Enhancing user's experience in urban underground tunnels through innovation of landscape elements & environmental integration

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Abstract. This research investigates new approaches to improving the user experience within underground urban tunnels by emphasising the integration of functionality for all users while achieving landscape elements and environmental factors. The study aims to integrate tunnel design standards with artistic installations and lighting to transform underground tunnels into visually attractive and psychologically comfortable spaces. The Maadi Metro Tunnel in Cairo was chosen as an example for the study due to its pivotal location. The study has an interdisciplinary approach. Firstly, to determine the function and visual comfort of the tunnel, a questionnaire was conducted for the users at peak time to find out the problems related to the design needs and visual comfort, based on design standards. Secondly, the lighting, acoustic comfort, and thermal comfort. It was evaluated using the Design Builder, DIAlux, and then a redesign was proposed to improve the design flaws that were inferred from the questionnaire and design standard, such as the materials used, the disabled and elderly needs, improving thermal comfort and lighting, and conducting a re-analysis of thermal comfort and lighting. To make sure it is achieved. Ultimately, it was determined that improving the function, visual and thermal comfort could enhance the users' experience.

1. Introduction

The swift economic expansion and urbanization witnessed over the last twenty years have led to significant advancements in the creation of underground spaces [1]. Initially, this development was prompted by challenges in urban development, including traffic congestion, limited resources, and the necessity for city resilience [2].

The underground pedestrian system (UPS), as an all-encompassing strategy for utilizing urban underground spaces (UUS), is becoming increasingly prevalent in numerous cities worldwide. As outlined by Belanger in 2007 [3], UPS comprises: a transportation network integrating subway systems and national or regional transit hubs. The recent surge in underground space utilization aligns with broader sustainability objectives [4] and the preservation of valuable land resources [5].

Additionally, provisions for public open spaces and enhancements to street environments, particularly those aimed at improving pedestrian experiences, are incorporated to accommodate the anticipated increase in pedestrian traffic resulting from high-density developments. The utilization of underground space serves not only to conserve land, relieve traffic congestion, and optimize resource utilization but also benefit pedestrians by offering shelter from inclement weather [6] and facilitating road crossings [7].

Utilizing underground spaces offers significant solutions to urban challenges such as congestion, limited open areas, and aging infrastructure [8]. Feedback from underground space users was collected regarding comfort, safety, and design aspects. The efficient utilization of underground spaces brings numerous advantages including consistent temperature and humidity levels, mitigation of land use pressure, sound isolation, and protection from natural disasters. To assess people's willingness, several factors must be considered to mitigate the flaws of underground space usage, including entrance design, spatial perception, views and orientation, natural lighting, and interior design elements [9].

The experiential quality of utilizing underground spaces is predominantly influenced by comfort, design, and safety considerations. Comfort factors encompass elements such as appeal, navigation ease, and natural light availability. Safety considerations involve aspects such as emergency evacuation routes (in case of fire, flooding, or earthquakes), visibility, and the presence of other individuals. The term "pedestrian type" may refer to various categories of pedestrians distinguished by their behaviours, characteristics, or activities.

Pedestrian behaviour encompasses the actions, and routines exhibited by individuals while walking or utilizing pedestrian areas. Grasping these nuances in pedestrian behaviour holds paramount importance for urban planners, traffic engineers, and policymakers as they strive to develop pedestrian-friendly environments, enhance safety for all pedestrian demographics, and craft efficient public spaces. A key objective of constructing underground pedestrian systems is to enhance walkability and connectivity [10]. Research on walking often includes considerations of "experience resistance," which arises from the physical effort of ascending stairs, in addition to time-use resistance [11], as both necessitate energy expenditure.

Hence, this paper identifies the problems of pedestrian tunnels from a functional perspective, especially for the elderly and the disabled, the problems of thermal and lighting comfort, the importance of integrating landscape elements to add visual comfort, and their impact on the thermal comfort of users to assess the extent of people's willingness to use underground pedestrian tunnels in Egypt.

2. Methods and Methodology

To study this research problem, the researchers selected the Maadi Metro human tunnel (29°57'38.21"N, 31°15'26.26"E) as one of the most human tunnels commonly used in Cairo, Egypt (Figure1). Cairo generally has a hot-arid climate. The average temperature is 35°C, the prevailing wind speed is in the North-Western direction with 4 m/s, and the average of Relative Humidity 55%. This tunnel was selected to test the influence of changes in landscape features on the environmental elements and the user experience. The methodology of this research is an interdisciplinary approach study (Figure2) between the current case and the redesign case; in the current case, a questionnaire was conducted for the users at peak time to determine the function and visual comfort of the tunnel to find out the problems related to the design needs and visual comfort based on design standards. Then, there is the lighting, acoustic comfort, and thermal comfort. It was evaluated using the Design Builder, DIAlux, and then a redesign was proposed to improve the design flaws that were inferred from the questionnaire and design standard, such as the materials used, the disabled and elderly needs, improving thermal comfort and lighting, and conducting a re-analysis of thermal comfort and lighting to make sure it is achieved.

Figure 1. Maadi Metro Human Tunnel Location

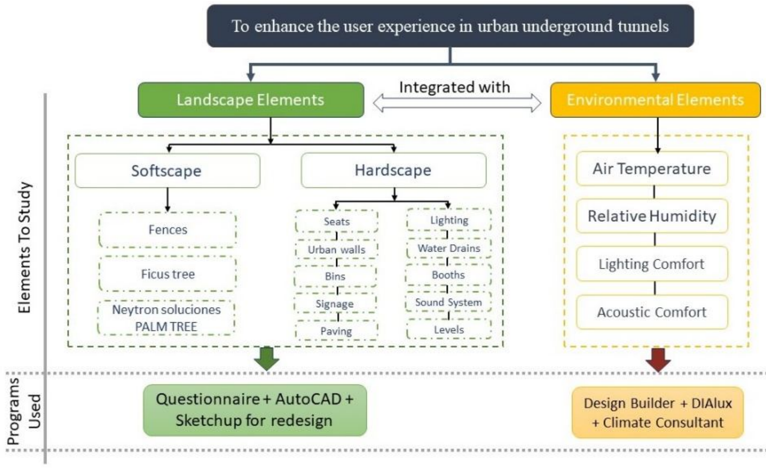


Figure 2.Research Methodology

A questionnaire was conducted for the users at peak time from 7:30 am to 9:00 am with 90 users of the Maadi Pedestrian Underground Tunnel. They were given the questionnaire, which was also made available online via a Google Form, to measure the extent to which the pedestrian tunnel in the Maadi area fulfils the moral needs of different types of users as shown in (Table 1).

Table 1. Questionnaire questions for the users of the Maadi Pedestrian

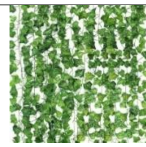
Type	Question & Answer options
Gender	1- What is your Gender? (Male /Female)
Age	2- How old are you? (Less than 13 / between 13-19/ between 20-60/more than 60)
Preferring	3- To get from 9th Street to 7th Street (or vice versa) at Maadi, which would you prefer? (The Pedestrian Underground Tunnel / The Upper Pedestrian Stairway)
Reasons of Preferring Underground Tunnel	4- In the previous question, if you chose the underground pedestrian tunnel, mention the reason? (You can choose more than answer) (More Comfortable/ More Liveable/ Safer and More Secure/ Easier to Move/ Other Reasons)
Secure	5- How secure do you feel inside Maadi underground pedestrian tunnel? (Very Insecure/ Insecure/ Neutral/ Secure/ Very Secure)
Ventilation	6- Show your Satisfaction about Ventilation at Maadi underground pedestrian tunnel? (Very Dissatisfied / Dissatisfied / Neutral/ Satisfied / Very Satisfied)
Thermal Comfort	7- Show your Satisfaction about Thermal Comfort at Maadi underground Pedestrian tunnel? (Very Dissatisfied / Dissatisfied / Neutral/ Satisfied / Very Satisfied)
Visual Comfort	8- Show your Satisfaction about Visual Comfort at Maadi underground pedestrian tunnel? (Very Dissatisfied / Dissatisfied / Neutral/ Satisfied / Very Satisfied)
Lighting	9- Is there Sufficient Lighting inside The Pedestrian Underground Tunnel in Maadi? (Strongly disagree / Disagree / Neutral/ Agree / Strongly agree)
Vendors	10- How do you feel when there are Street Vendors at The Entrance to The Pedestrian Underground Tunnel in Maadi? (Feeling Safe / Feeling Afraid / Feeling Stressed)
Guiding Signs	11- Are there enough Guiding Signs at Maadi Underground Pedestrian Tunnel? (Strongly disagree / Disagree / Neutral/ Agree / Strongly agree)
Disabilities	12- Is the Maadi Underground Pedestrian Tunnel considerate to individuals with disabilities? (Strongly disagree / Disagree / Neutral/ Agree / Strongly agree)

Landscape elements can improve people engagement with attractive urban walls, comfortable atmosphere inside the tunnel, and encourage them to use it safely. A sense of community and the promotion of social connections can be achieved by incorporating natural components such as plants and green areas elements inside and near subway stations. These factors have the potential to enhance pleasure and emotional well-being. The research will illustrate the following elements.

2.1. Softscape Elements

The interior of the tunnel can be transformed into a more attractive space, making it more comfortable. Furthermore, the use of Softscape elements can contribute to the activation of a station patio, which provides opportunities for gathering and interaction that promote social cohesion. Some factors affecting the type of softscape will be used according to the ventilation and natural lighting. So, the design will depend on artificial green elements, as they will cost less in maintenance and save on using water for irrigation as shown in (Table 2).

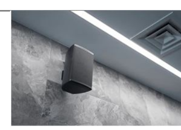
Table 2. Elements of softscape can be a major change to enhance the quality of the tunnel

Element		**Fences**		**Ficus tree**	**Neytron soluciones PALM TREE**
Figure					
Description		-Realistic green look -Artificial Leaf both interior and exterior usage. - Easy Installation	-Realistic green forthe backgrounds. -Artificial Leaf both interior and exterior usage. - Easy Installation	-Realistic textured branches -No maintenance required	Palm trees' leaves can be used at corners or entrances.
Data	**Material**	Plastic	Plastic Silk	Silk Plastic	Polyethylene
	Colour	Green/others	Green/others	Green	Green
	Style/Weight	Apple leaves	Ivy leaves	1.8 kg	2.8 kg
	Dimension	3L x 0. 02W..M	2D x 5W x 30H CM	Pot 5*5.9/47.2 H	18 x 18 x 100 cm

2.2. Hardscape Elements

The hardscape components of metro tunnels, such as surface and retaining walls, often employ robust and durable materials like concrete, steel, and stone for functionality, safety, and visual blending with the urban environment. Certain hardscape elements can significantly improve the tunnel's ambiance, promoting a pleasant passage for users devoid of concerns or negative encounters. We will illustrate these elements with examples as shown in (Table 3).

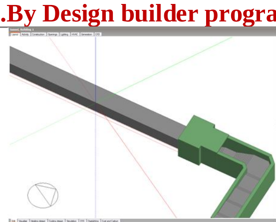
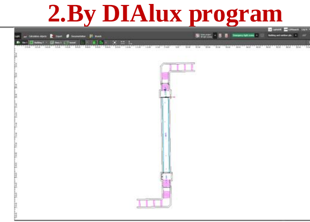
Table 3. Elements of hardscape can be a major change to enhance the quality of the tunnel.

1. Seats	**2. Urban walls**	**3. Bins**	**4. Signage**	**5. Paving /finishes**
				
anti-corrosion, sun-proof, and rust-proof	Finishing-Advertising walls - Painted walls-green walls	Recycle machine-Classified trash bins	pedestrian signs Guiding them to exits & entrances.	Pervious pavement-Kinetic flooring
6.Water Drains	**7. Booths**	**8. Lighting**	**9.Sound System**	**10.Levels**
				
For rainwater	used to vend merchandise	symmetric lighting-counter beam lighting-pro-beam lighting	classified into categories according to the environmental atmosphere	wheelchair staircase, wheelchair lift, and slopes for bikes or goods.

2.3. Environmental Elements

To start analysing the environmental elements, we need to analyse the general Climate conditions in Cairo. The simulation's weather data was obtained from Climate Consultant Software and the mean values of air temperature (Ta), and Relative humidity (RH) were utilized as input parameters for design builder simulation model (Table4). Then, Design Builder program was chosen to analyse the comfort parameters due to its ability to cover a wide range of output information (energy fuel, Lighting demand, air temperature, heat balance and relative humidity). The DIAlux program was employed to assess whether the artificial lighting implemented in the tunnel is appropriate for its dimensions. Following the simulation, adjustments to the design were proposed, and subsequently reevaluated to ensure they effectively contribute to user comfort.

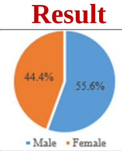
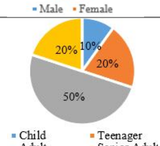
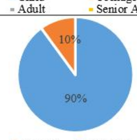
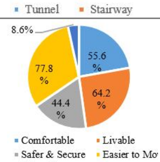
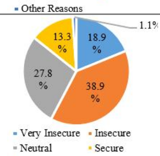
Table 4. Case study model on environmental simulation programs

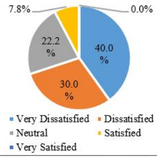
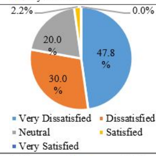
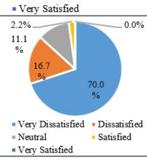
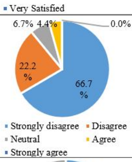
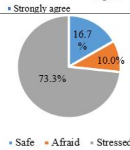
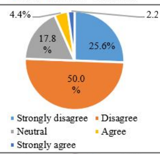
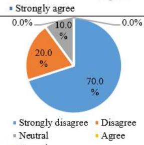
Environmental Elements simulation	
1.By Design builder program	**2.By DIAlux program**
	
To analyse Lighting demand, air temperature, heat balance, relative humidity and more energy consumption	To test the artificial lighting intensity corresponds with the space's volume

3. Results and Discussion

In this part of the research, the results of the user questionnaire were analysed to find out the weakness points in the tunnel design that affect improving the user experience from a functional, aesthetic, and environmental aspect, as shown in (Table 5).

Table 5. The questionnaire results.

Type	Result	Comment for understanding the design problems
Gender		The ratio is close between males and females, which provides an equal opportunity between the gender in using the pedestrian underground tunnel.
Age		The percentage varies between different age groups of pedestrian tunnel users, as most users are adults, aged between 20 and 60 years.
Preferring		The Upper Pedestrian Stairway next to the study area is not preferred by the great majority of users over The Pedestrian Underground Tunnel. This suggests that the pedestrian tunnel has a significant impact on how people cross from Street 7 to Street 9 and vice versa.
Reasons of Preferring Underground Tunnel		Based on users' opinions, the most influence aspect when deciding to utilize the pedestrian tunnel to go from Street 9 to Street 7 and vice versa was how Easier it was to move.
Secure		The largest percentage of user opinions was that they feel Inscure passing through the pedestrian underground tunnel in study area.

Ventilation		According to user feedback, the vast majority feel that there is no adequate ventilation inside the pedestrian tunnel in the study area.
Thermal Comfort		According to user feedback, the vast majority feel significant Thermal discomfort inside the pedestrian tunnel in the study area
Visual Comfort		According to user feedback, the vast majority feel significant visual discomfort inside the pedestrian tunnel in the study area because of levels that's hide the daylighting and materials for walls
Lighting		Based on users' opinions, the largest percentage believes that there aren't enough lighting units to adequately illuminate the pedestrian tunnel in study area.
Vendors		Based on users' opinions, the vast majority feel stressed due to the presence of street vendors at the entrance to the pedestrian tunnel in the study area
Guiding Signs		According to most of the user comments, the pedestrian tunnel does not have enough sufficient Guiding Signs.
Disabilities		According to most of the user feedback, the pedestrian tunnel was not suitable for use by Disabled people.

Based on the Design standards which focus on achieving function for all users, including the elderly and the disabled, while also emphasizing visual comfort through landscape features and ensuring thermal comfort for users. and the questionnaire findings and awareness of design flaws, a suggestion was put forward to enhance the tunnel's user experience. Initially, the focus was on enhancing the Landscape elements (Table 6). Durable stainless-steel seats were selected and embedded into the walls to facilitate passage. Additionally, non-writable tiles were employed for the walls to deter graffiti. light colour painted wall finishing to mitigate heat, designated spaces were allocated for advertisements, rather than allowing street vendors to clutter the walls. Furthermore, areas were reserved for installing artificial fixtures to enhance visual comfort for users. at the tunnel entrance, a guide map and signage were installed. On the lower-level entrance, plastic recycling machines, vending machines, and seating areas were strategically positioned to allow smooth movement without hindering corridors, thereby alleviating congestion caused by street vendors. Rain drains were thoughtfully placed at each level transition to address potential water accumulation issues.

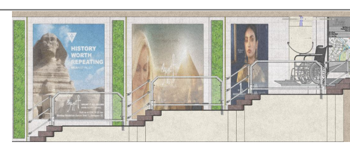
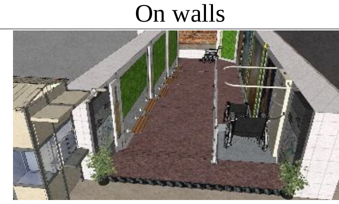
Concerning illumination, the tunnel previously experienced inadequate lighting both at entrances and therein, impacting user safety and comfort during all hours. To address this, longitudinal lighting fixtures were implemented on the tunnel ceiling, along with lighting lines embedded within the tunnel walls, offering users a sense of comfort and security.

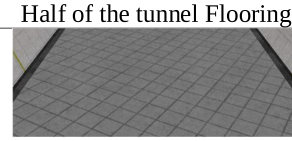
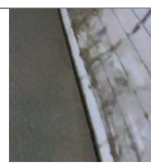
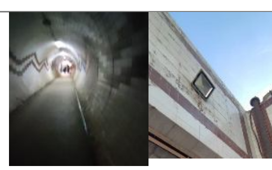
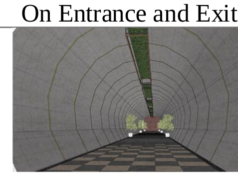
One significant flaw identified was the absence of accessibility options for individuals with disabilities to navigate through the tunnel. To address this issue, elevators were constructed at each level change to enable their seamless use of the tunnel. Additionally, sound system was installed to mitigate the loud noise generated by users within the tunnel, utilizing various frequencies known for dispersing sound in public spaces.

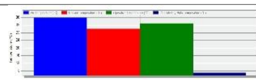
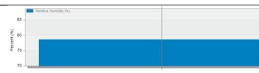
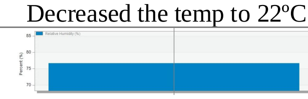
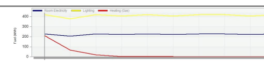
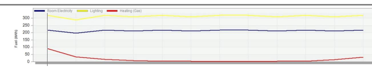
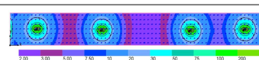
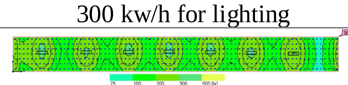
Regarding environmental factors, an evaluation conducted via the Design Builder program revealed that within the current model, temperatures within the tunnel could escalate to 34 degrees Celsius, coupled with a humidity level of up to 80%. These conditions indicate a deficiency in thermal comfort within the tunnel. Additionally, analysis using the DIAlux program exposed numerous unilluminated zones, registering as low as 2 Lux, this can be attributed to ineffective placement of lighting components and their failure to meet the required illumination levels for the tunnel.

During the redesign process, only the weak points were worked on, for example, with the gradual elevation there is proper ventilation, the revised design proposal underwent a reassessment to gauge the impact of modifications on user comfort. Results indicated a significant improvement, with temperatures decreasing to 22ºC and humidity levels decreasing to 76%. Furthermore, enhancements in the efficiency and distribution of lighting units led to nearly halving energy consumption. This notable progress translates into improved environmental elements and enhanced thermal comfort for users.

Table 6. The result of comparison between the current design and the upgrade design

Element			**Current Design**	**Upgrade Design**
Hardscape Elements	**1. Seats**		 On Stairs	 Fixed on wall - Durable stainless-steel seats
	2. Urban walls	Finishing	 Ceramic tiles - Granite for outdoor flooring	 Pervious flooring
		Advertising walls	 None	 On walls
		Green walls	None	 On entrance path walls
	3.Bins	Recycle machine	None	 On entrance node
		Classified trash bins	None	On entrance

4.Signage		None	 on the tunnel entrance
5. Paving / finishes	Kinetic flooring	None	 Half of the tunnel Flooring
	Material	 Granite on stairs outdoor tiles -cement tiles inside the tunnel	 Pervious flooring
	Pervious flooring	None	 Outdoor
6. Water Drains		 Only inside the tunnel	 placed at each level transition
7. Booths		 Vendors on paths	 On Entrance and Exit
8. Lighting		 Not Enough	 On ceiling of the tunnel and lighting lines in the cavities of the tunnel walls
9. Sound System		Vendors make noises	white noise for acoustic comfort
10. Levels		 36 steps	 

Landscape Elements	**Fences**	None	 Tree fences were used as walls of the entry corridors
	Ficus tree	None	
	PALM TREE	None	On Entrance and exit
Environmental Elements	**Air Temperature**	 Up to 34ºc	 Decreased the temp to 22ºC
	Relative Humidity	 80%	 Decreased to 76%
	Fuel	 400 kw/h for lighting	 300 kw/h for lighting
	Lighting	 From 2 Lux to less than 50 Lux	 From 75 Lux to 250 Lux

Therefore, upon reviewing the comparison between the existing design state, the upgrading design, and user feedback from the questionnaire, it becomes evident that pedestrian tunnels are crucial urban components, particularly in densely populated areas. By effectively integrating landscape and environmental design elements, these tunnels can fulfill their spatial function in a seamless and adaptable manner, without detriment to the environment or user experience. Regardless of age or condition, optimizing visual, acoustic, and thermal comfort ensures user safety and enriches their overall experience.

4. Conclusion

Through this research and comprehensive study, it became evident that prioritizing the design of pedestrian tunnels and emphasizing the integration between environmental and landscape elements as achieved in this tunnel (Table 7-8), a responsibility primarily taken by architects, yields substantial improvements in user experience. By conscientiously considering the needs of individuals with disabilities, children, and the elderly, architects can make informed decisions that enhance overall usability and accessibility, ultimately enriching the user experience and enhance the overall urban experience.

Table 7. The Landscape elements achieved in the upgraded design compared to their availability in the original design.

	seats	urban walls	bins	signage	paving	water drains	booths	lighting	sound system	levels	fences	ficus tree
Current design	-	-	-	-	-	√	-	-	√	-	-	-
Upgrade design	√	√	√	√	√	√	√	√	√	√	√	√

Table 8. The Environmental elements achieved in the upgraded design compared to their availability in the original design.

	air temperature	relative humidity	lighting	Sound system	Energy consumption
Current design	-	-	-	-	-
Upgrade design	√	√	√	√	√

5. References

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