial buildings in the Middle East produce 20–25% of carbon emissions (Gelil and Saab, 2015). Regarding Egypt, World Bank data show that in 2014, 8.5% of CO_2 emissions were produced by domestic buildings and the commercial and public sectors (The World Bank Group, 2017). Most tall office buildings are lacking when it comes to the environmental and social dimensions of sustainability(S. M. Atwa et al., 2017). Therefore, BPs have recently appeared as a way to accommodate business offices and light industrial corporations by grouping them together. Since 2000, the BP concept has appeared as a new form of development in Egyptian cities. Examples include Smart Village (Silicon Waha, 2016) on the Alexandria desert road, with a total plot area of 3 million m^2; Cairo BP (Business Park, 2013) in New Cairo, with a total plot size of 75,615 m^2; Capital BP (Dorra Group, 2012) in Al-Sheikh Zayed City, with a total plot area of 35,000 m^2; and Silicon Waha in NBC, with a total area of 126,002 m^2. These parks allow people to escape the intensive crowds of the capital cities, thus providing a solution to the centralization problem. They provide employees with the opportunity to use safe workspaces in the form of designed green areas surrounding the buildings(S. M. Atwa et al., 2017). Employees can thus focus more on the surrounding environment and the view from the windows, instead of just direct interactions with the interior workspaces, which have been addressed in many previous studies(S. M. Atwa et al., 2017).

As previously mentioned, the significance of a BP is its location outside the city center, where the land is cheaper and the urban pollution is much less severe(S. M. Atwa et al., 2017). BPs help to reduce stressful work environments, solve the ugliness of nearby parking lots, and promote the desirability of preferred walkable areas, thus benefiting employees' physical and mental health; these problems have often been talked about in relation to workplace areas (Kaplan, 2007). There is a considerable difference between office environments that are merely not damaging and those that advocate health and human well-being and foster productivity (AMRP, 2012). Designing inclusive, mixed-use societies with proper access to employment, shopping, recreation, and health care will assist in reducing car rides and promote healthier and more active lifestyles (Stone, 2016). Environmentalists usually view new business sites as massive urban developments that destroy landscapes and biodiversity values (Snep, Ierland, & Opdam, 2009). Consequently, recent studies have focused on the impact of enhancing biodiversity at business sites, which is, in fact, an effective way to achieve more sustainability in a specific region (Snep et al., 2009).

Furthermore, a positive relationship between access to a green outdoor space at work and decreased worker stress and improved attitudes in the workplace has been found in many previous studies (Lottrup, Grahn, & Stigsdotter, 2013). Interactions between buildings and landscapes brings people enjoyment and enhances workplaces (Saleh & Nassar, 2011). In addition, the green spaces in BPs provide substantial environmental benefits. The prior studies have shown that urban green spaces, can successfully mitigate UHI effects (Xiao et al., 2018). The green spaces recover the ambient environmental quality because they enhance the microclimate, absorb pollutants, reduce noise levels, and engage in sustainable urban design (edukalife, 2017). Additionally, green plants can promote indoor and outdoor environmental comfort, while providing many environmental advantages like carbon storage, reducing air pollution, and good habitats for urban biodiversity (Xiao et al., 2018). Moreover, green areas contribute to cooling as they have lower daytime and nighttime temperatures than the surrounding spaces (edukalife, 2017). Urban vegetation can also enhance the life quality and enable people to be into contact with the nature (Xiao et al., 2018). For example, trees can mitigate the effects of concrete and glass, which can turn BPs into ovens under the summer sun. Therefore, the combination of green spaces with urban planning is substantial for adjusting to and lessening the high thermal impacts of urban heat island processes (Xiao et al., 2018).

The actual challenge that should be addressed by urban planners is to enhance the natural ventilation in the built environment, and to preserve the livable outdoor conditions, which can be reached by a sustainable landscape design (Coccolo et al., 2018). The landscape has a considerable potential in reducing excessive climatic conditions in the outdoor thermal comfort, by moderating the air temperature (Coccolo et al., 2018). However, numerous urban landscapes are resource hungry, requiring considerable inputs of water, energy, and nutrients, while some plant selections are inappropriate for hot environments. The consequences of this are that often green parks, which are thirsty, consume unsustainable materials, contribute to water contamination, and provide limited habitat for native flora and fauna. To ensure landscape sustainability and secure a healthy future, landscapes should be made more efficient in their utilization of resources and should act *with* the ecological and climatic conditions rather than *against* them. For instance, the American Society of Landscape Architects (ASLA) set the main elements of sustainable landscaping as site selection and layout, vegetation, water consumption, soil, air and energy, waste management, and material selection (Sean Wheeler & ASLA, 2009).

Moreover, so as to guarantee an efficient workplace for employees, the participation of users is an important issue that should be considered so that architects can meet the customers' needs and improve the whole decision-making process (Saleh & Nassar, 2011). Users' knowledge of the landscape formation processes is essential in performing landscape assessments (Loures, Loures, Nunes, & Panagopoulos, 2015). Also, public contributions to plans can ensure the most effective use of limited budgets and time (Miskowiak, 2004). Recently published studies focused on the importance of user participation in decision making related to the landscape design process for parks. For example, Ikhwan et al. (Ikhwan, Anuar, & Saruwono, 2013) noted that it is important to identify who participates in and who will be affected by the decisions made by professionals. Shan (Shan, 2012) conducted face-to-face questionnaire surveys at 24 green urban sites across cities in China; in total, 595 respondents were successfully interviewed. The findings supported the push to make local governments more open, to develop effective strategies, and to promote public partnerships in decision making related to green urban spaces. Jausus (Jausus, 2014) introduced community sharing as a strategic approach to landscape maintenance in order to create vibrant open spaces in Malaysian towns. He identified the barriers that cause a lack of user participation in landscape maintenance and the factors that encourage public involvement in landscape maintenance; he also put forward the development concept of public participation as a tool in landscape maintenance. Borazjani and Abedi (Borazjani & Abedi, 2014) proposed systematic guidelines on participants' requirements and the relationship between the design and their contributions. In order to incubate a sustainable landscape design, a paradigm was established to ensure sustainability in planning, which was applied to the case of Tehran, Iran. After applying the questionnaire survey, they set the users' requirements according to the main criteria, which were access and connection, safety, health, sociability, and vitality.

Difficulties in communication between users and decision makers lead to uncertainty and a lack of consistency in landscape processes. The most common method used to describe a design to users is reports (Ikhwan et al., 2013), which require the user to use their imagination to construct the project in their mind. This makes their evaluation more prone to their perceptual limitations and cultural background, which has an effect on the reliability of the final feedback. Other alternative approaches have been proposed to reduce the effect of users' imaginations, such as supporting the reports with maps (Loures et al., 2015) or images (Saleh & Nassar, 2011). The evolution of maps and images led to the idea that computer simulations could be used to help users realize better design alternatives, which is considered as a more reliable method. The findings of previous studies suggested that visualizations can enhance public participation by allowing people to meet with professionals about proposed projects (Bilge, Hehl-lange, & Lange, 2016). Via visualization, design updates become easier and less expensive, and clients are able to see a realistic image of the final product, allowing them to understand the project (Saleh & Nassar, 2011). Landscape imagining makes it possible to display scenes that are nonexistent; these can be represented as static, animated, or interactive, and can be immersive or outside of context. From the related studies, it is clear that VR is a suitable computer simulated visualization tool for landscape design.

Slater mentioned that, the immersive virtual reality (IVR) technology has existed for more than 50 years, at first, it was a demonstrated laboratory-based idea. For the past 30 years, IVR was considered as practical, affordable and useful systems. The massive growth in research and development in this field led to use it as a method to simulate physical reality. VR has not been seen as a medium in its own right or as something that can make novel forms of experience, but it is a kind of simulating an experience (Slater, 2009). Moreover, he added that it is more beneficial to consider VR as a technological system that can replace a person`s sensory input and transform the meaning of his outputs to a precisely knowable alternate reality (Slater, 2014).

Advances in the computing field and mobile platforms have led to improvements in landscape visualization on mobile devices. MDs are a vital part of our daily lives owing to the advantages they provide in many fields, ranging from communication to navigation (Bilge et al., 2016). However, they are still not as capable as computers for performing tasks because of their limitations in display, detail and realism, immersion, connectivity, speed and processing capability, small screen size, and usability (as a MD usually allows only one person to display a visualization, unlike larger panoramic screens that can serve multiple audiences simultaneously) (Lovett, Appleton, Warren-kretzschmar, & Haaren, 2015). Furthermore, they have the merits of ubiquity, portability, accessibility, interactivity, being lightweight, and being context-aware compared to their predecessors. Unlike computers, MDs give more freedom to users without requiring any kind of dedication in terms of the place and time of use (Bilge et al., 2016). Bilge et al. used iPads to obtain the opinions of hard-to-reach stakeholders, students, and professionals regarding a new urban park design in Sheffield, UK. Participants were shown a short animated video of a 3D model of the site, followed by some questions about the mobile device's visualization. The survey showed that MD-based visualizations can help to create a wider base for decision making (Bilge, Hehl-lange, & Lange, 2014).

To summarize, few previous studies have reviewed the positive impacts of BPs on both the environment and users. In particular, the effect of sustainable landscape design on employees' comfort and the microclimates of BPs is not deeply discussed in the prior literature. In particular, for Egypt, the trend of BPs should be studied well to allow us to take a step toward the future extension of sustainable cities. This paper discusses potential landscape designs for an open space at a new BP located in NBC in Egypt. This approach includes three different landscape trends—traditional formal design, xeriscape design, and biomimicry—which will be deeply discussed in the following sections. The study proposes the use of VR and MDs as a way to acquire reliable feedback from users in order to make proper decisions about design criteria, which should be enhanced to meet consumers' needs. Hence, the study's aim is to utilize this approach to envision sustainable landscape design guidelines for open spaces, particularly those in BPs in Egypt. Furthermore, the research identifies an appropriate software tool that can develop an approach for augmenting user participation in the process of landscape design.

To summarize, indeed the construction methods of VR are multitudinous. Two common methods are creating a 360° panorama image and building a 3D virtual space, with the latter being a fully immersive method. Both are VR but functions for design study are different. In this study, the authors use the static VR technology, neither interactive nor immersive, which is 360° panorama image. Although it may seem a little bit confusing for VR experts, but for this proposal, we need to get the feedback of the users on the current alternatives without adding or changing in the design environment as in the interactive VR kinds.

In the method of using 360° panorama image, viewpoints are limited, the viewpoint selections are important issue for the user's questionnaire. In contrast, in the method of constructing 3D-virtual space, viewpoints are free so that a user can walk-through freely. But the criterion for questionnaire survey is more important. If users walk and/fly-through using different paths, the impression of every user will be different, it is better to explore from the same viewpoints. Moreover, the research focuses on encouraging their participation not by reports or images, but by more advanced technology like 360° panorama image, also it is considered as a simple communicating technology not as complicated as the IVR. It is more applicable to a wide range of users which is one of the paper`s targets to reach easily to various users. Eventually, the essential aim of this study is introducing a systematic way of thinking which is considered as a methodology of designing the landscape of GBPs that promotes the sustainability. It could be a step forward for the upcoming sustainable cities that mitigate the climate changes.

2. Materials and methods of evaluation

This part clarifies the evaluation methodology and how a final decision that includes contributions from both experts and users can be reached. The materials were collected from detailed descriptive data on the project and case study area, and the methods section shows the steps for designing and modelling the three landscape alternatives. In order to solve the problem of showing 2D images to users with reports, a 3D modeling procedure in static VR was done to convert the 2D designs into 360° panorama images that could be easily explored on MDs. Finally, this part also focuses on the evaluative criteria and sub-criteria of the landscape design alternatives, and the questionnaire filled in by the experts and users.

2.1. Evaluation methodology and decision making

As shown in Fig. 1, first, the researcher (or the landscape architect/designer) performed the modeling of the landscape design alternatives (2D design, 3D design, and adding landscape elements). After that, the models were converted into 360° panorama images to be explored by the users. Consequently, the users evaluated the designs to select the

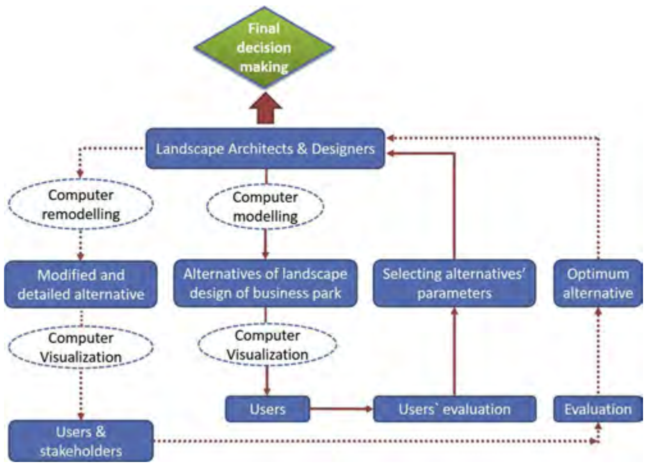

Fig. 1. Methodology of evaluation and decision-making processes.

best alternative. Based on the opinions of the users and feedback from experts, the architect could modify the best selected landscape design. Finally, the landscape architect could arrive at the optimal alternative that met users' needs and was in line with experts' opinions.

2.2. *Project: open space in Silicon Waha Park, NBC*

NBC, which was inaugurated in 1988, is a natural extension of Alexandria, as shown in Fig. 2. It is situated around 45 km southwest of Alexandria's downtown area and in a 7-kilometer range of the Mediterranean coast (New Urban Communities Authority, 2015). NBC, at 30.9150 °N, 29.5456 °E, is characterized by a subtropical desert/low-latitude arid hot climate (Köppen-Geiger classification: BWh). It features brief, moderate downpours in winter and long warm months with no downpours in summer (Essa and Etman, 2004). The mean annual temperature is 20 °C; the highest temperature is 35 °C during the sunniest hours in July and August, and the minimum temperature is 10 °C in January. The population at present is approximately 100,000, and it is expected to grow to up to 750,000 by 2032. NBC is regarded as a major new urban area because it is a residential-industrial city with a full range of facilities and services (Ghada Elshafei, Negm, GamalEldin, & Bady, 2017). It is one of the most important industrial zones in Egypt with about 1700 industrial facilities and institutions and 30,000 acres of built-up areas (residential areas, service areas, industrial zones, and tourism and recreation spots), as seen in Fig. 3.

To contribute to the future prosperity of NBC and take into account users' participation and satisfaction, a design plan was constructed while keeping the framework of the Eco NBC project outlined by VTT in mind. VTT proposed implementation actions that would essentially aim to reduce pollution and congestion, conserve resources, and protect nature, all while promoting local business and jobs, improving mobility, enhancing the urban environment, and promoting the participation of citizens (Antuña-Rozado et al., 2016). The sustainable landscape design is intended to contribute to the Eco NBC project framework. The following section introduces the landscape design for an open space that is still under construction in Silicon Waha Park. The park, as shown in Fig. 4, encompasses 42 buildings, 11 of which have been completed. The whole area of the project is 126,003 m^2; it is 25.46% built-up areas and 40.08% green and parking areas. The total area of the selected case study is 3600 m^2. This vital area is an assembly point for most of the employees in the park.

2.3. *Landscape design modeling of alternatives*

This study presents three different landscape design methods for measuring users' satisfaction and comfort in a way that is reliable and applicable. The design process had four phases, as shown in Fig. 5.

Phase one entailed collecting data and determining the design characteristics. In the first case, the design followed the traditional-formal landscape, as shown in Fig. 6a, which is characterized by clean, clear, symmetrical, and rectilinear forms. The design consisted of large green areas, lawns, trees, flowers, shrubs, pergolas, high-quality seating decks, pedestrian paths, fountains, trash bins, and services like restaurants and toilets. In the second case, the design was xeriscape, as shown in Fig. 6b, which was asymmetric and used cacti, palms, native trees, and rocks. The utilized plants would require less water and maintenance. The design contained sandy areas to minimize water usage, pedestrian paths, seating decks made from recyclable materials, recycle bins, and cafés. The xeriscape design focused on the environmental aspects and tried to be very eco-friendly. The third design followed the biomimicry trend in landscape, as shown in Fig. 6c, which is characterized by a modern look; an informal appearance; curved lines; mixed borders; and natural, wild, and colorful aspects. The landscape elements are inspired by natural forms. The extensive use of trees, plants, and flowers means more water is needed for irrigation. From the sustainability point of view, a xeriscape design, as proposed in Alternative 2, fulfills most of the sustainable landscape criteria: plants require less water for, need less maintenance, and are native species. The materials used for park facilities are eco-friendly, waste is recycled, and garbage is collected in separate trash bins.

In phase two, the three landscape designs were implemented using AutoCAD 2018® (Autodesk, 2015), as shown in Fig. 7. Then, the plans were exported to Trimble SketchUp 2018® (Trimble, 2015) to produce 3D models of the area in phase three, owing to the software's easy access and easy-to-use interface. After that, for the last phase, all of the landscape elements were obtained from the program's 3D warehouse and conventionally added to the three landscape design models in SketchUp 2018®, as shown in Fig. 8(a, b, and c).

Fig. 2. Borg Al Arab City. It is a natural extension of Alexandria [1].
https://www.google.co.jp/maps/place/Alexandria

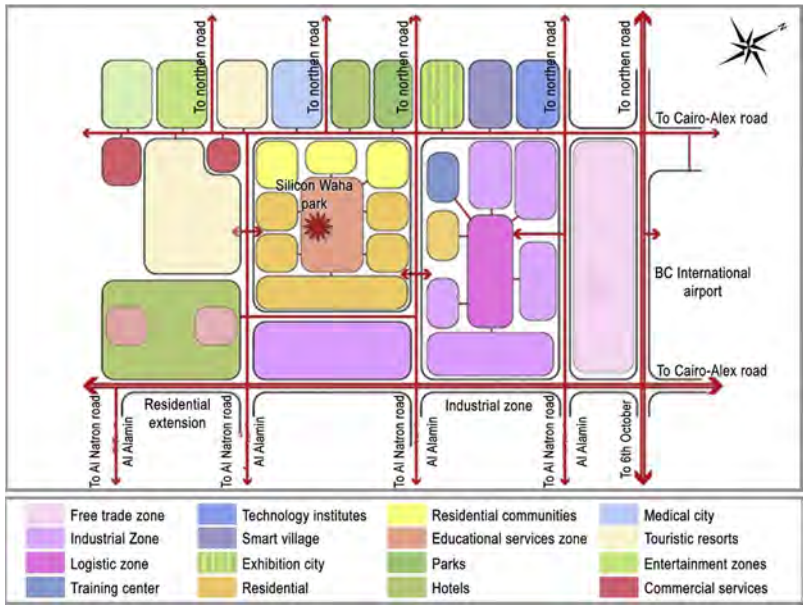

Fig. 3. General strategic plan of New Borg Al Arab City [2].
http://mmohsen.weebly.com/professional.html

Fig. 4. Silicon Waha master plan—Case study area [3].
http://siliconwaha.net/why-borg-alarab.html

Fig. 5. Phases of landscape design modelling.

2.4. Development of VR models

For the questionnaire survey of this study and the evaluation, 360° panorama images were constructed to help participants to visualize different alternatives easily. The models were rendered using the v-ray plugin in SketchUp 2018® to get as close as possible to reality. The following steps were involved:

1) Checking the construction of the whole 3D built environment surrounding the open space.
2) Taking camera shots in daylight, as most of the users will work during the day.
3) Setting the height of the camera for each of the three alternatives to 1.5 m.
4) The camera positions/viewpoints for each alternative were as follows: at the center of the main entrance, at the center point of the designed area, two shots from the paths on the right side and the left side, and on the path opposite to the main entrance.

Fig. 6. The three types of landscape design (a) Traditional-formal landscape [4], (b) Xeriscape design [5], and (c) Biomimicry in landscape [6].
http://www.thestoneshopinc.com/how-to-make-formal-garden-design/
http://gardensharebristol.blogspot.com/2007/08/kendrick-lake-park.html
https://land8.com/5-great-ecological-power-houses-of-landscape-architecture/

5) The number of photographed points was 5 for each alternative, so in total there were 15 photos.
6) Selecting an object from the VFS main toolbar to set the camera on the exterior with high-quality presets, then setting the camera type to spherical with 360° override FOV.
7) For the output size, the width was 6000 and height was 2000 with an image aspect ratio of 3, and the shutter speed was 300 for the exterior scenes.
8) Additionally, for the indirect illumination, the amount of ambient occlusion was 1.2, 25 for subdivs, and 15 for the radius.
9) Finally, rendering was done to get the 360° panoramic images for the landscape design, as shown in Fig. 9(a, b, and c).

Afterward, all of the models were uploaded to a virtual tour website (Easypano Holdings, 2017) so as to be converted into static VR images that could be opened on IOS and Android mobile devices, which enabled the user to explore the landscape designs by wearing VR headset (Fig. 10). These models helped the participants to visualize the different alternatives while answering the prepared questionnaire, thus providing evaluations of the three landscape design models. For more illustration to the proposed case study and landscape design alternatives, renderings from the window were taken as shown in Fig. 11(a, b, and c).

2.5. Evaluative criteria and questionnaire

Sara et al. (S. Atwa, 2015) considered the main concerns and indicators of the social aspect as one of the evaluation criteria of landscape sustainability aspects, followed by the environmental and economic dimensions. Previous studies stated that interactions with the landscape, human well-being, diverse and vital spaces, flexible design areas, welcoming places, comfort, and easy-to-use areas are the major concerns related to social aspects, and derived indicators to evaluate landscape areas. Saleh and Nassar (Saleh & Nassar, 2011) put forward an approach to landscape regeneration design criteria and sub-criteria that can vary from one project to another. The four main criteria are linkage, image, uses, and sociability, which are evaluated by landscape experts with a given score to weigh their importance.

The evaluation in this study was based firstly on experts: 10 architects and landscape designers who introduced their method for enhancing user participation. A questionnaire sheet was prepared for the professionals; it contained general questions related to the function, suitable mood, and appropriate style of landscape areas in a BP. Also included were questions about the four main evaluation criteria for the different landscape models, in which all were evaluated with specified marks. The criteria and sub-criteria were prepared by landscape design specialists with reference to the previously mentioned studies. The evaluation followed a quantitative analysis method based on scores from 1 to 5 (poor to excellent). The results were collected and analyzed to give each criterion and sub-criterion a relative weight. The list of criteria and sub-criteria groups can be seen in Table 1.

The targeted users had a variety of socioeconomic characteristics. The sample consisted of urban designers, engineers, university staff, and employees. In the first survey, which lacked VR, the questionnaire targeted about 50 people, but only 28 gave valid feedback and responses. The participants were aged from 25 to 50, 16males and 12 females were included. The questionnaire began with a simple introduction informing the users about the main aim of the research and asking some questions about name, age, job title, and address. The next step presented a typical questionnaire sheet, which consisted of questions related to expected functions, preferred landscape styles, suitable moods, favorable plant types and colors, and compatible paving materials for paths. The following part presented questions related to the four main evaluation criteria for the three landscape design alternatives: access and connection, comfort, activities, and sociability. The sheet was designed to ask respondents about their opinions after

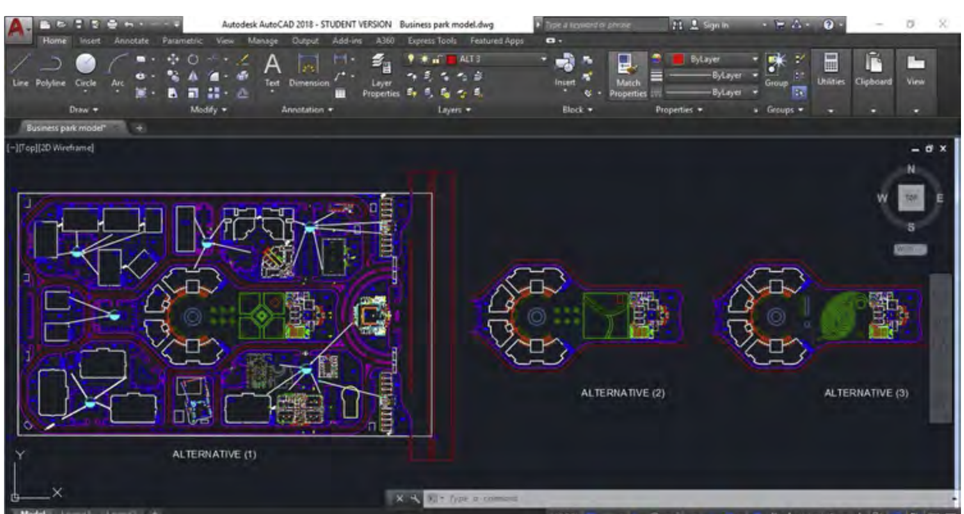

Fig. 7. 2D design drawings of alternatives 1, 2, and 3 in AutoCAD 2018.

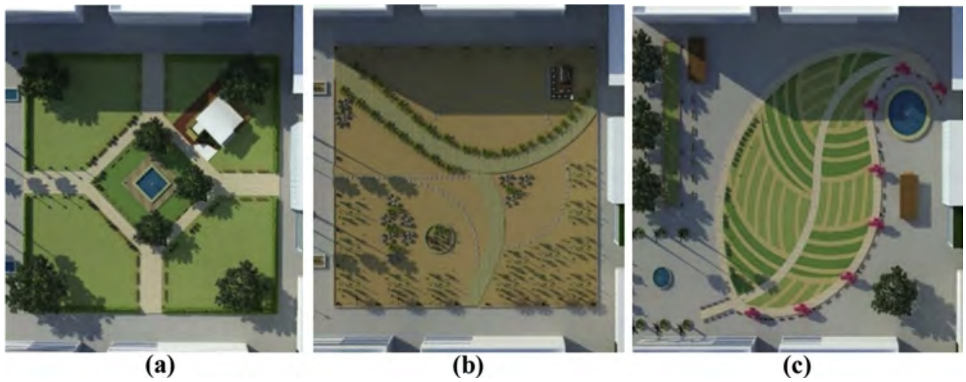

Fig. 8. The layout of the three landscape design (a) alternative 1, (b) alternative 2, and (c) alternative 3.

viewing the simple images of each design alternative, as shown in Fig. 12(a, b, and c), so the sheet was to be completed three times. In the second survey, VR technology was applied. The questionnaire targeted 80 people, but only 50 gave valid and complete responses. The 50 participants were between the ages of 25 and 50, with 28males and 22 females being present. While the user was wearing the VR headset, he/she would answer the questions in the prepared questionnaire. The sheet was designed to ask the questions while the participant was exploring the three static VR models, so the survey sheet was to be filled out three times.

3. From evaluation to the development of guidelines

This section starts by statistically analyzing the answers from the

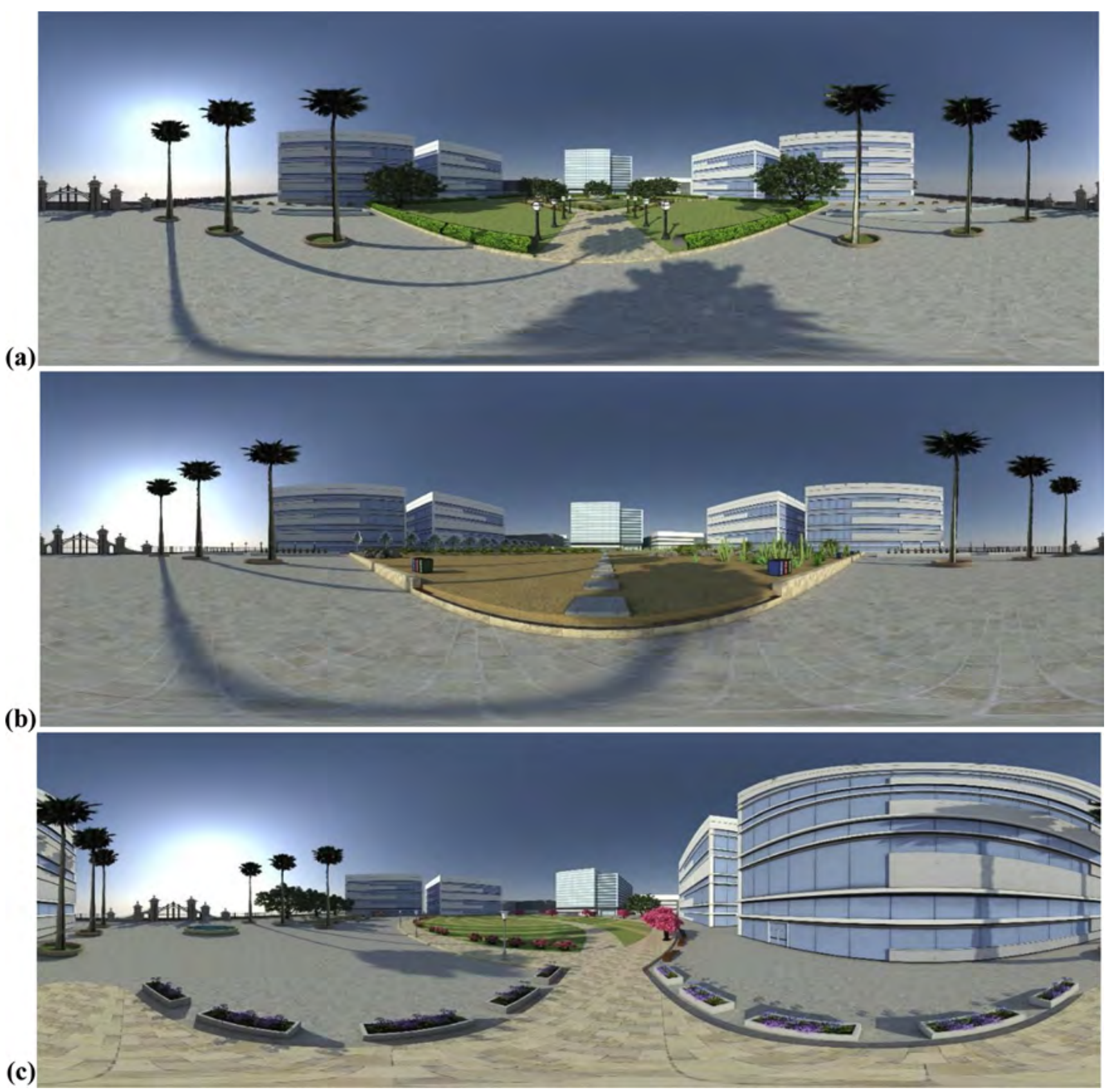

Fig. 9. 360° panoramic images of the three alternatives (a) alternative 1, (b) alternative 2, and (c) alternative 3.

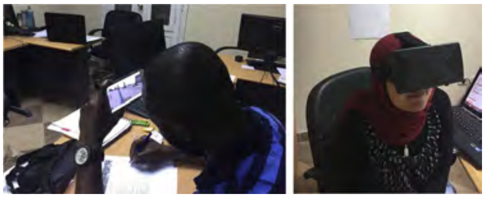

Fig. 10. Presentation of the static VR 3D model to participants on an iPhone or using VR headset.

questionnaire survey of experts and users. Then, it discusses the essential characteristics of each landscape design alternative, which affected the users' opinions while looking around with the VR headset. It then shows the relation between the evaluation criteria and main landscape design features of the alternatives. Finally, it proposes a list of sustainable landscape design guidelines that can be applied to the upcoming business parks in general and particularly in Egypt.

3.1. Statistical analysis of the questionnaire survey

The statistical analysis was performed to define the participants' feedback, which was based on that by the experts, so as to determine the preferred alternative. After administering the questionnaire surveys before and after the VR experience, the answers were collected and exported to the statistical software. The analysis procedure detailed below was based on well-known statistical concepts (Feller, 2008).

When analyzing the landscape elements, it was noticed that not all elements had the same criteria, and each criterion did not have the same relative weight. Those weights were deduced from the experts' questionnaire answers. Let the total number of sub-criteria from all four categories to be denoted by L. The weight of a sub-criteria (i) was calculated from (M) experts' answers as follows:

$$w_i = \frac{1}{M}\sum_{k=1}^{M} e_k(i)$$

where $e_k(i)$ is the feedback of expert k for sub-criteria i. This absolute weight was normalized over all weights to be converted into a percentage from the normalized weight for a sub-criteria i, which is given by:

$$W_i = \frac{w_i}{\sum_{i=1}^{L} w_i} \times 100\%$$

The previous equation calculated the relative weights to be multiplied by the users' feedback. The average feedback from all N users for a certain sub-criteria i was calculated as follows:

$$U_i = \frac{1}{N}\sum_{k=1}^{N} u_k(i)$$

where $u_k(i)$ is the feedback of user k for sub-criteria i. Hence, the weighted evaluation of a sub-criteria i of an alternative a:

$$E_i(a) = W_i U_i$$

The final accumulated score of alternative a was produced via a simple addition process, where other accumulation criteria may be applied:

Fig. 11. Renderings from the window of each alternative (a) alternative 1, (b) alternative 2, and (c) alternative 3.

Table 1
The evaluation criteria and sub-criteria for open spaces in business parks.

Criteria	Sub-criteria	Criteria	Sub-criteria
Access and Connection (AC)	AC1: Accessible and welcoming entry	**Comfort (C)**	C1: Safety and security
	AC2: Walkable, safe, and convenient		C2: Privacy
	AC3: Private paths for handicapped people		C3: Harmony with nature
	AC4: Connection between paths and water		C4: Attractiveness
	AC5: Improved visual access		C5: Sense of beauty
	AC6: Has continuity and diversity		C6: Flexibility of spaces
	AC7: Enhanced lighting at night		C7: Landscape elements are high quality
Activities (A)	A1: Enhanced passive and active uses	**Sociability (S)**	S1: Welcoming places
	A2: Variety of recreational uses		S2: Lively spaces
	A3: Enough spaces for activities		S3: Creates cooperative environment
	A4: Functional landscape		S4: Improves participation
	A5: Attraction of users		S5: Interactivity between users
	A6: High-quality landscape amenities		S6: Improves health and wellbeing
	A7: Availability of cafes, stores, gym		S7: Feeling of space ownership

Fig. 12. Some viewpoints of the three landscape designs attached to the questionnaire (a) alternative 1, (b) alternative 2, and (c) alternative 3.

$$S_a = \sum_{k=1}^{L} E_k(a)$$

After analyzing the data, the outputs of the statistical analysis were added to Table 2 in order to determine the normalized weight of experts W_i for each sub-criterion and the average score of users $\boldsymbol{U_i}$ for each sub-criterion. We determined the selected alternative according to the highest score of the sum of weighted evaluations of a sub-criterion E_i.

For a better illustration of all sub-criteria evaluations, the results are shown in a radar format in Fig. 13; the charts plot the absolute average of each sub-criteria evaluation on a scale from 1 to 5. Fig. 13a introduces a good representation of the results on the users before wearing the VR headset; in this way, the results can be visually analyzed and the strengths and weaknesses of each alternative can be observed clearly. As can be seen in the figure, the access and connection (AC) aspect is the most dominant, followed by comfort (C), then activities (A). In alternative 3, AC5 has the highest score, followed by C4 and C5. After the VR experience, AC5 still has the highest score, followed by C7. In alternative 1, AC3 and AC4 almost disappear from the radar chart, contrary to Fig. 13b, which clearly shows their values. The values of AC1, AC7, and S6 in alternative 1 are slightly higher than their counterparts in alternative 3. This is in contrast to Fig. 13b, which shows that the scores of all sub-criteria in alternative 3 are bigger than alternatives 1 and 2. After the VR experience, the results of all sub-criteria seemed more reliable and had relatively the same importance. The percentage ratios among all criteria were considered approximately close; this means that the four criteria were all relatively important and essential in landscape design assessment.

For example, in alternative 1, the sub-criterion walkable, safe, and convenient (AC2) was the most dominant because of the straight and rectangular-shaped paths, which were clear and easy to walk on. The trees, shrubs, fountains, and flower pots improved the visual access, and consequently made AC5 s-ranked. Regarding safety and security (C1), users found the entrance gate to be secure and felt safe inside the BP's walkable tracks, which were far away from any cars. The high-quality landscape amenities that were used led to high marks for C7 and A6. The hardscape design elements were classic wood-backed benches with ornamental armrests, wood backless freestanding benches, marble fountains, and HF wood slat receptacles. The extensive use of large trees

Table 2
Results of the statistical analysis of the questionnaire on the three alternatives.

Main Criteria	Sub-criteria	W_i	Alternative 1				Alternative 2				Alternative 3			
			Before VR		After VR		Before VR		After VR		Before VR		After VR	
			U_i	E_i	U_i	E_i	U_i	E_i	U_i	E_i	U_i	E_i	U_i	E_i
Access and Connection (AC)	AC1: Accessible and welcoming entry	**4.08**	3.85	15.7	3.63	14.8	2.42	9.92	2.59	10.5	3.57	14.5	4.13	16.9
	AC2: Walkable, safe, and convenient	**4.37**	3.71	16.2	4.04	17.7	3	13.1	2.63	11.5	4.14	18.1	4.13	18.1
	AC3: Private paths for handicapped people	**4.08**	2.14	8.75	2.40	9.84	2.71	11	2.13	8.73	3.85	15.7	3.31	13.5
	AC4: Connection between paths and water	**3.5**	1.85	6.50	3.22	11.3	2.14	7.50	2.4	8.44	4.28	15	3.63	12.7
	AC5: Improved visual access	**4.23**	3.85	16.3	3.77	15.9	2.85	12	2.68	11.3	4.85	20.5	4.27	18
	AC6: Has continuity and diversity	**3.06**	3	9.19	3.09	9.47	2.71	8.32	2.5	7.66	3.85	11.8	3.95	12.1
	AC7: Enhanced lighting at night	**3.06**	3.85	11.8	2.95	9.05	3.28	10	2.54	7.8	3.71	11.3	3.36	10.3
Comfort (C)	C1: Safety and security	**4.23**	3.85	16.3	3.36	14.2	3.14	13.3	2.4	10.1	4	16.9	3.68	15.5
	C2: Privacy	**2.62**	3.14	8.25	2.63	6.92	2.85	7.50	2.59	6.8	4	10.5	3.4	8.95
	C3: Harmony with nature	**2.91**	3.57	10.4	3.36	9.82	3	8.75	2.95	8.62	4.57	13.3	4	11.6
	C4: Attractiveness	**3.94**	3.57	14	3.45	13.6	2.85	11.2	2.63	10.3	4.85	19.1	4.13	16.3
	C5: Sense of beauty	**3.64**	3.85	14.0	3.63	13.2	3	10.9	2.63	9.62	4.85	17.7	4	14.5
	C6: Flexibility of spaces	**3.5**	3.42	12	3.36	11.7	3.57	12.5	2.63	9.23	4.14	14.5	3.68	12.8
	C7: Landscape elements of high quality	**3.79**	3.42	13	3.68	13.9	3.14	11.9	3.18	12	4.28	16.2	4.18	15.8
Activities (A)	A1: Enhanced passive and active uses	**3.21**	3.57	11.4	2.77	8.9	2.85	9.17	2.4	7.73	3.85	12.3	3.5	11.2
	A2: Variety of recreational uses	**3.35**	3	10	3	10	3.28	11	2.27	7.63	4	13.4	3.5	11.7
	A3: Enough spaces for activities	**3.21**	3.28	10.5	3.31	10.6	3.42	11	2.68	8.61	3.85	12.3	3.45	11
	A4: Functional landscape	**3.5**	3	10.5	3.45	12.1	3	10.5	2.59	9.07	4	14	3.45	12.1
	A5: Attraction of users	**3.94**	3.42	13.5	3.5	13.7	2.57	10.1	2.63	10.3	4.71	18.5	4	15.7
	A6: High-quality landscape amenities	**3.94**	3.42	13.5	3.59	14.1	3.14	12.3	3.09	12.1	4.42	17.4	4.09	16.1
	A7: Availability of cafes, stores, gym	**3.35**	3.42	11.5	2.72	9.15	3.71	12.4	2.27	7.63	4	13.4	3.4	11.4
Sociability (S)	S1: Welcoming places	**3.64**	3.28	11.9	3.59	13.1	3	10.9	2.63	9.62	3.85	14	4.04	14.7
	S2: Lively spaces	**3.06**	3.42	10.5	3.31	10.1	2.85	8.75	2.59	7.94	3.85	11.8	4	12.2
	S3: Creates cooperative environment	**3.79**	3.14	11.9	3.22	12.2	2.85	10.8	2.59	9.83	4	15.1	3.45	13.1
	S4: Improved participation	**3.35**	3.28	11	3.04	10.2	3.28	11	2.5	8.39	4.28	14.3	3.5	11.7
	S5: Interactivity between users	**3.64**	3.71	13.5	2.86	10.4	3	10.9	2.5	9.12	3.85	14	3.5	12.7
	S6: Improved health and wellbeing	**4.08**	4	16.3	3.40	13.9	3.14	12.8	2.95	12	3.85	15.7	3.81	15.6
	S7: Feeling of space ownership	**2.77**	3.57	9.9	3.13	8.69	2.28	6.33	2.72	7.56	3.71	10.3	3.45	9.58
Total Score		**100**		**339**		**329**		**297**		**260**		**413**		**377**
Percentage*(%)				**68**		**66**		**59**		**52**		**83**		**75**

This percentage was calculated with reference to a perfect alternative, which would achieve a score of 5 in each sub-criterion resulting in $S_{\text{perfect}} = 500$ after applying the experts' weights. The total percentage of alternative a is $\left(\frac{S_a}{500}\right) \times 100\%$.

and wide green areas helped to enhance health and wellbeing (S6). The well-shaded areas with diverse seating options made the park more welcoming (S1) and created a cooperative environment (S3) for employees. In alternative 2, the curved footpaths with variable widths and diverse styles gave the sub-criterion AC2 the highest score amongst the AC criteria. The desert-look of the design attracted some high marks for sub-criterion C4. High-quality landscape facilities (A6) such as seats and trash bins, which were made from durable and recyclable materials, also attracted users to do some environmental-educational activities. Finally, palm trees, cacti, and native plants were able to improve human well-being (S6), as some workers mentioned in their evaluations. However, in alternative 3, the highest score was given to AC2 due to the informal, curved, diverse, and walkable pathways, which were considered as more convenient by the users. The colorful trees and flowers, various green spaces of different sizes, and large water elements ensured high scores for the sub-criteria AC5, C4, C7, A5, and A6. Also, the extensive use of vegetation enhanced human health and well-being (S6). Fig. 14(a, b) show the total user scores in each case. The scores following the VR experience were lower for alternatives 2 and 3, but not so much for alternative 3. Furthermore, the difference between alternatives 1 and 3 became smaller, while that between alternatives 1 and 2 became larger.

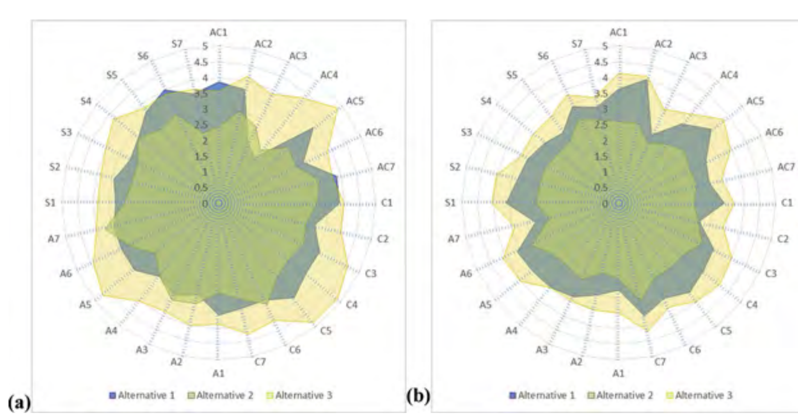

Fig. 13. Radar technique format for comparing the three alternatives, displaying how public users evaluated in detail the criteria of the landscape assessment in the participation process (a) before VR application, (b) after VR application.

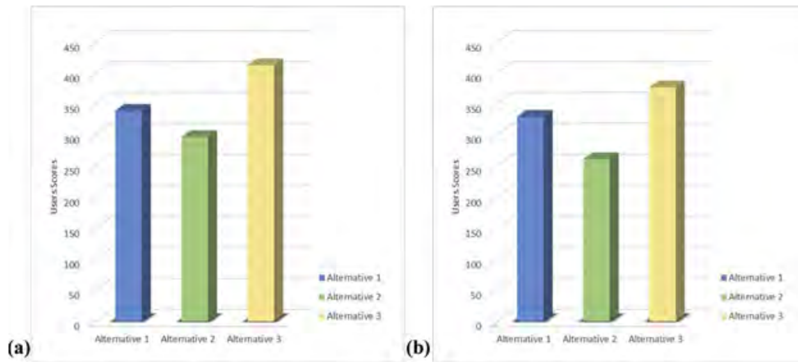

Fig. 14. Evaluation of alternatives by users; the selected one was Alternative 3 (a) before VR application, (b) after VR application.

Table 3
The relation between evaluation criteria and landscape design features of the 3 alternatives according to users' opinion.

Landscape Design Elements	Alternative 1					Alternative 2					Alternative 3				
	Substantial Features	Evaluation Criteria				Substantial Features	Evaluation Criteria				Substantial Features	Evaluation Criteria			
		AC	C	A	S		AC	C	A	S		AC	C	A	**S**
Green **areas**	Large rich & green spaces	29 ×	44 •	55 •	90 *	Large sandy spaces	29 ×	43 •	54 •	73 √	Rich & diverse green spaces	30 ×	44 •	56 •	89 √
Vegetation	Trees, shrubs, & flowers	29 ×	60 •	35 ×	30 ×	Palms & cacti (desert plants)	29 ×	61 •	19 ×	31 ×	Colorful trees & flowers	30 ×	65 •	18 ×	31 ×
Water elements	Rectangular shapes	30 ×	32 ×	38 ×	13 ×	No decorative water elements	0 –	0 –	0 –	0 –	Curved and round shapes	30 ×	32 ×	48 •	14 ×
Paths	Solid & sharp lines	61 •	22 ×	40 •	30 ×	Curved lines of constant width	60 •	24 ×	40 •	29 ×	Curved lines of variable widths	61 •	23 ×	38 ×	30 ×
Seats	High-quality wooden benches	13 ×	40 •	31 ×	52 •	Benches made from recyclables	13 ×	28 ×	33 ×	54 •	High-quality modern benches	14 ×	40 •	30 ×	52 •
Lighting units	High-quality classic units	47 •	34 ×	33 ×	28 ×	Modern with constant height	45 •	33 ×	34 ×	27 ×	Modern with diverse heights	44 •	32 ×	32 ×	27 ×
Landscape design photos															

3.2. The relationship between the evaluation criteria and landscape design features of the alternatives

This section clarifies the major landscape design features in each alternative that influenced the users' opinions. Table 3 illustrates the relationship between the four evaluation criteria and the primary components of the landscape designs, which were classified into softscape and hardscape elements. The softscape elements were green areas and vegetation. The hardscape elements were water elements (fountains), paths, seats, and lighting units. The relationships were concluded from the previously mentioned statistical calculations, which were derived from the users' points of view. The calculations were done after the VR experience, as follows:

LDE contribution for each Cr = Sum of E_i (for each SC_n)/Total score of E_i (C) %

where LDE is the landscape design element, Cr is the main criteria, E_i is the weighted evaluation of sub-criterion i of an alternative, SC means sub-criteria, and n is the number of sub-criteria.

According to the above calculations for LDE, the relations were as follows: a weak relation was from 10 to 40%, which was given the symbol (×), (•) was for a moderate relation from 40 to 70%, (√) was for a strong relation from 70 to 90%, and (*) was for the most dominant relation, which was ≥ 90.

For example, (see Table 2) in alternative 1, the landscape design element "green areas" had an effect on AC5 and AC6, with scores of 15.9 and 9.47 for Ei, respectively, according to users' evaluations; that represented 29% of the total score of the AC criteria. The comfort criteria C3, C4, and C5 had scores of 9.82, 13.6, and 13.2, respectively, which represented 44%. The activities criteria A1, A2, A3, and A5 with scores of 8.9, 10, 10.6, 13.7, respectively, which represented 55%. Finally, the sociability criteria S1, S2, S4, S5, and S6 had scores of 13.1, 10.1, 10.2, 10.4, and 13.9, respectively, which represented 90%.

3.3. Proposal for sustainable landscape design guidelines for business parks

A new approach should be formed for the landscape design of BPs in Egypt. To apply the sustainability concept to Egyptian society, the design should be covered by an outer layer of favorable design aspects, so as to achieve integration between the sustainable core and the best visual scene. Therefore, in this case, the optimum design will be achieved by merging the highest-scored alternative visual scene with the sustainability aspects of the second alternative in the design core. Hence, this section proposes a list of main design guidelines, as shown in Table 4, to enhance landscape design for the sake of creating livable/active open spaces in the BPs, based on expert/user opinions and evaluations, taking into consideration the main sustainable landscape elements. This approach was derived from the sustainable sites initiatives that were set by ASLA (Sean Wheeler & ASLA, 2009), which are applicable to BPs.

Also, Table 4 reveals the relationship between the proposed design guidelines, which are classified below the main sustainable landscape

Table 4
List of design guidelines for sustainable landscaping of the open spaces of business parks.

Main sustainable landscape elements/ Design guidelines for open spaces		Evaluation criteria for open spaces				Dimensions of sustainability		
Element	*Design guideline*	*AC*	*C*	*A*	*S*	*Env.*	*Soc.*	*Eco.*
Site/ Layout	Prepare a long-term plan to adapt to environmental changes	—	○	—	—	○	—	○
	Design suitable master plan with environmental regulations	—	—	—	—	○	—	—
	Minimize energy demand of the site through orientation	—	○	—	—	○	—	○
	Design welcoming entrance	○	○	○	○	—	○	—
	Design safe paths for handicapped people	○	○	—	○	—	○	—
Soil	Use safe soil that does not need harmful pesticides	—	—	—	—	○	—	○
	Use local and native soils	—	—	—	—	○	—	○
	Use soils that need less water	—	—	—	—	○	—	○
	Use long-term soil that will not decay	—	—	—	—	○	—	○
Air & Energy	Generate electricity for the park from renewable sources	—	—	○	—	○	—	○
	Design lighting units that use solar energy	—	○	—	—	○	—	○
	Design waterfalls for aesthetic purposes and energy generation	○	○	—	○	○	○	—
Vegetation	Implement a plan for natural flora and fauna to maintain the ecological balance of the site	—	—	—	—	○	—	○
	Use plantings for shading purposes	—	○	○	○	○	○	○
	Plant trees for cooling and shelter needs	○	○	○	○	○	○	○
	Use local and adaptive plants with variable/attractive colors	○	○	—	○	○	○	○
	Use plants that need less maintenance	—	—	—	—	○	—	○
	Replant existing trees or plants on site	—	—	—	—	○	—	○
Water	Design attractive water flows/channels/fountains used for irrigation in addition to aesthetic purposes	○	○	—	○	○	○	○
	Collect rainwater for re-using	—	—	—	—	○	—	○
	Use irrigation systems for water rationalization	—	—	—	—	○	—	○
	Reuse gray water for irrigation	—	—	—	—	○	—	○
Materials	Use local and recyclable materials	—	—	○	—	○	—	○
	Create space for the sorting and storing of recyclable materials	—	○	—	—	○	—	○
	Use materials that need less maintenance	—	—	—	—	○	—	○
	Use durable materials	—	—	—	—	○	—	○
	Design hardscape elements like decks, trash bins, etc., from environmentally-friendly materials	—	○	○	○	○	○	○
Waste	Establish a plan for solid waste management	—	—	—	—	○	—	○
	Reduce toxic materials risks through integrated site-level waste treatment	—	○	—	○	○	○	○
	Use separated trash receptacles	—	—	—	—	○	—	—
	Use waste as a potential product that can be reused within the park	—	○	—	—	○	—	○

elements, and the evaluation criteria of open spaces (access and connection, comfort, activities, and sociability) with respect to the three essential dimensions of sustainability (environmental, social, and economic). The list shows the contribution of each design guideline to the four evaluation criteria and to the three pillars of sustainability. Two groups of contributions with boundaries of over 50% and less than 50% were picked from Table 3. In Table 4, they are indicated using the following symbols: — for less contribution and ○ for more contribution. The table starts with a general design guideline about the site plan and soil selection, which should be appropriate based on the site's nature, and some instructions for enhancing air and energy efficiency. Then, it sets a main design guideline for the vegetation, water, material selection, and waste management. As shown in Table 4, it is clear that most of the design guidelines for the landscape element contribute more to the environmental and economic dimensions of sustainability than the social one. This evidences the strong relationship between the design guidelines for open spaces and the dimensions of sustainability. As for the contribution of the evaluation criteria of open spaces, the comfort criteria is the most dominant, followed by sociability; access and connection and activities make the same contribution. The design guidelines for the site element contribute more to the comfort criteria than the other evaluation criteria. The soil element makes no contribution to the four evaluation criteria but has extensive significance due to its contribution to the environmental and economic dimensions of sustainability. As for the air and energy design guidelines, they contribute more to comfort than the other evaluation criteria; also, they contribute more to the environmental dimension than the economic and social ones. The design guidelines for vegetation, water, materials, and waste contribute less to the access and connection and activities criteria. As for vegetation, it makes more of a contribution to the comfort and sociability criteria. The design guidelines for water, materials, and waste contribute less to the comfort criteria, but more to environmental and economic sustainability.

4. Conclusions

Three different landscape alternatives were designed using 2D and 3D software programs, then converted into static VR images. A group of users evaluated the alternatives while exploring the designs using VR headset and an MD (iPhone). They then answered a questionnaire and indicated the best alternative. Before that, a prepared questionnaire for experts was administered to give relative weights to the landscape design evaluation criteria and sub-criteria. When the participants were asked if they were willing to use MDs (iPhones, iPads, smartphones, tablets, etc.) in the designing and decision-making processes, 86% of them gave positive answers. The users respond well with the VR headset, and it proved to be an easy, time-saving, and successful method for obtaining the accurate opinions of a workplace's users, which could help to enhance the whole design process. The users who answered the questionnaire without using VR technology took a lot longer than the ones who used VR headset. There were more respondents in the VR portion; they were interested in using this technology because it gave the design a more realistic feel. The targeted people for the questionnaire did not prefer exploring the simple and traditional images of the design alternatives. There is a strong potential for 3D visualization on mobile devices to contribute to enhancing public participation and design scenarios involving employees, stakeholders, professionals, and businesses.

The research created a methodology, based on input from landscape experts and users, which can be utilized when designing the landscapes of open spaces in new and future workplaces. This analysis allowed the researchers to determine new ways to merge sustainability concepts with the visual amenities that make people feel the most comfortable. The results showed that it is more efficient to utilize not only the landscape architect's point of view, but also to involve the users of the place. Furthermore, the non-constructed open areas of Silicon Waha Park in NBC were the most appropriate case study for this experiment, taking into consideration the sustainable landscape design guidelines list. In addition, the study targeted Egyptian governmental institutions, environmentalists, landscape designers, and stakeholders in considering the development of guidelines for similar projects with comparable characteristics. The approach used in this study can be applied to recent BPs, particular in Egypt, as renovation projects, which could be a step toward sustainable future cities. Also, it applies to upcoming BP projects in Egypt as well, as they have the same nature, climatic conditions, and functions. The upcoming designers who will follow this approach are encouraged to upgrade the VR technology utilization in this approach to allow the users to move through the landscape alternatives. This will give more chance for the users to express more relevant feelings about the design but with extra costs in the VR glasses technology and the required supporting design software. A collaboration between architects and VR experts are highly recommended.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2019.101543.

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