

TECHNICAL ARTICLE

Planning and evaluation of rooftop garden designs: A survey-based assessment study at faculty of Agriculture

Planejamento e avaliação de projetos de jardins em telhados: Um estudo de avaliação baseado em levantamento na Faculdade de Agricultura

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Abstract

Rooftop gardens provide valuable opportunities to increase green space and improve sustainability on college campuses. Nowadays, the Egyptians have begun implementing roof gardens on their buildings, but on a narrow scale, although university campuses suffer from deficiencies in this regard. Therefore, the current study was conducted during the 2022 and 2023 years in the College of Agriculture, Zagazig University, Egypt, to propose landscape layouts for the agriculture college roofs. Three landscape designs were planned using 3D software and evaluated by a group of specialists and users. Results showed that trees and palms were preferred to some extent by 60% (specialists) and 48.6% (users), while flowering herbaceous plants were preferred by 100% (specialists) and 91.7% (users), followed by medicinal and aromatic plants. Furthermore, total responses (specialists + users) regarding the five human senses' satisfaction by proposed designs were 75.7% (Site A), 69.4% (Site B), and 75% (Site C). As for specialists' total responses, design fundamentals were achieved at 66.7% (Site A), 70% (Site B), and 70% (Site C). Also, results revealed that 70.6% (Site A), 78.4% (Site B), and 65.8% (Site C) of users' responses agreed regarding the existence of suitable recreational areas, whereas 58.8% of users' responses agreed about the possibility of using the proposed design of Site A for conducting agricultural experiments. The study recommends implementing the proposed designs to use these rooftops as educational models and provide recreational areas and an aesthetic appearance.

Keywords: campus, human senses, landscaping, roof garden.

Resumo

Jardins em telhados oferecem oportunidades para aumentar os espaços verdes e melhorar a sustentabilidade no campus. Atualmente, os egípcios começaram a implementar jardins telhados em seus edifícios, mas em pequena escala, embora os campi universitários sofram de deficiências nesse sentido. Portanto, o presente estudo foi conduzido durante os anos de 2022 e 2023 na Faculdade de Agricultura da Universidade Zagazig, Egito, para propor layouts paisagísticos para os telhados da faculdade de agricultura. Três projetos paisagísticos foram planejados usando software 3D e avaliados por especialistas e usuários. Os resultados mostraram que as árvores e palmeiras foram preferidas em certa medida por 60% (especialistas) e 48,6% (usuários), enquanto as herbáceas floridas foram preferidas por 100% (especialistas) e 91,7% (usuários), seguidas por plantas medicinais e aromáticas. Ademais, as respostas totais (especialistas + usuários) quanto à satisfação com os sentidos humanos foram de 75,7% (Sítio A), 69,4% (Sítio B) e 75% (Sítio C). Quanto às respostas totais dos especialistas, os fundamentos do design foram alcançados em 66,7% (Sítio A), 70% (Sítio B) e 70% (Sítio C). Aliás, os resultados revelaram que 70,6% (Sítio A), 78,4% (Sítio B) e 65,8% (Sítio C) das respostas dos usuários concordaram quanto à existência de áreas de lazer adequadas, enquanto 58,8% das respostas dos usuários concordaram quanto à possibilidade de usar o projeto proposto do Sítio A para a realização de experimentos agrícolas. O estudo recomenda a implementação dos projetos propostos para usar esses telhados como modelos educacionais e fornecer áreas de lazer e uma aparência estética.

Palavras-chave: campus, jardins nos telhados, paisagismo, sentidos humanos.

Introduction

Green roofs provide an opportunity to introduce designed gardens and landscaping into crowded urban environments. College and university campuses with their large constructions are ideal locations for green roof projects, which can enhance the aesthetic and recreational environment for students, teaching staff, employees, and the surrounding community. According to Abass et al. (2020), urban buildings contribute to the provision of large unused surfaces, especially on their roofs and walls. These exterior surfaces are constructed from materials intended to reflect heat, such as glass, concrete, and brick. Also, urban administrative buildings in limited land areas may develop rooftop gardens from unused rooftop areas (Abdel-Wahab et al., 2025). Covering these roofs with green vegetation can provide solutions to many environmental, social, and economic problems, particularly in urban areas. The campus is as fundamental as it is unavoidable.

University campuses have significant potential and feasibility for implementing green roofs. These sites can be utilized for numerous functions after construction, such as educational, experimental, recreational, and research purposes (Wescott and Sundell, 2016). Examples of rooftop development already exist in Korea for research

purposes at universities. At these sites, soil characteristics, vegetation, environmental conditions, and plant species populations are studied following green roof installation (Lee et al., 2013). Although roof top gardens are a long-established practice in developed countries, in Amman they are still personal trials that are not involved in government policies and common design practices (Mughrabi et al., 2021). In Egypt also, rooftop farming is implemented on personal and individual bases, for example in "kafr Aoun" village. But the government has no defined plan for extended rooftop farming on the national level (Gammal et al., 2024)

Terms "green roof, eco-roof, living roof, vegetated roof, and rooftop garden" were used to describe two types of green roofs: intensive and extensive roofs, featuring naturalistic or self-established vegetation (Francis and Lorimer, 2011; Ahasan et al., 2014). A green roof refers to the application of coverage part or all a rooftop surface with vegetation, shrubs, or trees for aesthetic, environmental, and/or agricultural purposes (Gammal et al., 2024). Additionally, rooftop agriculture is a form of building-based urban agriculture, which includes both protected and unprotected farming practices, such as rooftop greenhouses as well as open air rooftop gardens and farms (Appolloni et al., 2021).

Green roofs are categorized into three primary types: extensive, intensive, and semi-intensive, distinguished by their function and design. Implementation of green roofs offers numerous benefits, including environmental advantages (stormwater mitigation and runoff water control (Zhang and He, 2021; Cirrincione et al., 2021; O'Hara et al., 2022; Schrieke et al., 2023); sound insulation, noise reduction, and increased biodiversity (Zhang and He, 2021); heat stress reduction (Herath et al., 2021) and reducing of urban heat island effect (Cirrincione et al., 2021; Park et al., 2022; O'Hara et al., 2022) due to their capacity to absorb shortwave radiation and cooling the atmosphere; potential to reduce annual energy consumption by 12% and lessen the average indoor temperature by 2.44 °C as well as average outdoor temperature by 3 °C (Goda et al., 2023); providing of oxygen and reduction of air pollution (Abdel-Wahab et al., 2025)) and economic benefits (sustainable vegetable production (Gajbe, 2021); urban infrastructure improvement (Zhang and He, 2021), energy consumption reduction through shading, evapotranspiration, and insulation, and increased roof lifespan through protection from thermal stress and UV radiation fluctuations (Feng and Hewage, 2018; Netusil et al., 2022).

Intensive roof gardens achieve social benefits, including: increasing human health and wellbeing (Gidlöf-Gunnarsson and Öhrström, 2007), offering recreation places and aesthetics (Zhang and He, 2021; Netusil et al., 2022), may provide the ability to recover from stress and mental fatigue, and enhance employee productivity and well-being (Abdel-Wahab et al., 2025) as green environments, thermal comfort, and aesthetics increase productivity.

Recently, the adoption of rooftop gardens has become increasingly common in urban areas in developing countries. However, the adoption of well-equipped green roofs remains unsuccessful and limited to open farms (Rawal and Thapa, 2022). Even though there is no extensive body of research focused specifically on college campus rooftop gardens, recent years have seen an increase in publications examining the benefits, challenges, and design considerations related to incorporating green spaces on college campus rooftops. Therefore, this research aims to utilize building roofs by 1) Present rooftop gardens' proposals for the college of Agriculture, Zagazig University, to serve as educational models for students, recreational areas for faculty members, and enhance aesthetic appeal, while taking users' needs/concerns into account. 2) Evaluate each proposed design.

Materials and Methods

Study location

The present study was conducted during 2022 and 2023 years at the College of Agriculture, Zagazig University, Zagazig, Egypt. The Faculty of Agriculture was established in 1958 as a higher agricultural institute and became a college affiliated with Ain Shams University in 1968. In 1974, with the establishment of Zagazig University, the Faculty of Agriculture became the first building block of Zagazig University. It is situated at latitude (30° 35' 06.91"N) and (31° 31' 12.20"E). The college campus consists of thirteen buildings and three main entrances with 61207 m² as total area, 19865 m² buildings and 8400 m² green spaces. Also, there is another separate building in addition to research and animal production farms with an independent entrance (Fig. 1).



Fig. 1. College of Agriculture, Zagazig University, Sharqia, Egypt ©Google Earth.

Location analysis

Three buildings were selected to propose a rooftop garden for their roofs:

- Horticulture Department Building (Site A): consists of four floors on an area of 1216.28 m².
- Management Building (Site B): consists of four floors on an area of 2102.05 m², and the roof is divided into three parts, each with a private entrance.
- Economics Department Building (Site C): consists of three floors on an area of 699.66 m².

Planning a suitable design

Individual interviews were conducted with specialized experts (specialists) and users/beneficiaries (users) who will use these gardens to find out their proposals and ideas about the designs that could be implemented on the rooftops under study to meet user requirements from functional, environmental, and aesthetic perspectives (Inspired by Al-Fahham and Al-Asadi (2018); Handl et al. (2023)). SKETCHUP PRO 2021¹ software trial version was used to design rooftop garden proposals. One layout was drawn for each garden and three-dimensional images of each proposed layout were created.

Proposed designs of rooftop gardens

The three proposed layouts were designed to be multi-use, combining food production, aesthetic enhancement (Sutton, 2014; Wang et al., 2021), entertainment and seating areas, recreation and sports activities, educational models, and satisfying the five human senses (Figs. 2, 3, and 4). An intensive and extensive roof garden were combined. The intensive parts were used for small-sized fruit trees and shrubs, some selected for their aesthetic value, while the extensive parts were used for grass, and flowering or aromatic herbaceous plants. Solar panels were suggested to provide the necessary energy, along with a wire fence for protection.

The proposed design for Site A included 34 species belonging to 17 families, distributed as 2 trees, 1 palm, 4 shrubs, 2 vines, 12 perennials, 4 annuals, 4 grasses, and 5 succulents. These included 5 vegetables, 2 fruits, 4 aromatic plants, and 9 flowering plants. The proposed design for Site B included 46 species belonging to 25 families, distributed as 4 trees, 3 palms, 5 shrubs, 2 vines, 17 perennials, 6 annuals, 4 grasses, and 5 succulents. These included 5 vegetables, 4 fruits, 5 aromatic plants, and 14 flowering plants. The proposed design for Site C included 24 species belonging to 15 families, distributed as 4 trees, 1 palm, 1 shrub, 2 vines, 10 perennials, 4 annuals, and 2 grasses. Among them, 4 vegetables, 4 fruits, 6 aromatic plants, and 8 flowering plants (Table 1).

¹ Trimble Inc. (2021) SketchUp Pro, Version 21.0.339, Computer software. Westminster, Colorado, United States. <https://www.sketchup.com>

Table 1. Plants suggested to be in various location designs

| Plant species | Family | Plant group | Site A | Site B | Site C |
|---|-----------------|----------------|--------|--------|--------|
| <i>Acalypha wilkesiana</i> | Euphorbiaceae | Shrubs | + | | |
| <i>Agave attenuate</i> | Asparagaceae | Succulents | + | | |
| <i>Aloe vera</i> | Asphodelaceae | Succulents | | + | |
| <i>Brassica oleracea</i> var. <i>capitata</i> f. <i>alba</i> | Brassicaceae | Annuals* | | + | |
| <i>Brassica oleracea</i> var. <i>capitata</i> f. <i>rubra</i> | Brassicaceae | Annuals* | | + | |
| <i>Buxus microphylla</i> | Buxaceae | Shrubs | + | + | |
| <i>Callistemon viminalis</i> | Myrtaceae | Shrubs | | + | |
| <i>Capsicum annuum</i> | Solanaceae | Annuals* | + | + | |
| <i>Carica papaya</i> | Caricaceae | Trees | | + | + |
| <i>Catharanthus roseus</i> | Apocynaceae | Perennials** | | + | |
| <i>Chamaedorea elegans</i> | Arecaceae | Palms | | + | |
| <i>Chrysanthemum</i> × <i>morifolium</i> | Asteraceae | Perennials** | + | | |
| <i>Citrus margarita</i> | Rutaceae | Trees | + | + | + |
| <i>Citrus</i> × <i>sinensis</i> | Rutaceae | Trees | + | + | |
| <i>Codiaeum variegatum</i> | Euphorbiaceae | Shrubs | | + | |
| <i>Coleus scutellarioides</i> | Lamiaceae | Perennials | | + | |
| <i>Cordyline fruticose</i> | Asparagaceae | Perennials | + | | |
| <i>Cycas revoluta</i> | Cycadaceae | Palms | | + | + |
| <i>Cymbopogon citratus</i> | Poaceae | Grass and Lawn | + | + | + |
| <i>Cynodon dactylon</i> x <i>C. transvaalensis</i> | Poaceae | Grass and Lawn | + | + | |
| <i>Dianthus caryophyllus</i> | Caryophyllaceae | Perennials** | | | + |
| <i>Dracaena marginata</i> | Asparagaceae | Perennials | + | + | |
| <i>Duranta erecta</i> | Verbenaceae | Shrubs | + | | |
| <i>Echinocactus grusonii</i> | Cactaceae | Succulents | + | + | |
| <i>Epipremnum aureum</i> | Araceae | Perennials | + | + | |
| <i>Fragaria</i> × <i>ananassa</i> | Rosaceae | Perennials* | + | | + |
| <i>Gazania rigens</i> | Asteraceae | Perennials** | + | + | |
| <i>Gerbera jamesonii</i> | Asteraceae | Perennials** | + | | + |
| <i>Jasminum grandiflorum</i> | Oleaceae | Vines | + | + | + |
| <i>Kalanchoe thyrsiflora</i> | Crassulaceae | Succulents | + | + | |
| <i>Lactuca sativa</i> | Asteraceae | Annuals* | + | | + |
| <i>Lycopersicon esculentum</i> | Solanaceae | Annuals* | + | + | + |
| <i>Lycopersicon esculentum</i> var. <i>cerasiforme</i> | Solanaceae | Annuals* | + | | |
| <i>Malus domestica</i> | Rosaceae | Trees | | | + |
| <i>Matthiola incana</i> | Brassicaceae | Perennials** | | + | |
| <i>Monstera deliciosa</i> | Araceae | Perennials | | + | |
| <i>Paspalum setaceum</i> | Poaceae | Grass and Lawn | + | + | + |
| <i>Pelargonium graveolens</i> | Geraniaceae | Perennials | | | + |
| <i>Pelargonium zonale</i> | Geraniaceae | Perennials** | + | + | + |
| <i>Pennisetum setaceum</i> 'Rubrum' | Poaceae | Grass and Lawn | + | + | |
| <i>Petunia</i> × <i>hybrida</i> | Solanaceae | Perennials** | + | + | |
| <i>Plumeria rubra</i> | Apocynaceae | Shrubs | | + | |
| <i>Portulaca grandiflora</i> | Portulacaceae | Succulents | | + | |
| <i>Prunus persica</i> | Rosaceae | Trees | | + | + |
| <i>Rosa banksiae</i> | Rosaceae | Vines | + | + | + |
| <i>Rosmarinus officinalis</i> | Lamiaceae | Perennials | + | + | + |
| <i>Salvia officinalis</i> | Lamiaceae | Perennials | | + | + |
| <i>Salvia splendens</i> | Lamiaceae | Perennials** | | + | |
| <i>Sansevieria cylindrica</i> | Asparagaceae | Succulents | + | | |
| <i>Sansevieria trifasciata</i> | Asparagaceae | Succulents | + | + | |

Table 1. cont.

| | | | | | |
|-------------------------------|----------------|--------------|---|---|---|
| <i>Schefflera arboricolum</i> | Araliaceae | Shrubs | | + | |
| <i>Solanum melongena</i> | Solanaceae | Annuals* | | + | + |
| <i>Spathiphyllum wallisii</i> | Araceae | Perennials | | + | |
| <i>Strelitzia reginae</i> | Strelitziaceae | Perennials** | + | + | + |
| <i>Syngonium podophyllum</i> | Araceae | Perennials | | + | |
| <i>Tagetes erecta</i> | Asteraceae | Annual** | | + | + |
| <i>Tecoma stans</i> | Bignoniaceae | Shrubs | + | | + |
| <i>Tradescantia spathacea</i> | Commelinaceae | Perennials | | + | + |
| <i>Yucca aloifolia</i> | Asparagaceae | Perennials | + | + | + |
| <i>Zamioculcas zamiifolia</i> | Araceae | Palms | + | + | |

* Vegetables, ** Flowering herb

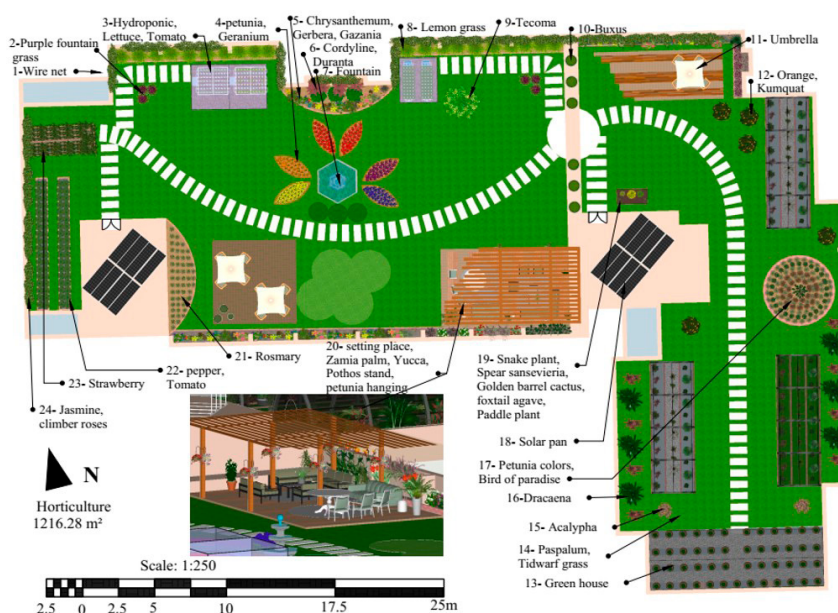


Fig. 2. The proposed design of Site A (Horticulture department).

Evaluation process

A questionnaire form was prepared that included evaluation criteria using a three-point Likert scale (Likert, 1932). Evaluation criteria were selected based on specialists' and users' desires, gathered through personal interviews conducted before the design process. Questions were selected that fit the reality of the study and were evaluated linguistically and scientifically by specialists in floriculture and landscape gardening, agricultural extension, and statistics to appear in a way that achieves its purpose. It was handed out to 10 specialists in ornamentals and landscape design and a random sample of potential garden users (75% - 80% of target groups). Similar studies with different questions were conducted by Al-Fahham and Al-Asadi (2018) and Handl et al. (2023).

Participants were provided with information about the questionnaire by the researcher, and each design was explained. The questionnaire was available in electronic and paper formats. Also, 2D maps, 3D images, and videos were created for each proposed design using the design software program. The 3D images simulated the nature that the gardens will be like later to make it easier for users to anticipate the designs.

Respondent data

Ten specialists participated in evaluation process, including 3 females and 7 males whose academic degrees were 5 professors, 2 assistant professors, and 3 lecturers. Additionally, 109 respondents represented the users, with distributions of 22, 28, and 21 males, and 12, 9, and 17 females for Site A, Site B, and Site C, respectively (Table 2).

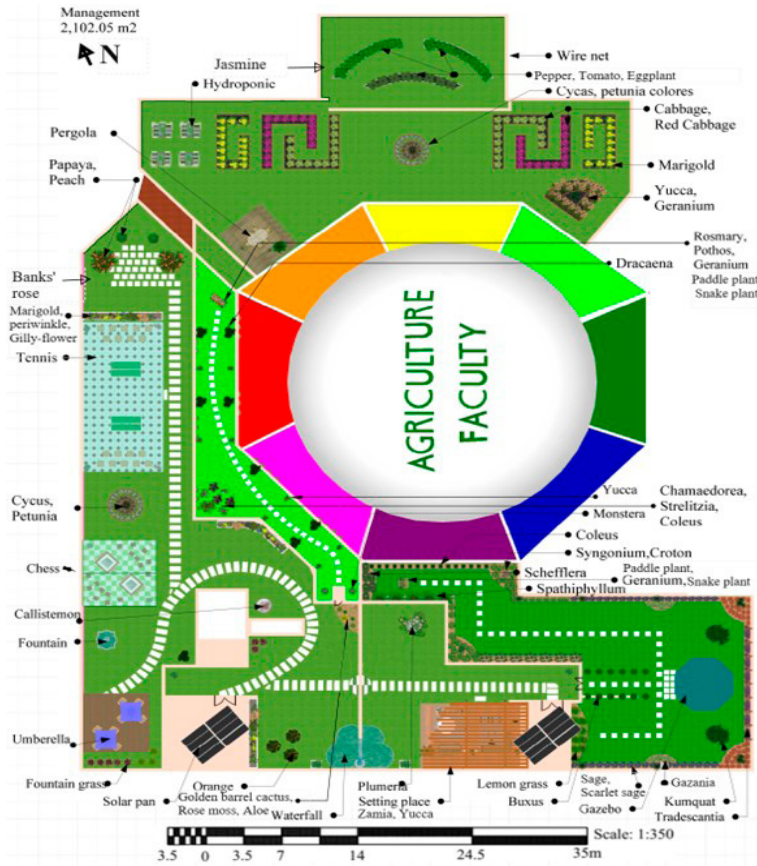


Fig. 3. The proposed design of Site B (Management building).

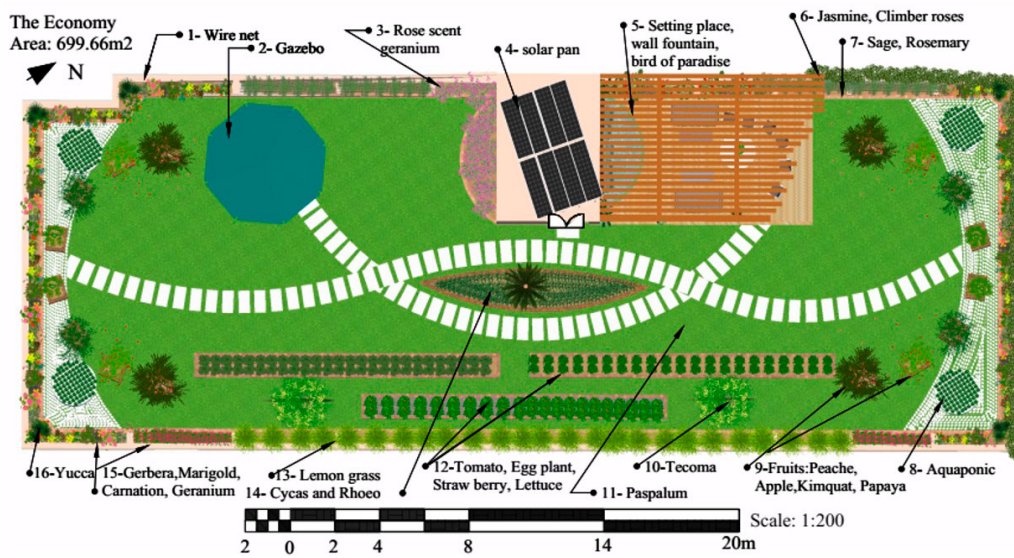


Fig. 4. The proposed design of Site C (Economic Department).

Table 2. Data of specialists and users participating in the survey

| Evaluators | | Users | | | Specialists |
|-----------------|---|--------|--------|--------|-------------|
| | | Site A | Site B | Site C | |
| Gender | Male | 22 | 28 | 21 | 7 |
| | Female | 12 | 9 | 17 | 3 |
| Academic degree | Professor | 16 | 26 | 12 | 5 |
| | Assistant professor | 8 | 5 | 9 | 2 |
| | Lecturer | 5 | 6 | 10 | 3 |
| | Assistant teacher | 5 | - | 7 | - |
| Specialization | Floriculture, medicinal and aromatic plants | | | 8 | |
| | Floriculture breeding | | | 1 | |
| | Physiology of ornamental plants | | | 1 | |

Questionnaire analysis:

Data were entered into Microsoft Excel 2019. Responses percentage of each question, Total responses (section), and Total responses (specialists + users) were calculated. For the first section (Plant components in a rooftop garden), the number of users is equal to the total number of respondents from the three departments.

$$\begin{aligned} \text{Total responses (section)\%} &= \frac{\text{Total responses of questions (section)}}{\text{number of questions (section)} \times \text{number of respondents}} \times 100 \\ \text{Total responses (Specialists + users)\%} &= \frac{\text{Total responses of questions (section) for (Specialists + users)}}{\text{number of questions (section)} \times \text{number of respondents (Specialists + users)}} \times 100 \end{aligned}$$

Results

Plant components in a rooftop garden

Table 3 reveals that 55.3% of respondents preferred the plant components suggested for rooftop gardens. In addition, 46.7% of specialists' responses were "Preferred", while 56.1% of users' responses were "Preferred". Furthermore, trees and palms were "to some extent preferred" by 60% and 48.6% of specialists and users, respectively, while "Not preferred" by 40% of specialists and 33.9% of users. Flowering herbaceous plants were the most preferred plant component by specialists and users, at 100% and 91.7%, respectively, followed by medicinal and aromatic plants at 70% and 77.1%, and shrubs and climbers at 60% and 70.6% for specialists and users, respectively. Shade and semi-shade plants were "to some extent preferred" by 70% of specialists and 50.5% of users, whereas lawns were "Preferred" by 30% of specialists and 47.7 of users.

Table 3. Percentage of responses from specialists and users regarding plant components in a rooftop garden

| Item | Preferred (%) | | Some extent (%) | | Not preferred (%) | |
|-------------------------------|---------------|-------|-----------------|-------|-------------------|-------|
| | Specialists | Users | Specialists | Users | Specialists | Users |
| Trees and palms | 0 | 17.4 | 60 | 48.6 | 40 | 33.9 |
| Shrubs and climbers | 60 | 70.6 | 40 | 27.5 | 0 | 1.8 |
| Flowering herbaceous | 100 | 91.7 | 0 | 6.4 | 0 | 1.8 |
| Lawn | 30 | 47.7 | 40 | 30.3 | 30 | 22 |
| Medicinal and aromatic plants | 70 | 77.1 | 30 | 21.1 | 0 | 1.8 |
| Shade and semi-shade plants | 20 | 32.1 | 70 | 50.5 | 10 | 17.4 |
| Total responses | 46.7 | 56.1 | 40 | 30.7 | 13.3 | 13.2 |
| | 55.3 | | 31.5 | | 13.2 | |

Diversity of plants within the proposed designs

Data presented in Table 4 indicates that the total responses (specialists + users) of "Agree" regarding diversity of plants within the proposed designs were 49.2%, 59.6%, and 57.3%, while "to some extent" responses were 33.7%, 32.3%, and 29.2% for Sites A, B, and C, respectively. In addition, the total response percentages of specialists who agreed with the diversity of plants within the proposed designs were 43.3% (Site A), 50% (Site B), and 50% (Site C). Also, users' total response percentages were Agree at 51% (Site A), 62.2% (Site B), and 59.2% (Site C).

According to specialists, Table 4 shows that the percentages agreeing with trees and palms diversity were 20%, 50%, and 70% within the proposed designs for Sites A, B, and C, respectively. Further, the highest diversity of plants was in flowering herbaceous at 80% (Site A), 70% (Site B), and 80% (Site C). For shrubs and climbers' diversity, most specialists' responses were "Agree" at 70% (Site A), 50% (Site B), and 50% (Site C), while responses were "to some extent" at 30% (Site A), 40% (Site B), and 30% (Site C). Moreover, regarding medicinal and aromatic plants, responses percentages of "Agree" were 60%, 50%, and 70%, and "to some extent" were 30%, 40%, and 30% for Sites A, B, and C, respectively.

Table 4. Percentage of responses from specialists and users regarding plants diversity within the proposed designs

| Item | Agree (%) | | | Some extent (%) | | | Disagree (%) | | |
|--|-------------|-------------|-------------|-----------------|-------------|-------------|--------------|------------|-------------|
| | Site A | Site B | Site C | Site A | Site B | Site C | Site A | Site B | Site C |
| Specialists | | | | | | | | | |
| Trees and palms | 20 | 50 | 70 | 30 | 30 | 10 | 50 | 20 | 20 |
| Shrubs and climbers | 70 | 50 | 50 | 30 | 40 | 30 | 0 | 10 | 20 |
| Flowering herbaceous | 80 | 70 | 80 | 20 | 20 | 20 | 0 | 10 | 0 |
| lawns | 10 | 20 | 20 | 50 | 70 | 60 | 40 | 10 | 20 |
| Medicinal and aromatic plants | 60 | 50 | 70 | 30 | 40 | 30 | 10 | 10 | 0 |
| Shade and semi-shade plants | 20 | 60 | 10 | 60 | 40 | 80 | 20 | 0 | 10 |
| Total responses | 43.3 | 50 | 50 | 36.7 | 40 | 38.3 | 20 | 10 | 11.7 |
| Users | | | | | | | | | |
| Trees and palms | 29.4 | 56.8 | 71.1 | 29.4 | 29.7 | 18.4 | 41.2 | 13.5 | 10.5 |
| Shrubs and climbers | 61.8 | 70.3 | 47.4 | 32.3 | 27 | 18.4 | 5.9 | 2.7 | 34.2 |
| Flowering herbaceous | 85.3 | 83.8 | 84.2 | 14.7 | 10.8 | 15.8 | 0 | 5.4 | 0 |
| lawns | 38.2 | 43.2 | 44.7 | 26.5 | 46 | 26.3 | 35.3 | 10.8 | 29 |
| Medicinal and aromatic plants | 58.8 | 70.3 | 73.7 | 38.2 | 24.3 | 26.3 | 3 | 5.4 | 0 |
| Shade and semi-shade plants | 32.3 | 48.7 | 34.2 | 55.9 | 43.2 | 55.3 | 11.8 | 8.1 | 10.5 |
| Total responses | 51.0 | 62.2 | 59.2 | 32.8 | 30.2 | 26.8 | 16.2 | 7.7 | 14.0 |
| Total responses (Specialists + Users) | 49.2 | 59.6 | 57.3 | 33.7 | 32.3 | 29.2 | 17.0 | 8.2 | 13.5 |

Concerning users' responses, 29.4%, 56.8%, and 71.1% of responses for Sites A, B, and C, respectively, agreed regarding the diversity of trees and palms within the proposed designs, while 29.4% (Site A), 29.7% (Site B), and 18.4% (Site C) agreed "to some extent" (Table 4). As for diversity of flowering herbaceous, 85.3% (Site A), 83.8% (Site B), and 84.2% (Site C) of users' responses were "Agree". Regarding shrubs and climbers' diversity, users agreed at 61.8% (Site A), 70.3% (Site B), and 47.4% (Site C). Furthermore, 58.8%, 70.3%, and 73.7% of users agreed with medicinal and aromatic plants diversity for Sites A, B, and C, respectively. Regarding shade and semi-shade plants, maximum responses were "Agree" in Site B at 48.7%, and "to some extent" in Site A (55.9%) and Site C (55.3%).

Satisfying the five human senses

According to Table 5, with reference to specialists + users' total responses of satisfying human senses by the proposed designs, most responses were "satisfied" at 75.7%, 69.4%, and 75% for Sites A, B, and C, respectively. Moreover, the design of Site A was best for satisfying the five senses of specialists, while the Site C design was rated best by users. Specialists' responses confirmed that the designs of Sites A, B, and C satisfy hearing at 80%, 70% and 70%; sight at 90%, 80% and 80%; smell at 70%, 50% and 80%; touch at 80%, 60% and 60%; and taste at 70%, 60% and 70%, respectively. Furthermore, regarding users' responses, 73.5%, 70.3%, and 63.2% were "satisfied" with hearing, and 88.2%, 91.9%, and 89.5% were "satisfied" with sight for Sites A, B, and C, respectively. In the same context 73.5% (Site A), 70.3 (Site B), and 86.8% (Site C) of the responses were "Satisfied" with smell.

Table 5. Percentage of responses from specialists and users regarding satisfying the five human senses by proposed designs

| Item | Satisfied (%) | | | Some extent (%) | | | Not Satisfied (%) | | |
|--|---------------|-------------|-------------|-----------------|-------------|-------------|-------------------|------------|------------|
| | Site A | Site B | Site C | Site A | Site B | Site C | Site A | Site B | Site C |
| Specialists | | | | | | | | | |
| Hearing | 80 | 70 | 70 | 20 | 30 | 30 | 0 | 0 | 0 |
| Sight | 90 | 80 | 80 | 10 | 20 | 20 | 0 | 0 | 0 |
| Smell | 70 | 50 | 80 | 30 | 30 | 20 | 0 | 20 | 0 |
| Touch | 80 | 60 | 60 | 20 | 30 | 40 | 0 | 10 | 0 |
| Taste | 70 | 60 | 70 | 30 | 30 | 30 | 0 | 10 | 0 |
| Total responses | 78.0 | 64.0 | 72.0 | 22.0 | 28.0 | 28.0 | 0.0 | 8.0 | 0.0 |
| Users | | | | | | | | | |
| Hearing | 73.5 | 70.3 | 63.2 | 23.5 | 29.7 | 36.8 | 3 | 0 | 0 |
| Sight | 88.2 | 91.9 | 89.5 | 11.8 | 8.1 | 10.5 | 0 | 0 | 0 |
| Smell | 73.5 | 70.3 | 86.8 | 26.5 | 24.3 | 13.2 | 0 | 5.4 | 0 |
| Touch | 70.6 | 62.2 | 68.4 | 29.4 | 35.1 | 31.6 | 0 | 2.7 | 0 |
| Taste | 67.7 | 59.5 | 71.1 | 29.4 | 37.8 | 26.3 | 2.9 | 2.7 | 2.6 |
| Total responses | 74.7 | 70.8 | 75.8 | 24.1 | 27.0 | 23.7 | 1.2 | 2.2 | 0.5 |
| Total responses (Specialists + Users) | 75.5 | 69.4 | 75.0 | 23.6 | 27.2 | 24.6 | 0.9 | 3.4 | 0.4 |

Achieving design fundamentals

As illustrated in Table 6, with respect to specialists + users, the proposed designs achieve design fundamentals at 70.8% (Site A), 72.3% (Site B), and 75.7% (Site C). In relation to specialists, the total “Satisfied” responses were 66.7%, 70% and 70%, while for users they were 72.1%, 73%, and 77.2% for Sites A, B, and C, respectively. Regarding specialists’ responses, the proposed designs achieve simplicity at 90% (Site A), 80% (Site B) and 90% (Site C).

Furthermore, the proposed design for Site C was best ‘in achieving unity (70%) and variety and diversity (90%), while the proposed design for Site B was best ‘in achieving balance (70%) and contrast (60%), and the proposed design for Site A was best ‘in achieving proportion and scale (90%). In the same context, users agreed that the proposed design of Site C was best in achieving simplicity (86.8%), unity (81.6%), variety and diversity (89.5%), and balance (78.9%), while the proposed design of Site A was best in achieving proportion and scale (88.3%), and the proposed design of Site B was best in achieving contrast (51.4%).

Table 6. Percentage of responses from specialists and users regarding achieving design fundamentals by the proposed designs

| Item | Satisfied (%) | | | Some extent (%) | | | Not Satisfied (%) | | |
|--|---------------|--------|--------|-----------------|--------|--------|-------------------|--------|--------|
| | Site A | Site B | Site C | Site A | Site B | Site C | Site A | Site B | Site C |
| Specialists | | | | | | | | | |
| Simplicity | 90 | 80 | 90 | 10 | 20 | 10 | 0 | 0 | 0 |
| Unity | 60 | 60 | 70 | 40 | 40 | 30 | 0 | 0 | 0 |
| Variety and diversity | 80 | 80 | 90 | 20 | 10 | 10 | 0 | 10 | 0 |
| Balance | 50 | 70 | 60 | 50 | 30 | 40 | 0 | 0 | 0 |
| Proportion and scale | 90 | 70 | 70 | 0 | 30 | 30 | 10 | 0 | 0 |
| Contrast | 30 | 60 | 40 | 70 | 30 | 50 | 0 | 10 | 10 |
| Total responses | 66.7 | 70.0 | 70.0 | 31.7 | 26.7 | 28.3 | 1.7 | 3.3 | 1.7 |
| Users | | | | | | | | | |
| Simplicity | 85.3 | 70.3 | 86.8 | 8.8 | 27 | 13.2 | 5.9 | 2.7 | 0 |
| Unity | 70.6 | 78.4 | 81.6 | 29.4 | 21.6 | 18.4 | 0 | 0 | 0 |
| Variety and diversity | 79.4 | 89.2 | 89.5 | 20.6 | 8.1 | 10.5 | 0 | 2.7 | 0 |
| Balance | 67.6 | 78.4 | 78.9 | 32.4 | 21.6 | 21.1 | 0 | 0 | 0 |
| Proportion and scale | 88.3 | 70.3 | 78.9 | 8.8 | 29.7 | 21.1 | 2.9 | 0 | 0 |
| Contrast | 41.2 | 51.4 | 47.4 | 50 | 40.5 | 42.1 | 8.8 | 8.1 | 10.5 |
| Total responses | 72.1 | 73.0 | 77.2 | 25.0 | 24.8 | 21.1 | 2.9 | 2.3 | 1.8 |
| Total responses (Specialists + Users) | 70.8 | 72.3 | 75.7 | 26.5 | 25.2 | 22.6 | 2.7 | 2.5 | 1.7 |

Evaluating the overall proposed designs

Table 7 clarifies that the total responses (specialists + users) of “Agree” regarding the evaluation of the overall proposed designs were 74.5%, 64.1% and 59.7%, for Sites A, B and C, respectively. In addition, specialists agreed by 67.8% (Site A), 56.7% (Site B) and 63.3% (Site C), while users agreed by 76.5% (Site A), 66.1% (Site B), and 58.8% (Site C).

According to specialists, suitable recreational areas existed within the proposed designs for Sites A, B, and C at 80%, 90%, and 80% respectively (Table 7). Additionally, the responses for artificial landscape components

were “agree” by 70% (Site A), 70% (Site B), and 60% (Site C). Regarding diversity in colors, 80% (Site A), 70% (Site B) and 70% (Site C) of specialists’ responses were “agree,” while for sitting areas, 70% (Site A), 60% (Site B) and 70% (Site C) of responses were “agree”. Furthermore, all proposed designs included educational models for students at 60% (Site A), 40% (Site B), and 60% (Site C). Moreover, Sites A and C were easy to maintain by 80% and 70%, respectively, while Site B recorded 40% of responses. Conducting agricultural experiments recorded “agree” by 30% of responses in both Sites A and C.

Table 7. Percentage of responses from specialists and users regarding the overall evaluation of the proposed designs

| Item | Agree (%) | | | Some extent (%) | | | Disagree (%) | | |
|--|-----------|--------|--------|-----------------|--------|--------|--------------|--------|--------|
| | Site A | Site B | Site C | Site A | Site B | Site C | Site A | Site B | Site C |
| Specialists | | | | | | | | | |
| Suitable recreational areas | 80 | 90 | 80 | 10 | 10 | 20 | 10 | 0 | 0 |
| Diversity in plant types | 90 | 90 | 90 | 10 | 0 | 10 | 0 | 10 | 0 |
| Artificial landscape components | 70 | 70 | 60 | 30 | 30 | 40 | 0 | 0 | 0 |
| Diversity in colors | 80 | 70 | 70 | 20 | 30 | 30 | 0 | 0 | 0 |
| Sitting areas | 70 | 60 | 70 | 30 | 30 | 20 | 0 | 10 | 10 |
| Water features | 50 | 50 | 40 | 50 | 50 | 60 | 0 | 0 | 0 |
| Educational models for students | 60 | 40 | 60 | 40 | 40 | 30 | 0 | 20 | 10 |
| Easy to maintain | 80 | 40 | 70 | 20 | 60 | 30 | 0 | 0 | 0 |
| Conducting agricultural experiments | 30 | 0 | 30 | 60 | 50 | 40 | 10 | 50 | 30 |
| Total responses | 67.8 | 56.7 | 63.3 | 30.0 | 33.3 | 31.1 | 2.2 | 10.0 | 5.6 |
| Users | | | | | | | | | |
| Suitable recreational areas | 70.6 | 78.4 | 65.8 | 23.5 | 18.9 | 34.2 | 5.9 | 2.7 | 0 |
| Diversity in plant types | 91.2 | 94.6 | 86.8 | 8.8 | 2.7 | 13.2 | 0 | 2.7 | 0 |
| Artificial landscape components | 73.5 | 64.9 | 52.6 | 26.5 | 29.7 | 42.1 | 0 | 5.4 | 5.3 |
| Diversity in colors | 82.4 | 81.1 | 76.3 | 17.6 | 18.9 | 23.7 | 0 | 0 | 0 |
| Sitting areas | 85.3 | 78.4 | 65.8 | 14.7 | 18.9 | 31.6 | 0 | 2.7 | 2.6 |
| Water features | 67.6 | 70.3 | 55.3 | 32.4 | 29.7 | 44.7 | 0 | 0 | 0 |
| Educational models for students | 76.5 | 54.1 | 47.4 | 23.5 | 35.1 | 47.3 | 0 | 10.8 | 5.3 |
| Easy to maintain | 82.4 | 51.4 | 57.9 | 17.6 | 45.9 | 42.1 | 0 | 2.7 | 0 |
| Conducting agricultural experiments | 58.8 | 21.6 | 21.1 | 35.3 | 37.8 | 44.7 | 5.9 | 40.6 | 34.2 |
| Total responses | 76.5 | 66.1 | 58.8 | 22.2 | 26.4 | 36.0 | 1.3 | 7.5 | 5.3 |
| Total responses (Specialists + Users) | 74.5 | 64.1 | 59.7 | 24.0 | 27.9 | 35.0 | 1.5 | 8.0 | 5.3 |

According to users' responses (Table 7), the proposed design for Site A was best for including artificial landscape components (73.5%), diversity in colors (82.4%), sitting areas (85.3%), educational models for students (76.5%), ease of maintenance (82.4%), and suitability of conducting agricultural experiments (58.8%). Conversely, the proposed design for Site B was best in incorporating suitable recreational areas (78.4%), diversity in plant species (94.6%), and water features (70.3%).

Discussion

Planting trees on roofs was the least desired plant element by participants, a similar result obtained by Jim and Hui (2022), maybe due to the large size crowns, increasing root growth rate, and increasing the load on roofs. Abuseif et al. (2022) stated that the planting of trees on buildings varies from planting into natural ground, because on buildings there may be structures below or above which obstruct both roots and crowns, potentially limiting the growth of the trees. However, the specialists suggested that small flowering and fruit trees, as well as slow-growing palms, can be implemented on rooftops in suitable containers or concrete beds. On the contrary, Park et al. (2022) found that the green roof scenario with 50% trees and 50% shrubs were best in semi-open areas, while 30% trees with 70% grass or 70% trees and 30% grass was best in open areas. Additionally, the study aligns with Al-Fahham and Al-Asadi (2018) that flowering herbaceous plants were the most preferred plant component by both specialists and users. The study attributes the importance of flowering herbaceous plants and their widespread preference in rooftop gardens to the variety of size, diversity in flower colors and shapes, as they provide the required variety in garden colors, add beauty and elegance to the place, satisfy the human sense of sight, and have limited root spread. As for aromatic plants, they impart an aromatic scent and satisfy the sense of smell, while for shrubs, they preferred for the restricted spread of their crown and root system and compensate for the lack of using trees.

Since plant diversity plays a vital role in ecosystems balance and supporting livelihoods (Diaz et al., 2018), so plant diversity was assessed in the proposed designs. The highest diversity of plants was observed in flowering herbaceous. Among these flowering herbaceous species were *Catharanthus roseus*, *Matthiola incana*, *Pelargonium zonale*, *Petunia × hybrida*, *Salvia splendens*, *Strelitzia reginae*, and *Tagetes erecta*. Moreover, the Site C design exhibited the highest diversity of trees, due to the inclusion of diverse fruit tree species (*Carica papaya*, *Citrus margarita*, *Malus domestica* and *Prunus persica*), along with the limited rooftop area of the site. Furthermore, some shrubs and climbers used in the proposed designs as *Acalypha wilkesiana*, *Buxus microphylla*, *Callistemon viminalis*, *Codiaeum variegatum*, *Duranta erecta*, *Jasminum grandiflorum*, *Plumeria rubra*, and *Rosa banksiae*. In agreement with Lee et al., (2023), an open and constructed vegetation design that involves both grass and shrubs may have more potential for stress reduction than a monotonous vegetation model.

The incorporation of elements that satisfy human senses within the garden design is an attempt to create a sensory garden. As Souter-Brown et al. (2021) assert, the implementation of such gardens has been demonstrated to effectively reduce stress, enhance wellbeing, and improve the productivity of individuals in the workplace. The findings of this study indicate that the three proposed designs can be implemented to satisfy human senses and enhance productivity on a university campus. This study also attributes the satisfaction of hearing to the inclusion of the movement of the water element and the friction of plant leaves in the proposed designs. At the same time, the satisfaction of the sense of smell is due to the inclusion of plants such as *Cymbopogon citratus*, *Jasminum grandiflorum*, *Pelargonium graveolens*, *Rosmarinus officinalis* and *Salvia officinalis*. Furthermore, the inclusion of various plant textures such as *Cycas revoluta*, *Callistemon viminalis*, *Cymbopogon citratus*, *Gazania rigens*, *Rosmarinus officinalis*, *Salvia officinalis* and *Tagetes erecta*,

contribute to the satisfaction of the sense of touch. Other plants have also been selected to satisfy the sense of taste, such as *Capsicum annuum*, *Carica papaya*, *Citrus × sinensis*, *Fragaria × ananassa* and *Lycopersicon esculentum*.

When choosing the right activities that not only improve the physical and emotional needs of the users but also satisfy their recreational needs was very important in a landscape (Pouya, 2019), some of these activities were included in the proposed designs, which the study attributes to the positive response of the respondents. Furthermore, the artificial elements in gardens and permanent landscapes are regarded as essential accessories that complement their design. These elements are crucial for the completion of the garden or landscape's overall coordination and design. They enhance the artistic vision created by the designer, elevating the aesthetic appeal while also improving functional efficiency (Handl et al., 2022).

Plant color arrangement plays a crucial role in determining the visual impact of landscape design. When plant colors are improperly configured, the overall color harmony of the design can be compromised (Zhang, 2013). This study attributes the diversity in colors to the diversity in plants, where *Acalypha wilkesiana*, *Brassica oleracea* var. *capitata* f. *rubra*, *Tradescantia spathacea*, *Codiaeum variegatum*, *Cordyline fruticosa* and *Duranta erecta* give colorful leaves, while *Gazania rigens*, *Tagetes erecta*, *Tecoma stans*, *Matthiola incana* and *Pelargonium zonale* give colorful flowers. As well as, all proposed designs included educational models for students, such as greenhouses, hydroponic and aquaponic units, and solar panels, in addition to identifying some different types of plants and the possibility of following their agricultural operations. Moreover, the study posits that the possibility of conducting agricultural experiments on the proposed designs is due to the presence of a hydroponic system and greenhouses in Site A, and the existence of adequate space for the cultivation of annuals and perennials in Site C. The results of the study are consistent with the conclusions of Pouya (2019) that the well-designed roof can be used as a place for rest, recreation, and education.

Conclusions

Rooftop gardens represent an experiment to create aesthetic and recreational areas to reduce stress and life pressures, enhance well-being, and improve people's productivity in the work environment. Also, designed green rooftops provide valued opportunities to increase green space and improve sustainability on college campuses.

The implementation of trees and lawn on rooftops is technically workable when appropriate engineering considerations are incorporated. Small flowering and fruit trees, as well as slow-growing palms, can be successfully integrated into rooftop designs utilizing suitable container systems or concrete beds, in accordance with established industry practices. While natural lawns are applicable when proper drainage and maintenance systems are in place, artificial alternatives may be considered where maintenance resources are constrained. Flowering herbaceous, medicinal, and aromatic plants can be extensively incorporated for their aesthetic value, fragrance, and textural diversity, thereby enhancing the sensory experience. Furthermore, the rooftop garden can function as a sustainable initiative generating revenue for laboratory development and educational processes.

The proposed designs require increasing water elements. As for Site A, it lacked balance and contrast, while Site B requires more diversity of medicinal and aromatic plants, and introducing some educational models for students, as well as Site C lacked contrast. The study recommends implementing the proposed designs, taking the questionnaire results into account, using these roofs as educational models for students, providing recreational areas for faculty members, and providing an attractive aesthetic appearance.

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Author Contribution

ASIA: Conceptualization, Data Curation, Formal Analysis, Methodology, Software, Visualization, Writing – Original Draft, Writing – Review & Editing. **AAM:** Conceptualization, Supervision. **ASHG:** Conceptualization, Data Curation, Investigation, Supervision, Validation, Visualization, Writing – Review & Editing. **MAIA:** Data Curation, Formal Analysis, Methodology, Supervision, Validation, Visualization, Writing – Original Draft, Writing – Review & Editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All the research data is contained in the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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