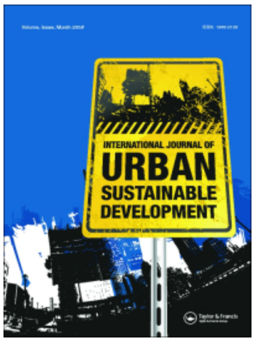


Taylor & Francis
Taylor & Francis Group

International Journal of Urban Sustainable Development

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tjue20

Novel criteria for sustainable use of urban spaces under bridges in cities by applying DEMATEL technique

Shaimaa H. Zaki, Azza G. Haggag & Ahmed M. Selim

To cite this article: Shaimaa H. Zaki, Azza G. Haggag & Ahmed M. Selim (2023) Novel criteria for sustainable use of urban spaces under bridges in cities by applying DEMATEL technique, International Journal of Urban Sustainable Development, 15:1, 299-320, DOI: 10.1080/19463138.2023.2267504

To link to this article: https://doi.org/10.1080/19463138.2023.2267504

Published online: 19 Oct 2023.

INTERNATIONAL JOURNAL OF URBAN SUSTAINABLE DEVELOPMENT
2023, VOL. 15, NO. 1, 299–320
https://doi.org/10.1080/19463138.2023.2267504

OPEN ACCESS Check for updates

Novel criteria for sustainable use of urban spaces under bridges in cities by applying DEMATEL technique

Shaimaa H. Zaki [a], Azza G. Haggag [b] and Ahmed M. Selim [a]

[a]Department of Architecture, Modern Academy for Engineering and Technology, Cairo, Egypt, Lecturer at; [b]Department of Architecture, Modern Academy for Engineering and Technology, Cairo, Egypt

ABSTRACT

At the beginning of the 21st century, cities suffered from high traffic density and mobility problems due to rapid urbanisation and population growth. Bridges were built to encounter these challenges. As a result, the urban voids (urban spaces under bridges) have increased tremendously. In this study, a qualitative analysis was established to understand the negative impacts of urban voids focusing on under-bridges urban spaces. Furthermore, five criteria, as well as thirty-one sub-criteria were derived from the extensive literature and previous international experiences. Additionally, a quantitative analysis was conducted through experts' interviews. Criteria and sub-criteria were assessed using the decision-making trial and evaluation laboratory (DEMATEL) to determine whether each criterion/sub-criteria belongs to the cause or effect group. Results indicated that the most important criterion was urban identity, as well as the most important sub-criteria belong to each criterion, were social services, investment diversity, sustainable recourses management, ICT-infrastructure, and urban integration.

ARTICLE HISTORY
Received 20 April 2023
Accepted 1 October 2023

KEYWORDS
Urban spaces under bridges; urban voids; Dematel; urban sustainability; MCDM

Introduction

In the cities, urban voids constitute around 10–25% of the city area (Lin et al. 2017; Pluta 2017; Hashem et al. 2022). Under-bridges urban spaces are one of the urban voids. In past, the urban voids under bridges were visually accessible but remained underused and neglected by planners (Devetakovic et al. 2015; Ahmed et al. 2020). Therefore, these urban spaces were used as places for street vendors, and the homeless living which increase the street criminality rate and have become threatening public security. Additionally, it introduces a complicated negative impact on the urban fabric of the cities, where it causes environmental, and economical problems. For instance, visual pollution as a result of the waste-filled yards which not only affects the citizens' health but also contributes to a decrease in the surrounding properties' value (Tomita et al. 2020).

Consequently, under-bridges urban spaces have been considered a great challenge for urban planners, due to it had substantial social, environmental, and economic impact on urban development, especially with the rapid population and urbanisation growth in cities (Artmann et al. 2018). Recently, governments and planners strived to form strategies and urban solutions to reduce the impact of these problems by investing and utilising these urban spaces in the development process (Ghahremani et al. 2021).

From this point of view, this study sought to introduce novel criteria to achieve multiple social, economic, and environmental benefits from under-bridges urban spaces. Thus, contributing to gain comprehensive sustainable development in the cities. In this respect, the study has pointed out the sustainable urbanism approach and its pillars, discussing the negative impacts of urban voids, and focusing on

CONTACT Ahmed M. Selim ahmed.selim@eng.modern-academy.edu.eg Department of Architecture, Modern Academy for Engineering and Technology, Cairo, Egypt

under-bridges urban spaces. Additionally, an overview of international experiences in reusing under-bridge urban spaces was highlighted. Furthermore, five criteria (main dimensions), as well as thirty-one sub-criteria (sub-dimensions) were derived from the extensive literature. Subsequently, the decision-making trial and evaluation laboratory (DEMATEL) was applied as an analytical tool to evaluate, rank, and identify potential relationships between the criteria, and sub-criteria based on experts' interviews.

Finally, to clarify the potential relationships between the criteria, and sub-criteria, the cause-and-effect diagrams were created to illustrate the strength of the relations, and whether each criterion and sub-criteria belong to the cause or effect group. In this context, the concluded criteria, sub-criteria, and cause-and-effect diagrams could support the decision makers and urban planners to propose innovative and creative urban solutions for under-bridges urban spaces that achieve sustainable development for the cities and avoid its negative impacts.

Background

Sustainability in urbanization

Recently, cities are competing to achieve urban sustainability pillars, whether social, economic, and environmental (Turvey 2019). Although many existing studies are discussing this trend, there is a debate about the required criteria and variants to boost the sustainability approach in cities (Afanasyeva et al. 2020). In this context, there was a strong consensus from the researchers that the integration of infrastructure and preserving the urban identity of the cities could promote the sustainability approach for it (Liu et al. 2020). Accordingly, sustainable urbanism connotes a new relationship between the natural environment, urban form and infrastructure, economic and institutional processes, and social livelihood (Yan et al. 2018). More specifically, sustainable urbanism adopts a systemic and synergistic reorganisation of environmental, economic, and social goals, preserving urban identity and infrastructure development to enhance the long-term health of natural systems and the vitality of urban communities (Kremer et al. 2019) as illustrated in (Table 1).

Sustainable urban spaces

Sustainable urban spaces are places where people live and want to stay, with a real sense of place. It should be well designed with functional places that citizens need to use and enjoy (Nagumey 2015). Additionally, the urban design of these spaces must be cost-effective, visually attractive, and environmentally friendly (Chao et al. 2020). Understandably, sustainable urban spaces could improve citizens' physical and mental health, strengthen communities, and make cities and neighbourhoods more attractive places to live and work (Douglas et al. 2017). Consequently, the overall goals of sustainable urban spaces are to promote the use of sustainable practices, maximise the lifespan of buildings and facilities, and enhance the natural environment (Faragallah 2018).

Urban space under bridges

There are spaces in cities that are perceived as leftovers. These spaces include the gaps between buildings or dead-end streets, awkward angles and corners, and undesired spaces under bridges. These spaces are defined as urban voids (Pluta 2017) or static spaces. Indeed, urban spaces under bridges are among the most critical spaces that have a negative impact on the city's image. Generally, the under-bridge urban space is the space created by the overpass (Salamak and Klaudiusz 2016).

The under-bridge urban space: a dark history

In past, the under-bridge urban spaces had a negative impact on the urban sense of the cities as following:

- Social negative impacts: considered suitable places for criminal activities that threaten public security, providing places for homeless people and illegal housing (Laksono and Vijar, 2019).
- Economic negative impacts: led to a deterioration of surrounding areas, preventing investment and development, and contributed to declining property values (Ning et al. 2020).
- Environmental negative impacts: increasing visual health risks and pollution as a result of these waste-filled yards (Lak and Mina, 2020).

Therefore, professionals in urban design realised that these spaces have the potential to be covered as small

Table 1. Sustainability criteria in urbanisation.

Sustainability criteria	Features and goals
Social Merit	It's the issue that is primarily concerned with relationships between individual actions and the surrounding created environment, or between institutional systems and individual life chances. Due to priorities and specific resource limitations, these relationships require challenging judgments about problem classification and agenda setting that include 'burden-sharing' among community members. (Senem Deviren 2010)
Economic Viability	Sustainable economic in urbanization seeks to end poverty by utilizing natural resources, striking a balance between production and consumption, and generating employment opportunities. Cities provide prospects for growth, poverty alleviation, and employment. They can serve as a host for academic, scientific, and business sector institutions that focus on innovation research and development. (TELSAÇ and Kandeğer 2022)
Environmental Effectiveness	The environmental pillar is to protect and promote natural resources, and development considers the maintenance of their qualities and level of performance. The environment must be protected, garbage must be disposed of appropriately, green areas must be provided, and balance must be achieved (TELSAÇ and Kandeğer 2022). (SAVi, 2020)
Infrastructure Enhancement	The development of buildings, roads, energy, and water infrastructure that takes into account its effects on the economy, society, and environment is known as sustainable infrastructure. Urban planning and infrastructure that are not environmentally friendly might cause significant issues for future generations. While the possibility for efficiency and significant advancement is enhanced by a big population residing in cities with the appropriate rules, in the case of absent infrastructure, all these benefits might become a nightmare. (Hinge et al. 2020)
Urban Identity	Urban identity is a phenomenon that binds people to "their" city as it is expressed in various aspects, such as the "sense of unity" that can be seen in the city's structures, streets, landmarks, and buildings. (Abdeen 2021)

public spaces, public enclaves, and spaces of activity in the city, which would be beneficial for both the city and its citizens instead of its negative impacts.

Previous experience

Currently, and despite the negative impacts of under-bridge urban spaces. Many initiatives were taken place to utilise these spaces (Samir et al. 2022), whereas urban planners have started rethinking the reuse of under-bridge urban spaces as public places to take advantage of these spaces through innovative functions to achieve sustainable benefits. These experiences were, for instance, demonstrated in (Table 2).

Sustainable future

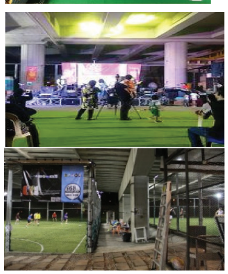
Regarding the above discussion, and the reviewed literature on this approach. Five criteria (main dimensions), as well as thirty-one sub-criteria (sub-dimensions) were derived as illustrated in (Table 3), to ensure sustainable future and innovative solutions for rehabilitation under-bridges urban spaces.

Regarding the previous table and the summarised literature, *social merit* includes six sub-criteria that enhance the quality of life on the cultural or health level and secure the future. The *economic feasibility* sub-criteria are focused on increasing investment opportunities that benefit the state as well as individuals and exploiting the value of the land. likewise, *environmental effectiveness* sub-criteria promote preserving all the surrounding environment, including air, water resources, and energy sources. In the same context, *infrastructure enhancement* comprises six sub-criteria including green infrastructure that supports the 'Information Communication Technology' (ICT) approach. Meanwhile, the *urban identity* sub-criteria boosts preserving characteristics, culture, and identity of cities.

Materials and methods

Based on Multi-Criteria Decision-Making approach (MCDM) (Kundakci 2016), this study methodology has two sections as illustrated in (Figure 1). The first, *qualitative phase*; by using inductive method, an extensive background was summarised to formulate the research goal, and *five* criteria (main dimensions), and *thirty-one* sub-criteria (sub-dimensions) were derived based on reviews as shown in (Table 3) above. The second, *quantitative phase*; By applying decision-making trial and evaluation laboratory (DEMATEL) as a decision-making technique. Experts' interviews by (10) experts were carried out including (3) academic staff in urban planning, (3) environmental planning professionals, (2) non-governmental organizations (NGOs), and last (2) are considered economic experts, to determine whether each criterion/sub-criteria belong to the cause or effect group. Each expert filled in pairwise comparisons, from which the direct-relation matrices were then formed.

Table 2. Previous experience in reusing under-bridge urban spaces.

	Experience		Description/characteristics
1	**Project name**: Underpass Park **Location**: Toronto, Canada (Francis et al. 2010).		**Description**: • Public space designed by PFS studio, as a Part of Waterfront Toronto's Stage 1 LEED Gold Neighborhood Development (ND). This project was a combination of art, light, and furniture creatively transforms this dead space into a dynamic communal park. **Characteristics**: • Integrate sustainability aspects such as: energy-efficient LED lighting – recycled material – reuse historical granite. • Use light and airy plants, wood-topped flowy furniture. • Include playground, basketball courts, skate park, flexible open space. • Include a series of ribbon walls and park benches, flexible community space which can be used for markets, festivals, seasonal public events.
2	**Project name**: Fly the flyover. **Location**: Hong Kong (Yeng 2016).		**Description**: • The concept of the project is to redefine and transform unused spaces into vibrant spaces by recovering this space for public activities such as arts, and cultural uses. **Characteristics**: • Provide various facilities gallery, outdoor open spaces, multi-purpose rooms, an open stage, urban farms, a restaurant, food kiosks, and a pop-up store. • The project feature is the colorful murals on the columns. • The project uses recycled materials.
3	**Project name**: Under the Thomson flyover **Location**: (Hoh 2015).		**Description**: • Government wants to turn the space under Thomson flyover into recreational spots, with minimum infrastructure to achieve the best usage for this space. • This public space has economic benefits by recovering part of costs through collecting rent. **Characteristics**: • Provide special multi-purpose recreational space. • Utilize a futsal park of international standards all for a small fee.
4	**Project name**: The A14 highway elevated road and control center **Location**: Paris, France (Bonnafous 2017).		**Description**: • The concept of the project is to turn the space into control center. **Characteristics**: • The building and the elevated road become one part and combine with the structure of the elevated road. • It increases its beauty. • Buildings have not contacted the floor. • Provide transparent light modeling. • It is an iconic building.

DEMATEL technique

The (DEMATEL) was developed in Switzerland in the seventies of the twentieth century (Abikova 2019). This technique has been integrated to solve complex problems and analyse a variety of causal relations (Golabeska 2018). It is considered an effective method for identifying cause-effect chain components of complex interdependent factors (Pinto et al. 2022). This method is outstanding due to detecting the relation between criteria, ranking, and revealing the intensity of their effects on each criterion (Kwartnik-Pruc et al. 2022). In the same context, the DEMATEL method has been increasingly used to solve various urban, social, economic, and environmental problems (Si et al., 2018). In this research, the DEMATEL method was used to identify potential relationships between the criteria, and sub-criteria derived above in (Table 3) for reusing the under-bridge urban spaces. Also, to determine whether each criterion and sub-criteria belong to the cause or effect group.

The (DEMATEL) technique was the approach to reveal the complex relationships between *five* criteria

Table 3. The criteria and sub-criteria for sustainable reuse of under-bridges spaces.

Criteria (main dimension)	Sub-criteria (sub-dimension)	Source
Social merit (**P1**)	• Begging reduction (**S1**) • Street Criminality rate (**S2**) • Social services (**S3**) • Social interaction (**S4**) • Culture diversity (**S5**) • Health conditions (**S6**)	(Khan and Shah 2020), (Cherian et al. 2020), and (Gronholm et al. 2021)
Economic viability (**P2**)	• Land value (**Ec1**) • Economic growth (**Ec2**) • Job opportunities (**Ec3**) • Investment diversity (**Ec4**) • Small-scale business (**Ec5**) • Tax benefits (**Ec6**) • Tourism attraction (**Ec7**)	(Prasetyo and N., K. 2020), (Avdeeva et al. 2021), (Alla 2021), and (Huseynli 2022)
Environmental effectiveness (**P3**)	• Air quality (**En1**) • Noise level (**En2**) • Energy consumption (**En3**) • Sustainable recourses management (**En4**) • Vegetation (**En5**) • Recycled water usage (**En6**)	(Magiera and Jolanta 2021), (Khan and Rashmi 2019), and (Sauri and Ana 2019)
Infrastructure enhancement (**P4**)	• Green infrastructure (**I1**) • Night lighting control (**I2**) • Smart parking (**I3**) • Waste disposal (**I4**) • Road's maintenance (**I5**) • ICT-infrastructure (**I6**)	(Ferrari et al. 2019), (Andrade-Nunez and Aide 2020), and (Serebryakova et al. 2020)
Urban identity (**P5**)	• The image of the city (**U1**) • Resilient urban functions (**U2**) • Mixed land use (**U3**) • Green spaces (**U4**) • Traffic density (**U5**) • Urban integration (**U6**)	(Karakova et al. 2020), (Ghosh and Pratap 2021), and (Haas et al. 2021)

(main dimensions), as well as thirty-*one* sub-criteria (influential criteria/sub-dimensions) through five steps as followed:

- ***Step 1***: Creating the direct-relation matrix (X). Six matrices $X = [x_{ij}]$ were constructed. Criterion matrix was [P1, P2, … ., P5] and, sub-criterion matrices were [S1, S2, … ., S6], [Ec1, Ec2, … ., Ec7], [En1, En1, … ., En6], [I1, I2, … ., I6], and [U1, U2, … ., U6]. Experts evaluated the relations for criterion and for each sub-criterion. The importance of the measurement scale was defined as (0): no influence, (1): low influence, (2): medium influence, (3): strong influence, and (4): very strong influence. The arithmetic means of all of the experts' opinions for each matrix was calculated, and then a direct relation matrices $\underline{X}$ were generated as illustrated in (Table 4) and Appendix 1.
- ***Step 2:*** Creating the normalised direct-relation matrix (N). from the matrix (X) and by using Equations 1 & 2. The normalised direct-relation matrix (N) was obtained as illustrated in (Table 5).

$$\mathrm{N} = \frac{1}{\mathrm{k}} * \mathrm{X} \tag{1}$$

$$k = min\left\{max \sum_{j=1}^{n} x_{ij}, \sum_{i=1}^{n} x_{ij}\right\} \tag{2}$$

- ***Step 3:*** Creating the total relation matrix (T). from the matrix (N) and by using Equation.3. The total relation matrix (T) was derived as illustrated in (Table 6).

$$\mathrm{T} = \mathrm{N} \times (I - N)^{-1} \tag{3}$$

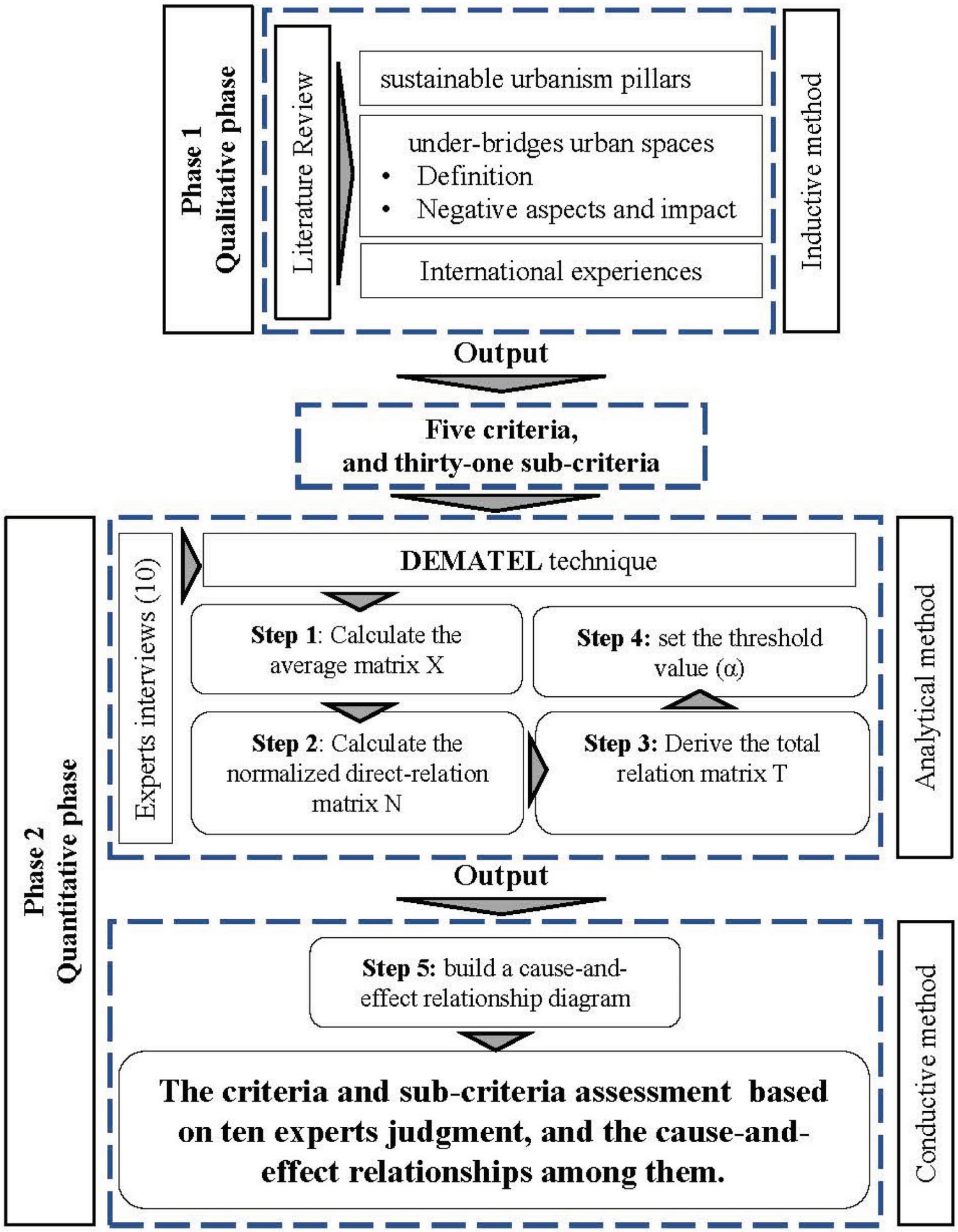


Figure 1. Research methodology.

- ***Step 4:*** Set the threshold value (α). from the matrix (T), (α) value was calculated by averaging the matrix (T) elements, and by using Equation.4. In this research, (α) value for the criterion was equal **1.789**. This calculation eliminates the elements with the minor effect in matrix (T), which support to understand the relationships between criterions, where all values in matrix T which are smaller than the threshold value (α) can be interpreted as a weak relationship and were set to zero as illustrated in (Table 7).

$$a = \frac{\sum_{i=1}^{n} \sum_{J=1}^{n} [tij]}{N} \tag{4}$$

- ***Step 5:*** build the cause-and-effect diagram. The previous four steps were repeated for each sub-criteria matrix as illustrated in Appendix 2,3&4.

Table 4. The direct relation matrix (X) for criterion.

	Social merit (P1)	Economic viability (P2)	Environmental effectiveness (P3)	Infrastructure enhancement (P4)	Urban identity (P5)
Social merit (P1)	0	2.5	1.33	1.17	3.33
Economic viability (P2)	3.5	0	2.5	3.33	3.33
Environmental effectiveness (P3)	2.17	2	0	3.67	3
Infrastructure enhancement (P4)	2.33	2.33	2.33	0	1
Urban identity (P5)	3.33	1.83	3.5	3	0

Then, the cause-and-effect diagrams were constructed by calculating the sum of each row (D) and each column (R) of the matrices (T) using equations 5 & 6 as illustrated in (Table 8). Based on the (D) and (R) values, the model can be represented as a diagram in which the values of (D+R) are placed on the horizontal vector and the values of (D-R) on the vertical vector as illustrated in (Figure 2). If the value of (D-R) was positive, it was classified in the cause group, and directly affected the others. On the other hand, if the value of (D-R) was negative, it was classified in the effect group, and largely influenced by the others. Additionally, the value of (D+R) determines the prioritisation of the importance of the criteria and the sub-criteria.

$$D = \sum_{j=1}^{n} T_{ij} \tag{5}$$

$$R = \sum_{i=1}^{n} T_{ij} \tag{6}$$

Results

Regarding the (DEMATEL) technique results, based on the (D-R), (D+R) values in (Table 8), and the threshold values (α) of the total criterion matrix and the total sub-criterion matrices. Cause-and-effect diagrams were created according to the roles illustrated in (Figure 2) above.

In this context, the results are summarised based on the Cause-and-effect diagrams as follows;

Figure 3 Cause-and-Effect diagram of the criteria (main dimensions) shows that economic viability (P2), environmental effectiveness (P3), and urban identity (P5) are classified into cause criteria group, due to (R-D) are positive values. While effect criteria group includes social merit (P1), and infrastructure enhancement (P4), due to (D-R) are negative values. According to (D+R) values, the prioritisation of the importance of five evaluation criteria was P5> P2> P3> P1> P4, as urban identity (P5) was the most important criterion with the largest (D+R) value = 19.00, whereas infrastructure enhancement (P4) was the minimum important criterion with the smallest (D+R) value = 16.738. Regarding (D-R) values, the most significant causal criteria in sustainable achievement in using under bridges urban spaces is economic viability (P2) has the highest (D-R) value of 2.746, which means (P2) should be given more consideration on using under bridge urban spaces projects (on these project types). Besides, the second causal criteria is environmental effectiveness (P3) value of 0.758, and third one is urban identity (P5) value with 0.627.

Figure 4 Cause-and-Effect diagram of the sub-criteria within (Social merit) demonstrates that social services (S3) and social interaction (S4) were the two most important sub-criteria based on the first and second highest (D+R) values of 28.792 and 28.074, whereas both social services (S3), social interaction (S4), and culture diversity (S5) were in the cause group based on their positive (D-R) values of 2.139, 3.471, and 0.997. For street criminality rate (S2), begging reduction (S1), and health conditions (S6) were in the effect group, given negative (D-R) values of −1.957, −2.869, and −1.780. Based on threshold value (α = 2.279), and total relationship matrix, social interaction (S4) was the most critical sub-criterion because of the direct influence on the other five sub-criteria, the second sub-criterion with direct influence was social services (S3) which had a direct impact on all sub-criteria except health conditions (S6). Finally, culture diversity (S5) had a direct influence on social

Table 5. The normalized direct-relation matrix (N) for criterion.

	(P1)	(P2)	(P3)	(P4)	(P5)
(P1)	0.000	0.221	0.117	0.103	0.294
(P2)	0.309	0.000	0.221	0.294	0.294
(P3)	0.192	0.177	0.000	0.324	0.265
(P4)	0.206	0.206	0.206	0.000	0.088
(P5)	0.294	0.162	0.309	0.265	0.000

Table 6. The total direct-relation matrix (T) for criteria.

	(P1)	(P2)	(P3)	(P4)	(P5)
(P1)	1.560	1.434	1.476	1.616	1.707
(P2)	2.347	1.705	2.029	2.283	2.223
(P3)	2.004	1.642	1.621	2.054	1.947
(P4)	1.613	1.340	1.432	1.411	1.460
(P5)	2.178	1.720	1.951	2.117	1.849

Table 7. The matrix (T) for criteria by considering the threshold value (α).

	(P1)	(P2)	(P3)	(P4)	(P5)
(P1)	0.000	0.000	0.000	0.000	0.000
(P2)	2.347	0.000	2.029	2.283	2.223
(P3)	2.004	0.000	0.000	2.054	1.947
(P4)	0.000	0.000	0.000	0.000	0.000
(P5)	2.178	0.000	1.951	2.117	1.849

The threshold value (α) =1.789.

services (S3), street criminality rate (S2), and begging reduction (S1).

Figure 5 Cause-and-Effect diagram for the sub-criteria within (Economic viability) illustrates that investment diversity (Ec4) and economic growth (Ec2) were the two most crucial sub-criteria based on the first and second highest (D+R) values of 15.441 and 15.086, whereas land value (Ec1), job opportunities (Ec3), small-scale business (Ec5), and tax benefit (Ec6) were in the cause group based on their positive (D-R) values of 1.063, 1.318, 1.234, and 0.330. Economic growth (Ec2), investment diversity (Ec4), and tourism attraction (Ec7) were in the effect group, given negative (D-R) values of −0.647, −0.556, and −2.743. Based on the threshold value (α = 1.004), and the total relationship matrix, investment diversity (Ec4) was the most critical sub-criteria because it directly influenced the other sub-criteria except land value (Ec1).

Figure 6 Cause-and-Effect diagram for the sub-criteria within (Environmental effectiveness) shows that sustainable resources management (En4), and energy consumption (En3) were the two most important sub-criteria based on the first and second highest (D+R) values of 14.003 and 12.964, whereas air quality (En1), energy consumption (En3), and sustainable resources management (En4) were in the cause group based on their positive (D-R) values of 1.571, 0.112, and 0.868. For noise level (En2), vegetation (En5), and recycled water usage (En6) were in the effect group, given negative (D-R) values of −0.597, −0.846, and −1.107. Based on the threshold value (α = 0.593), sustainable resources management (En4) was the most critical sub-criteria because the direct influence on the other sub-criteria except noise level (En2), and noise level (En2) had no influence on any sub-criteria.

Figure 7 Cause-and-Effect diagram for sub-criteria within (Infrastructure enhancement) shows that ICT-infrastructure (I6), and green infrastructure (I1) were the two most important sub-criteria

Table 8. Summary of D & *R* values of the criteria matrix and the sub-criteria matrices.

Criterion code		(D)	(R)	(D+R)	(D-R)
The criterion matrix (T), [P1, P2, … ., P5]					
Social merit (P1)		7.793	9.701	17.494	−1.909
Economic viability (P2)		10.587	7.841	18.427	2.746
Environmental effectiveness (P3)		9.267	8.509	17.776	0.758
Infrastructure enhancement (P4)		7.257	9.481	16.738	−2.224
Urban identity (P5)		9.814	9.186	19.000	0.627
Criterion code/sub-criterion code		(D)	(R)	(D+R)	(D-R)
The sub-criterion matrix (T), [S1, S2, … ., S6]					
P1	Begging reduction (S1)	10.827	13.696	24.524	−2.869
	Street Criminality rate (S2)	11.877	13.834	25.710	−1.957
	Social services (S3)	15.465	13.326	28.792	2.139
	Social interaction (S4)	15.772	12.301	28.074	3.471
	Culture diversity (S5)	13.233	12.236	25.470	0.997
	Health conditions (S6)	9.798	11.579	21.377	−1.780
Criterion code/sub-criterion code		(D)	(R)	(D+R)	(D-R)
The sub-criterion matrix (T), [Ec1, Ec2, … ., Ec7]					
P2	Land value (Ec1)	5.971	4.907	10.878	1.063
	Economic growth (Ec2)	7.220	7.867	15.086	−0.647
	Job opportunities (Ec3)	7.645	6.327	13.972	1.318
	Investment diversity (Ec4)	7.443	7.998	15.441	−0.556
	Small-scale business (Ec5)	7.412	6.178	13.590	1.234
	Tax benefits (Ec6)	7.178	6.848	14.027	0.330
	Tourism attraction (Ec7)	4.064	6.807	10.870	−2.743
Criterion code/sub-criterion code		(D)	(R)	(D+R)	(D-R)
The sub-criterion matrix (T), [En1, En1, … ., En6]					
P3	Air quality (En1)	6.287	4.717	11.004	1.571
	Noise level (En2)	1.525	2.123	3.648	−0.597
	Energy consumption (En3)	6.538	6.426	12.964	0.112
	Sustainable recourses management (En4)	7.435	6.568	14.003	0.868
	Vegetation (En5)	5.654	6.500	12.154	−0.846
	Recycled water usage (En6)	4.511	5.618	10.130	−1.107
Criterion code/sub-criterion code		(D)	(R)	(D+R)	(D-R)
The sub-criterion matrix (T), [I1, I2, … ., I6]					
P4	Green infrastructure (I1)	6.239	5.068	11.307	1.171
	Night lighting control (I2)	5.117	4.607	9.724	0.511
	Smart parking (I3)	5.649	3.638	9.287	2.011
	Waste disposal (I4)	2.352	4.500	6.852	−2.148
	Roads maintenance (I5)	3.012	5.723	8.734	−2.711
	ICT-infrastructure (I6)	6.346	5.179	11.525	1.167
Criterion code/sub-criterion code		(D)	(R)	(D+R)	(D-R)
The sub-criterion matrix (T), [U1, U2, … ., U6]					
P5	The image of the city (U1)	11.231	15.417	26.648	−4.186
	Resilient urban functions (U2)	13.802	15.675	29.477	−1.872
	Mixed land use (U3)	14.580	12.411	26.991	2.169
	Green spaces (U4)	15.099	12.997	28.096	2.102
	Traffic density (U5)	13.017	11.844	24.861	1.173
	Urban integration (U6)	17.292	16.679	33.971	0.614

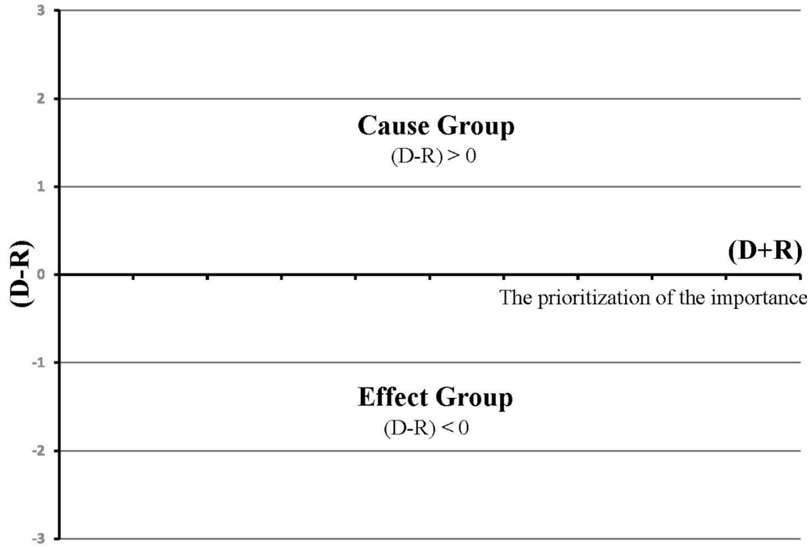


Figure 2. Cause–effect diagram model.

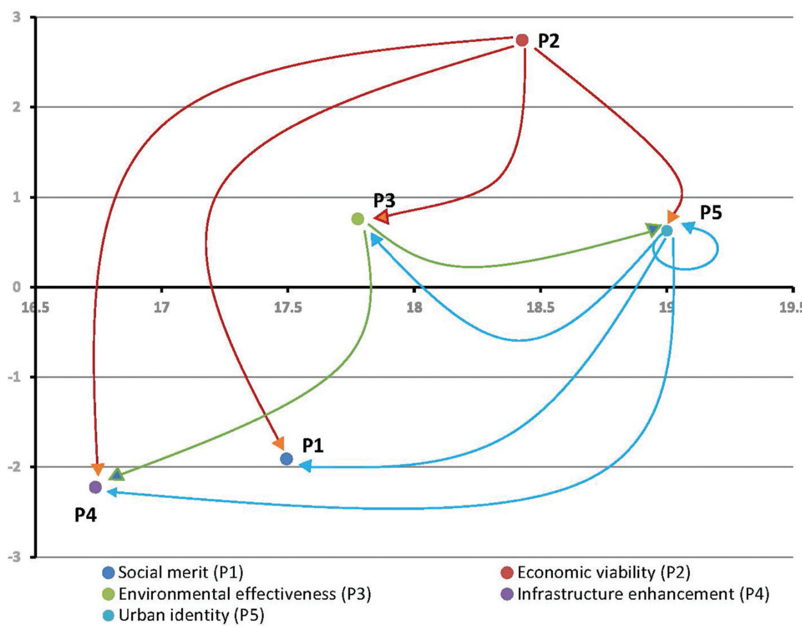


Figure 3. Cause–effect diagram for the criteria (main dimensions).

based on the first and second highest (D+R) values of 11.525 and 11.307, whereas green infrastructure (I1), night lighting control (I2), smart parking (I3), and ICT-infrastructure (I6) were in the cause group based on their positive (D-R) values of 1.171, 0.511, 2.011, and 1.167. Waste despisal (I4), and road maintenance (I5) were in the effect group, given negative (D-R) values of −2.148, and −2.711. Based on the threshold value ($\alpha = 0.726$), and total relationship matrix, green infrastructure (I1), and ICT-infrastructure (I6) were the most critical sub-criteria because the direct

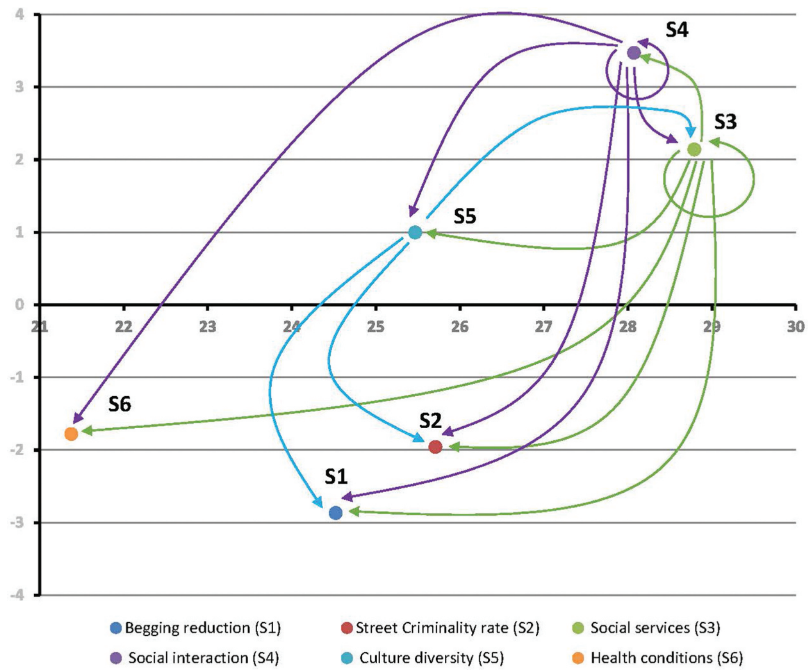


Figure 4. Cause–effect diagram for sub-criteria within (S).

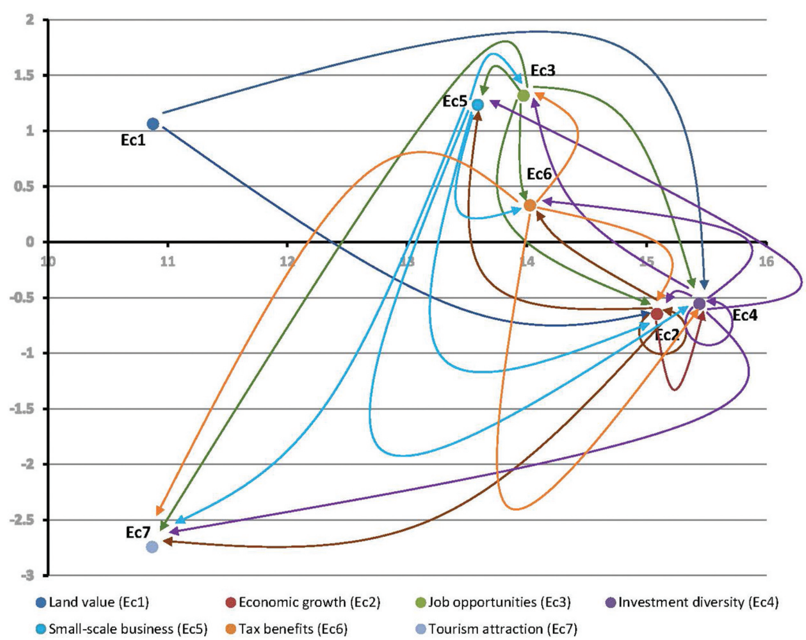


Figure 5. Cause–effect diagram for sub-criteria within (Ec).

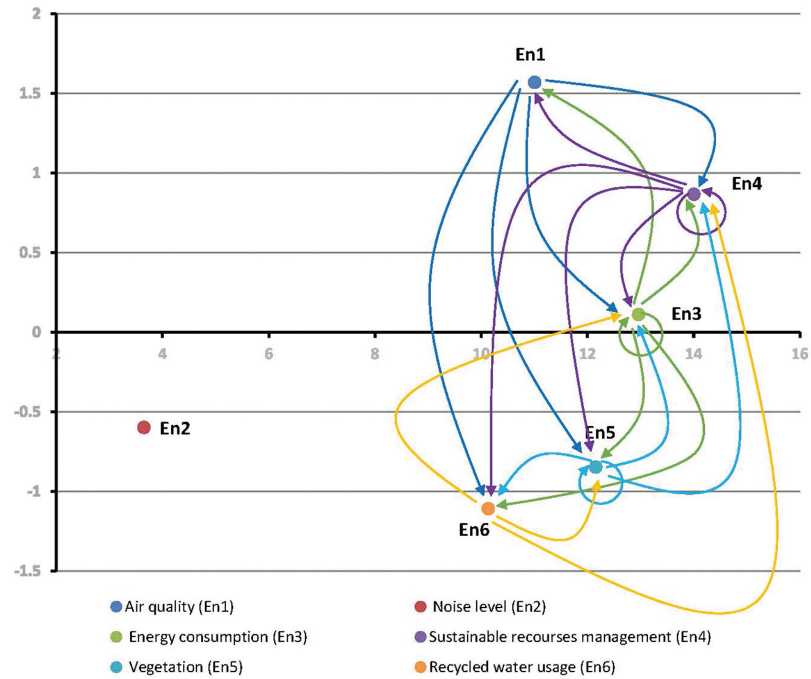


Figure 6. Cause–effect diagram for sub-criteria within (En).

influence on the other sub-criteria and waste despisal (I4), and road maintenance (I5) did not influence on any sub-criteria.

Figure 8 Cause-and-Effect diagram for sub-criteria within (Urban identity) demonstrates that urban integration (U6), and resilient urban functions (U2) were the two top sub-criteria based on the first and second highest (D+R) values of 33.971 and 29.477, whereas mixed land use (U3), green spaces (U4), traffic density (U5), and Urban integration (U6) were in the cause group based on their positive (D-R) values of 2.169, 2.102, 1.173, and 0.614. The image of the city (U1), and resilient urban functions (U2) were in the effect group, given negative (D-R) values of −4.186, and −1.872. Based on threshold value (α = 2.170), and total relationship matrix, urban integration (U6) was the most critical sub-criterion because it directly influenced the other sub-criteria.

Discussion

As shown in (Table 8), and with regard to the cause-effect diagrams of the criteria for the use of under-bridges urban spaces, which were revealed from the experts' opinions by using the (DEMATEL) technique. Although achieving environmental sustainability in cities is the prevailing global trend in recent years. Experts' evaluation of the main criteria reflected that the first priority was to preserve the urban identity and image of the city, while environmental effectiveness came in the third place. It is worth noting that the economic viability was in the second place, which confirms the necessity of having economic feasibility studies for these types of projects to ensure the achievement of their expected sustainable purpose. In the same context, the revealed cause – effect diagram for the criteria (main dimensions) also reflects that achieving economic viability, environmental effectiveness, and urban identity as a priority will have a direct impact on attaining social merit, and enhancing the city infrastructure, and then achieving comprehensive sustainability.

Regarding, Cause-and-Effect diagram of the five sub-criteria, it shows the following:

- within (**S**ocial merit). Experts' evaluation reflects that the provision of social services could increase social interactions and sense of place, promote social cohesion, and encourage citizens to act and strengthen social bonds.

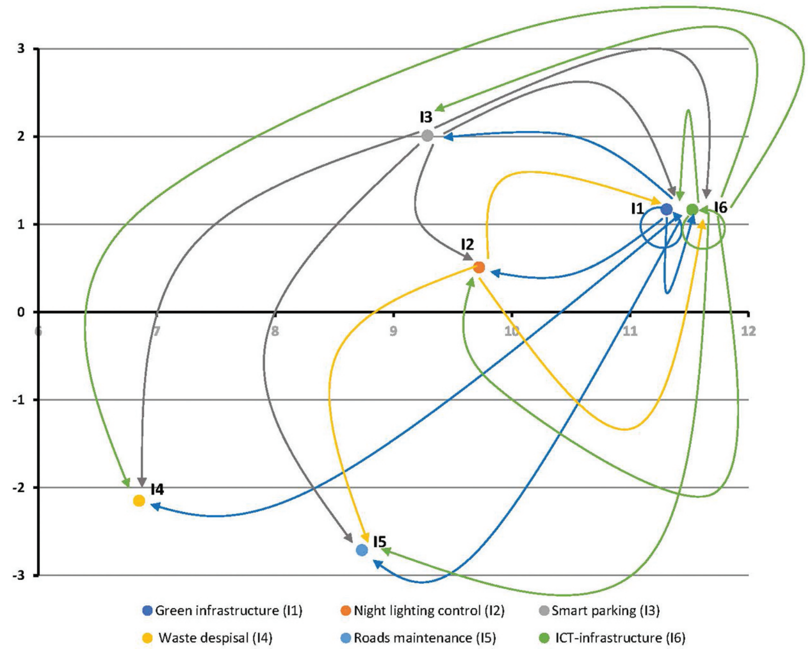


Figure 7. Cause–effect diagram for sub-criteria within (I).

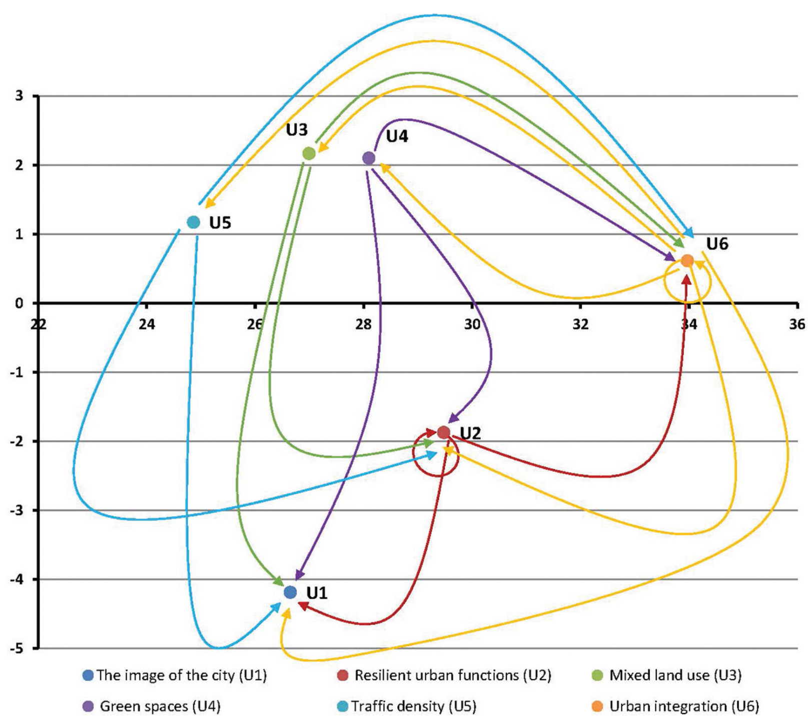


Figure 8. Cause–effect diagram for sub-criteria within (U).

Table 9. Summary of the sustainable benefits of reusing under-bridge urban spaces.

Sustainability pillars	Impacts
Environmental	Under bridge urban spaces can present many *environmental benefits*: • Can be used as ecological resource and a green infrastructure to promote ecosystem health (Someraro et al. 2017). • Vegetation and greening under-bridges urban spaces improve air quality, reduce heat island effects, pollution, and support climate change adaptation (Wong et al. 2021). • Encourage growing recycling networks.
Social	Under bridge urban spaces can present many *social benefits*: • Can provide the opportunity to compensate for the shortage of open spaces (Yabe et al. 2021). • Increase social interactions and sense of place (Ujang et al. 2018). • Provide creative functions as social services "open restaurants - entertainment activities cafeterias- education centers- urban agriculture … etc" (Tuijl et al. 2018). • Offer locations for temporary uses "seasonal celebrations- events- place for buy and sell- markets … etc" (Jepson and Alan 2015). • Provide learning benefits for children (Acar 2014).
Economic	Under bridge urban spaces can present many *economic benefits*: • Raising the level of low- and medium-scale investment (Fellnhofer 2016). • Can offer working spaces at low cost and places for temporary uses which can become an urban catalyst of city development (Balvociene and Kestuties 2021). • Provide job opportunities and skills developments. • Increase the value of properties of surrounding areas (Sodhi et al., 2021). • Not require high cost of complex design.

- within (**Ec**onomic viability). Experts' evaluation indicates that the provision of innovative functions, especially small scale-business, could increase job opportunities, boost economic growth, and raise the tourist attraction to the city.
- within **(En**vironmental effectiveness). Experts' evaluation shows that the environmental pillar through optimum exploitation of the local recourses could achieve sustainable resource management, reduce energy consumption, and improve air quality.
- within **(I**nfrastructure enhancement). Experts' evaluation reflects that relying on green infrastructure, ICT-infrastructure, and using smart parking as a function could reduce traffic density, and road maintenance.
- within (**U**rban identity). Where urban identity was classified as the most important criterion. Urban integration, and resilient urban functions were classified as the most important criteria within this criterion. That reflects how this criterion is important to preserve the image of the city and its sense.

More specifically, despite the negative impacts of under-bridge urban spaces in past, it could be an essential resource for the city to acquire great environmental, social, and economic benefits as summarised in (Table 9) if designed correctly.

Conclusion

Under-bridges urban spaces are places that can promote urban sustainability and enhance the image of the city. In this study, five criteria (main dimensions) were determined based on the reviewed literature to assess the potential uses, and projects that may be implemented in these urban places, to ensure that they boost sustainable development in the city. These criteria were as follows: social merit **P1**, economic viability **P2**, environmental effectiveness **P3**, infrastructure enhancement **P4**, and urban identity **P5**. Also, thirty-one sub-criteria (sub-dimensions) were revealed and categorised within these five criteria. The study applied (DEMATEL) technique not only to assess the criteria and sub-criteria based on ten experts' judgement but also to describe the cause-and-effect relationships among them. The most important criterion was urban identity. Additionally, the importance of the five evaluated criteria was prioritised as P5> P2> P3> P1> P4. More specifically, economic viability (P2), environmental effectiveness (P3), and urban identity (P5) were classified into cause criteria group, while the effect criteria group included social merit (P1), and infrastructure enhancement (P4). In the same context, the most important sub-criteria within each criterion were social services, investment diversity, sustainable recourses management, ICT-infrastructure, and urban integration. Noteworthy, the result illustrates that the experts tended to preserve the urban identity of the city and achieve economic viability for the expected uses than attaining environmental effectiveness. Finally, the study finds that under-bridges urban spaces can be an essential resource for the city to acquire great environmental, social, and economic benefits, therefore achieving comprehensive sustainable development for the cities. Notably, the study methodology can be applied to evaluate the optimum uses for the other urban spaces in the future research.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The authors(s) received no financial support for the research, and/or publication of this article.

Notes on contributors

Shaimaa H. Zaki graduated from the faculty of engineering, architecture department, Ain Shams University, Egypt (2003). She obtained her Master in "Reuse of Historical Palaces in Egypt Applied on Palaces of Mohamed Ali's Family" from the architecture department Cairo University, Egypt (2009). She obtained her PhD in "SOCIOECONOMIC APPROACH TO ASSESS PROJECTS OF REHABILITATION IN OLD NRIGHBORHOODS AND IN NEW URBAN COMMUNITIES" from the architecture department Cairo University, Egypt (2015). She is currently a Lecturer at the Department of Architecture Engineering, Modern Academy, Cairo, Egypt.

Azza G. Haggag graduated from the faculty of engineering, architecture department, Ain Shams University, Egypt (2001). She obtained her Master in "The Influence of Contamination Control on The Design of "Cleanrooms"" from the Ain Shams University, Egypt (2007). She is interested in studies of building technology and renewable energy, in addition to urban design and its relationship with the requirements of sustainability. She obtained her PhD in "A Methodology to Activate the Role of Architectural Design in Quality Risk Management of Pharmaceutical Plants- An Approach to Achieve Architectural Design Qualification in Production Areas" from Cairo University, Faculty of Engineering, Egypt (2013). A member of the Egyptian Engineers Syndicate. Working currently as a Lecturer at the Department of Architecture Engineering, Modern Academy, Cairo, Egypt.

Ahmed M. Selim graduated from the faculty of engineering, architecture department, Ain Shams University, Egypt (2000). He obtained his Master in "Electric Energy Rationalization in Housing by Computer Applications" from the Ain Shams University, Egypt (2007). He obtained his professional program (PRMG) in Project Management from The American University, Egypt (2012). He obtained his Diploma in "Data Base Management, GIS and Remote Sensing" from the Faculty of Geo-Information Science and Earth Observation, ITC, Netherland. Egypt (2005). He obtained his PhD in "Sustainable Management of Urbanization through Systems for the Establishment and Management of Infrastructure with the Participation of Private sector" from the Environmental Planning and Infrastructure Department, Faculty of Urban and Regional Planning, Cairo University, Egypt (2018). He is a member of the Egyptian Engineer Candidate. He is currently a Lecturer at the Department of Architecture Engineering, Modern Academy, Cairo, Egypt.

ORCID

Shaimaa H. Zaki http://orcid.org/0000-0001-9646-3242
Azza G. Haggag http://orcid.org/0000-0002-7984-8156
Ahmed M. Selim http://orcid.org/0000-0001-7257-5717

Declaration of conflicting interests

The authors(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Abdeen N. 2021. Urban planning and sustainable cities. Engineering Research Journal. 169:51–75. https://erj.journals.ekb.eg/article_152771_94556e5ed4f2fadbae78ae8eb6d03640.pdf.

Abikova J. 2019. Application of fuzzy DEMATEL–ANP methods for siting refugee camps. JHLSCM. 10(3):347–369. doi: 10.1108/JHLSCM-12-2018-0078.

Acar H. 2014. Learning environments for children in outdoor spaces. Procedia-Social And Behavioral Sciences. 141:846–853. doi: 10.1016/j.sbspro.2014.05.147.

Afanasyeva A, Roza S, Irina K. 2020. Sustainable cities: major challenges and trends. IOP Conf Ser: Mater Sci Eng. 890 (1):012181. doi: 10.1088/1757-899x/890/1/012181.

Ahmed H, Ayesha M, Saad M, Rabia K. 2020. Study of utilizing residual spaces under flyovers in Lahore, Pakistan. Journal Of Art, Architecture And Built Environment. 3(1):84–98. doi: 10.32.350/jaabe.31.05.

Alla S. 2021. Methodological approaches to estimating the use of tax benefits and the practice of their application. Economy And Forecasting. 2021(2):27–44. doi: 10.15407/econforecast2021.02.027.

Andrade-Nunez M, Aide M. 2020. Using nighttime lights to assess infrastructure expansion within and around protected areas in South America. Environ Res Commun. 2(2):021002. doi: 10.1088/2515-7620/ab716c.

Artmann M, Luis I, Peilei F. 2018. Urban sprawl, compact urban development, and green cities. How do we know, how much do we agree? Ecol Indic. 96:3–9. doi: 10.1016/j.ecolind.2018.10.059.

Avdeeva E, Tatiana D, Oksana B, Svetlana B. 2021. The economic viability of remote employment and the demand for worker skills amid rapid digital integration. E3S Web Of Conferences. 244(12):11003. doi: 10.1051/e3sconf/202124411003.

Balvociene V, Kestuties Z. 2021. Cultural urban catalysts as meaning of the city. Architectural And Urban Planning. 17(1):16–28. doi: 10.2478/aup-2021-0002.

Bonnafous A. 2017. Permanent observatories as tools for ex-post assessment: the French case study. Discussion Paper 2014 10-International Transport Forum. doi: 10.1787/9789282108154-3-en.

Chao A, Amparo G, Vicente L, Alberto A. 2020. Indicators framework for sustainable urban design. Atmosphere. 11(11):1143. doi: 10.3390/atmos.11111143.

Cherian J, Gaikar B, Paul C. 2020. The role of cultural diversity and how they impact work team performance. International Journal Of Mechanical Engineering And Technology (IJMET). 11(9):11–22. doi:10.34218/IJMET.11.9.2020.002. Article ID: IJMET_11_09_002.

Devetakovic M, Ivana P, Ivana C, Ljiljana P. 2015. Fractal parametric models of urban spaces. Tehnicki Viesnik. 22(6):1547–1552. doi: 10.17559/TV-20150121222048.

Douglas O, Mick L, Mark S. 2017. Green space benefits for health and well-being: a life-course approach for urban planning, design and management. Cities. 66(June 2017):53–62. doi: 10.1016/j.cities.2017.03.011.

Faragallah R. 2018. The impact of productive open spaces on urban sustainability: the case of El Mansheya Square – Alexandria. Alex Eng J. 57(4):3969–3976. doi: 10.1016/j.aej.2018.02.008.

Fellnhofer K. 2016. Literature review: investment readiness level of small and medium sized companies. International Journal Of Managerial And Financial Accounting Forthcoming. 7(3/4):268. doi: 10.1504/IJMFA.2015.074904.

Ferrari B, Valerio Q, Anna B, Piermaria C, Emanuela M, Dalila R. 2019. Conservation and enhancement of the green infrastructure as a nature- based solution for Rome's sustainable development. Urban Ecosyst. 22(5):865–878. doi: 10.1007/s11252-019-00868-4.

Francis M, Jayoung K, Stephen R. 2010. Just a comfortable place to sit: Davis sittable space study. Department Of Environmental Design- University Of California, Davis. doi: 10.13140/RG-2.1.4434.6321.

Ghahremani H, Sepideh A, Linda C, Mahshid J. 2021. Transformation of urban spaces within cities in the context of globalization and urban competitiveness. J Urban Plann Dev. 147(3). doi: 10.1061/(ASCE)UP.1943-5444.0000703.

Ghosh P, Pratap R. 2021. Modeling urban mixed land-use prediction using influence parameters. GeoScape. 15(1):66–78. doi: 10.2478/geosc-2021-0006.

Golabeska E. 2018. The DEMATEL method in the analysis of the residential real estate market in Bialystok. Real Estate Management And Valuation. 26(1):16–25. doi: 10.2478/remav-2018-0002.

Gronholm P, Neerja C, Corrado B, Jayati M, Kavitha K, Graham T, Maya S, Tarun D. 2021. Prevention and management of physical health conditions in adults with severe mental disorders: WHO recommendations. Int J Ment Health Syst. 15(1):22. doi: 10.1186/s13033-021-00444-4.

Haas W, Jan H, Marian S. 2021. The role of urban green space in promoting inclusion: experiences from the nether lands. Front Environ Sci. 9:618198. doi: 10.3389/fenvs.2021.618198.

Hashem O, Sherine W, Tarek N. 2022. Urban voids: identifying and optimizing urban voids potential as a revitalization source in enhancing developing countries' city income. J Eng Appl Sci. 69(1):6. doi: 10.1186/s44147-021-00053-5.

Hinge G, Surampalli R, Goyal M. 2020. Sustainable infrastructure. Sustainability Book. chapter(14):295–311. doi: 10.1002/9781119434016.ch14.

Hoh D (2015). Turning dead spaces into dynamic places for entrepreneurship. *Research Report- Center for Livable Cities Singapore*.

Huseynli E. 2022. Sustainable tourism and its environmental, economic, social benefits to the host destinations. IMC Fachhochschule Krems- University Of Applied Sciences. doi: 10.13140/RG.2.2.31912.03845.

Jepson A, Alan K. 2015. Managing and developing communities, festivals, and events. Book. *USA, UK*: Palgrave and MacMillan. doi:10.1057/9781137508553.

Karakova TV, Zaslavskaya AY, Smolenskaya E. 2020. City branding. Features of urban image design. IOP Conf Ser: Mater Sci Eng. 775(1):012040. doi: 10.1088/1757-899x/775/1/012040.

Khan N, Shah F. 2020. Begging negative impact on the world community. SSRN Electron J. doi: 10.2139/ssrn.3530070.

Khan T, Rashmi B (2019). Environment resource management and sustainable development. *International Conference on "Multidimensional Role of Basic Science in Advanced Technology"- ICMBAT 2018- AIP Conference Proceedings*. Doi: 10.1063/1.5/00412

Kremer P, Annegret H, Dagmar H. 2019. The future of urban sustainability: smart, efficient, green, or just? Introduction to the special issue. Sustain Cities Soc. 51(2019):101761. doi: 10.1016/j.scs.2019.101761.

Kundakci N. 2016. Combined multi-criteria decision-making approach based on Macbeth and multi-MOORA methods. Alphanumeric Journal. 4(1):017–026. doi: 10.17093/aj.2016.4.1.5000178402.

Lak A, Mina R. 2020. Exploring analysis of the environmental qualities affecting the design of unmanaged urban under-bridge spaces. Armanshahr Architecture & Urban Development. 13(31):177–187. doi: 10.22034/AAUD.2020-113270.

Laksono S, Vijar P. 2019. Factors that influence optimization open space under the jenggolo sidoarjo flyover. IPTEK Journal Of Proceedings Series. (6). doi: 10.12962/j23546026.y2018i6.4669.

Lin T, Hui L, Mingyuan H. 2017. Three-dimensional visibility analysis and visual quality competition for urban open spaces aided by google sketch up and web GIS. Environ Plann B:

Urban Anal City Sci. 44(4):618–646. doi: 10.1177/0265813515605097.
Liu Z, Chunliang X, Chao Y. 2020. Improving urban resilience through green infrastructure: an integrated approach for connectivity conservation in the central city of Shenyang, China. Complexity. 2020(5):1–15. doi: 10.1155/2020/1653493.
Magiera A, Jolanta S. 2021. Environmental noise, its types, and effects on health. Roczniki Panstwowego Zakladu Higieny. 72 (1):41–44. doi: 10.32394/rpzh.2021.0147.
Nagumey A. 2015. Design of sustainable supply chains for sustainable cities. Environ Plann B: Urban Anal City Sci. 42(1):40–57. doi: 10.1068/639039.
Ning Q, Cheng J, Wang X. 2020. Urban micro space reconstruction strategy. IOP Conf Ser: Earth Environ Sci. 580(1):012032. doi: 10.1088/1755-1315/580/1/012032.
Pinto B, Fernando F, Ronald S, Mark S, Leandro P. 2022. Analysis causes of urban blight using cognitive mapping and DEMATEL. Ann Oper Res. 325(2):1083–1110. doi: 10.1007/s10479-022-04614-6.
Pluta A. 2017. Urban void as a potential of the contemporary city development. BIBLIOTEKA REGIONALISTY NR 17. (17):95–103. doi:10.15611/br.2017.1.08.
Prasetyo PE, Kistanti, NR 2020. Human capital, industrial economics and entrepreneurship as a driver for quality & sustainable economic growth. JESI. 7(4):2575–2589. doi: 10.9770/jesi.2020.7.4(1).
Pruc A, Grzegorz G, Anna T. 2022. Using the DEMATEL method to identify impediments to the process of determining compensation for expropriated properties. Land. 11(5):693. doi: 10.3390/land11050693.
Salamak M, Klaudiusz F. 2016. Bridges in urban planning and architectural culture. Procedia Eng. 161:207–212. doi: 10.1016/j.proeng.2016.08.530.
Samir S, Yasser M, Sherif E. 2022. Transformation and appropriations of the in-between spaces in Cairo. Open House Int. doi: 10.1108/OHI-07-2021-0135.
Sauri D, Ana A. 2019. Water reuse: a review of recent international contributions and an agenda for future research. Documents d' Analisi Geografica. 65(1):399–417. doi: 10.5565/rev/dag.534.
SAVi (The Sustainable Asset Valuation). 2020. SAVi Database. International Institute for Sustainable Development. https://www.iisd.org/system/files/publications/savi-database-primer-brochure.pdf.
Serebryakova E, Elena S, Oksana B, Irina K. 2020. Formation of the infrastructure of the waste processing cluster. E3S Web Conf. 164(4):01035. doi: 10.1051/e3sconf/202016401035.
Si S, Xiao Y, Hu-Chen L, Ping Z. DEMATEL technique: a systematic review of methodologies and applications. Math Probl En. 2018;2018:1–33. doi:10.1155/2018/3696457.
Sodhi N, Sara S, Samad S. 2021. The impact of increased density on residential property values in Sydney, New South Wales. Buildings. 11(12):650. doi: 10.3390/buildings11120650.
Someraro T, Roberta A, Alessandro P. 2017. Green infrastructure to improve ecosystem services in the landscape urban regeneration. IOP Conf Ser: Mater Sci Eng. 245(8):082044. doi: 10.1088/1757-899x/245/8/082044.
TELSAÇ C, Kandeğer B, (2022). Sustainable urbanization. 6th International New York Conference On Evolving Trends In Interdisciplinary Research & Practices. April 3-5, 2022 Manhattan, New York City.
Tomita A, Diego C, Janathan B, Frank T, Rob S. 2020. Exposure to waste sites and their impact on health: a panel and goes patial analysis of nationally representative data from South Africa, 2008-2015. Lancet Planet Health. 4(6):223–257. doi: 10.1016/S2542-5196(20)30101-7.
Tuijl E, Gret-Jan H, Leo B. 2018. Opportunities and challenges of urban agriculture for sustainable city development. European Spatial Research And Policy. 25(2):5–22. doi: 10.18778/1231-1952.25.2.01.
Turvey R. 2019. Urban planning and sustainable cities. IJSSOC. 11 (3):139–161. doi: 10.1504/IJSSOC.2019.103700.
Ujang N, Marek K, Suhardi M. 2018. Linking place attachment and social interaction: towards meaningful public places. JPMD. 11(1):00–00. doi: 10.1108/JPMD-01-2017-0012.
Wong N, Terrence T, Denia K, Hideki T. 2021. Greenery as a mitigation and adaptation strategy to urban heat. Nat Rev Earth Environ. 2(3):166–181. doi: 10.1038/s43017-020-00129-5.
Yabe T, Rao PS, Ukkusuri SV. 2021. Regional differences in resilience of social and physical systems: case study of Puerto Rico after hurricane maria. *Environment And Planning B: Urban Analytics And City Science*. 48(5):1042–1057. doi: 10.1177/2399808320980744.
Yan Y, Chenxing W, Yuan Q, Gang W, Jingzhu Z. 2018. Urban sustainable development efficiency towards the balance between nature and human well-being: connotation, measurement, and assessment. J Clean Prod. 178:67–75. doi: 10.1016/j.jclepro.2018.01.01.
Yeng A. 2016. Geotechnical works of the Hong Kong- Zhuhai-Macao bridge project. JGS Special Publication. 2(2):109–121. doi: 10.3208/jgssp.ESD-KL-3.
Senem Deviren A. 2010. Social sustainability in urban areas: communities, connectivity and the urban fabric. In: Manzi T, Lucas K, Jones TL Allen J, editors. Urban Research & Practice. Taylor &Francis Group; pp. 341–343.

Appendix 1: The direct-relation matrices (X) for sub-criterion

The direct-relation matrices (X) for social merit

	Begging reduction (S1)	Street criminality rate (S2)	Social services (S3)	Social interaction (S4)	Culture diversity (S5)	Health conditions (S6)
Begging reduction (S1)	0	3.83	1.17	2.5	2.5	1.17
Street criminality rate (S2)	3.5	0	3.5	1.17	2	2.5
Social services (S3)	3.83	3.5	0	3.83	3.17	2.5
Social interaction (S4)	3	3.5	3.83	0	3.5	3.5
Culture diversity (S5)	2.5	2.5	3	3.33	0	2.5
Health conditions (S6)	1.67	1.33	2.83	2.17	1.67	0

The direct-relation matrices (X) for Economic viability

	Land value (Ec1)	Economic growth (Ec2)	Job opportunities (Ec3)	Investment diversity (Ec4)	Small-scale business (Ec5)	Tax benefits (Ec6)	Tourism attraction (Ec7)
Land value (Ec1)	0	3.67	3.67	3.5	0	3.67	0
Economic growth (Ec2)	2.33	0	2.33	3.83	3.5	3.67	3.67
Job opportunities (Ec3)	1.67	4	0	3.67	4	3.5	3.5
Investment diversity (Ec4)	2.67	3.67	3.17	0	3.33	3.5	3.67
Small-scale business (Ec5)	2.33	3.5	3.5	3.67	0	3.17	3.67
Tax benefits (Ec6)	2.67	3.17	3.5	3.33	3.5	0	2.67
Tourism attraction (Ec7)	0.67	3.33	0.67	3.67	1	0.67	0

The direct-relation matrices (X) for Environmental effectiveness

	Air quality (En1)	Noise level (En2)	Energy consumption (En3)	Sustainable resources management (En4)	Vegetation (En5)	Recycled water usage (En6)
Air quality (En1)	0	0	3.67	3.67	3.83	1.67
Noise level (En2)	0	0	1	1	1	0
Energy consumption (En3)	3.83	0.5	0	3.67	3.33	2.67
Sustainable resources management (En4)	3.67	3.67	3.67	0	3.83	3.83
Vegetation (En5)	1.83	0	3	3.5	0	3.33
Recycled water usage (En6)	0	0	3.17	3	2.67	0

The direct-relation matrices (X) for Infrastructure enhancement

	Green Infrastructure (I1)	Night lighting control (I2)	Smart parking (I3)	Waste disposal (I4)	Road's maintenance (I5)	ICT-infrastructure (I6)
Green Infrastructure (I1)	0	3.5	1.83	3.5	3.33	3.33
Night lighting control (I2)	1.83	0	2	0	3.67	3.67
Smart parking (I3)	3.5	1.67	0	2	1.83	3.5
Waste disposal (I4)	3.5	0	0	0	1.17	1.17
Road's maintenance (I5)	1	2.83	0.83	1.17	0	0.83
ICT-infrastructure (I6)	3.33	2.17	3.33	3.5	3.33	0

The direct-relation matrices (X) for Urban identity

	The image of the city (U1)	Resilience urban functions (U2)	Mixed land use (U3)	Green spaces (U4)	Traffic density (U5)	Urban integration (U6)
The image of the city (U1)	0	2	2	2	1.17	3.33
Resilience urban functions (U2)	2	0	2	2	3.67	3.83
Mixed land use (U3)	3.33	3.5	0	3.33	1	3.33
Green spaces (U4)	3.5	3.5	3.17	0	1.5	3.5
Traffic density (U5)	3.5	3.67	1	1.67	0	3.17
Urban integration (U6)	3.5	3.5	3.67	3.67	3.67	0

Appendix 2: The normalized direct-relation matrices (N) for sub-criterion

The normalized direct-relation matrices (N) for social merit

	(S1)	(S2)	(S3)	(S4)	(S5)	(S6)
(S1)	0.000	0.261	0.080	0.171	0.171	0.080
(S2)	0.239	0.000	0.239	0.080	0.136	0.171
(S3)	0.261	0.239	0.000	0.261	0.216	0.171
(S4)	0.205	0.239	0.261	0.000	0.239	0.239
(S5)	0.171	0.171	0.205	0.227	0.000	0.171
(S6)	0.114	0.091	0.193	0.148	0.114	0.000

The normalized direct-relation matrices (N) for Economic viability

	(Ec1)	(Ec2)	(Ec3)	(Ec4)	(Ec5)	(Ec6)	(Ec7)
(Ec1)	0.000	0.180	0.180	0.172	0.000	0.180	0.000
(Ec2)	0.115	0.000	0.115	0.189	0.172	0.180	0.180
(Ec3)	0.082	0.197	0.000	0.180	0.197	0.172	0.172
(Ec4)	0.131	0.180	0.156	0.000	0.164	0.172	0.180
(Ec5)	0.115	0.172	0.172	0.180	0.000	0.156	0.180
(Ec6)	0.131	0.156	0.172	0.164	0.172	0.000	0.131
(Ec7)	0.033	0.164	0.033	0.180	0.049	0.033	0.000

The normalized direct-relation matrices (N) for Environmental effectiveness

	(En1)	(En2)	(En3)	(En4)	(En5)	(En6)
(En1)	0.000	0.000	0.247	0.247	0.258	0.112
(En2)	0.000	0.000	0.067	0.067	0.067	0.000
(En3)	0.258	0.034	0.000	0.247	0.225	0.180
(En4)	0.247	0.247	0.247	0.000	0.258	0.258
(En5)	0.124	0.000	0.202	0.236	0.000	0.225
(En6)	0.000	0.000	0.213	0.202	0.180	0.000

The normalized direct-relation matrices (N) for Infrastructure enhancement

	(I1)	(I2)	(I3)	(I4)	(I5)	(I6)
(I1)	0.000	0.263	0.137	0.263	0.250	0.250
(I2)	0.138	0.000	0.150	0.000	0.275	0.275
(I3)	0.263	0.125	0.000	0.150	0.138	0.263
(I4)	0.188	0.000	0.000	0.000	0.088	0.088
(I5)	0.075	0.213	0.063	0.088	0.000	0.063
(I6)	0.250	0.163	0.250	0.263	0.250	0.000

The normalized direct-relation matrices (N) for Urban identity

	(U1)	(U2)	(U3)	(U4)	(U5)	(U6)
(U1)	0.000	0.132	0.132	0.132	0.077	0.220
(U2)	0.132	0.000	0.132	0.132	0.242	0.253
(U3)	0.220	0.231	0.000	0.220	0.066	0.220
(U4)	0.231	0.231	0.209	0.000	0.099	0.231
(U5)	0.231	0.242	0.066	0.110	0.000	0.209
(U6)	0.231	0.231	0.242	0.242	0.242	0.000

Appendix 3: The total relation matrix (T) for sub-criterion

The total relation matrix (T) for social merit

	(S1)	(S2)	(S3)	(S4)	(S5)	(S6)
(S1)	1.813	2.042	1.843	1.762	1.760	1.608
(S2)	2.182	2.008	2.117	1.863	1.892	1.815
(S3)	2.796	2.809	2.513	2.529	2.489	2.329
(S4)	2.806	2.854	2.774	2.368	2.548	2.422
(S5)	2.358	2.381	2.324	2.174	1.978	2.018
(S6)	1.742	1.741	1.756	1.604	1.569	1.386

The total relation matrix (T) for economic viability

	(Ec1)	(Ec2)	(Ec3)	(Ec4)	(Ec5)	(Ec6)	(Ec7)
(Ec1)	0.561	1.042	0.876	1.048	0.724	0.939	0.781
(Ec2)	0.772	1.072	0.965	1.250	0.991	1.084	1.086
(Ec3)	0.786	1.300	0.911	1.309	1.065	1.134	1.140
(Ec4)	0.805	1.258	1.022	1.125	1.011	1.108	1.114
(Ec5)	0.789	1.248	1.030	1.273	0.869	1.091	1.112
(Ec6)	0.782	1.202	1.007	1.226	0.989	0.930	1.043
(Ec7)	0.413	0.744	0.517	0.768	0.528	0.562	0.531

The total relation matrix (T) for environmental effectiveness

	(En1)	(En2)	(En3)	(En4)	(En5)	(En6)
(En1)	0.835	0.376	1.313	1.339	1.336	1.089
(En2)	0.206	0.093	0.325	0.331	0.329	0.241
(En3)	1.065	0.414	1.156	1.380	1.354	1.168
(En4)	1.147	0.625	1.492	1.322	1.513	1.337
(En5)	0.850	0.340	1.169	1.213	1.011	1.071
(En6)	0.612	0.276	0.972	0.982	0.957	0.712

The total relation matrix (T) for infrastructure enhancement

	(I1)	(I2)	(I3)	(I4)	(I5)	(I6)
(I1)	0.931	1.062	0.791	1.039	1.263	1.153
(I2)	0.886	0.719	0.701	0.699	1.104	1.009
(I3)	1.069	0.890	0.619	0.903	1.085	1.084
(I4)	0.509	0.339	0.259	0.329	0.481	0.435
(I5)	0.517	0.593	0.387	0.466	0.519	0.530
(I6)	1.156	1.004	0.881	1.064	1.272	0.969

The total relation matrix (T) for urban identity

	(U1)	(U2)	(U3)	(U4)	(U5)	(U6)
(U1)	1.924	2.072	1.673	1.744	1.557	2.261
(U2)	2.483	2.406	2.018	2.110	2.025	2.760
(U3)	2.675	2.724	2.019	2.291	1.988	2.883
(U4)	2.772	2.814	2.261	2.184	2.081	2.986
(U5)	2.414	2.459	1.860	1.979	1.724	2.585
(U6)	3.149	3.199	2.579	2.692	2.470	3.204

Appendix 4: The matrix (T) for sub-criterion by considering the threshold value (α)

The matrix (T) for social merit by considering the threshold value (α)

	(S1)	(S2)	(S3)	(S4)	(S5)	(S6)
(S1)	0.000	0.000	0.000	0.000	0.000	0.000
(S2)	2.182	0.000	0.000	0.000	0.000	0.000
(S3)	2.796	2.809	2.513	2.529	2.489	2.329
(S4)	2.806	2.854	2.774	2.368	2.548	2.422
(S5)	2.358	2.381	2.324	2.174	0.000	0.000
(S6)	0.000	0.000	0.000	0.000	0.000	0.000
The threshold value (α) = 2.138						

The matrix (T) for economic viability by considering the threshold value (α)

	(Ec1)	(Ec2)	(Ec3)	(Ec4)	(Ec5)	(Ec6)	(Ec7)
(Ec1)	0.000	1.042	0.000	1.048	0.000	0.000	0.000
(Ec2)	0.000	1.072	0.965	1.250	0.991	1.084	1.086
(Ec3)	0.000	1.300	0.000	1.309	1.065	1.134	1.140
(Ec4)	0.000	1.258	1.022	1.125	1.011	1.108	1.114
(Ec5)	0.000	1.248	1.030	1.273	0.000	1.091	1.112
(Ec6)	0.000	1.202	1.007	1.226	0.989	0.000	1.043
(Ec7)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
The threshold value (α) = 0.958							

The matrix (T) for environmental effectiveness by considering the threshold value (α)

	(En1)	(En2)	(En3)	(En4)	(En5)	(En6)
(En1)	0.000	0.000	1.313	1.339	1.336	1.089
(En2)	0.000	0.000	0.000	0.000	0.000	0.241
(En3)	1.065	0.000	1.156	1.380	1.354	1.168
(En4)	1.147	0.000	1.492	1.322	1.513	1.337
(En5)	0.000	0.000	1.169	1.213	1.011	1.071
(En6)	0.000	0.000	0.972	0.982	0.957	0.000
The threshold value (α) = 0.888						

The matrix (T) for infrastructure enhancement by considering the threshold value (α)

	(I1)	(I2)	(I3)	(I4)	(I5)	(I6)
(I1)	0.931	1.062	0.000	1.039	1.263	1.153
(I2)	0.886	0.000	0.000	0.000	1.104	1.009
(I3)	1.069	0.890	0.000	0.903	1.085	1.084
(I4)	0.000	0.000	0.000	0.000	0.000	0.000
(I5)	0.000	0.000	0.000	0.000	0.000	0.000
(I6)	1.156	1.004	0.881	1.064	1.272	0.969
The threshold value (α) = 0.798						

The matrix (T) for urban identity by considering the threshold value (α)

	(U1)	(U2)	(U3)	(U4)	(U5)	(U6)
(U1)	0.000	0.000	0.000	0.000	0.000	0.000
(U2)	2.483	2.406	0.000	0.000	0.000	2.760
(U3)	2.675	2.724	0.000	0.000	0.000	2.883
(U4)	2.772	2.814	0.000	0.000	0.000	2.986
(U5)	2.414	2.459	0.000	0.000	0.000	2.585
(U6)	3.149	3.199	2.579	2.692	2.470	3.204
The threshold value (α) = 2.362						