An Evaluation Framework for Sustainable Urban Streets (SUS) in India: The Case Study of Bengaluru City

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ABSTRACT

Sustainable Urban Streets (SUS) are being developed to address the sustainability concerns raised due to the global urbanization, by balancing environmental, economic, social, and design variables in street design. This paper aims to develop an evaluation framework for SUS in Indian metropolitan cities, specifically focusing on Bangalore, by utilizing these four parameters. A questionnaire was developed to determine the overall performance of the streets and assess the applicability of the evaluation framework, followed by a preliminary survey on a specific street, conducted by a user and an expert. The survey results of an expert and fifty street users were cross-referenced to establish system reliability and neutrality. Finally, the research developed evaluation frameworks for Bengaluru's streets, which are applicable to other Indian metropolises. The results showed that the selected street scored 4.58 out of 10, indicating a mediocre ranking. This SUS evaluation framework is the first one to consider the four sustainability parameters and can assist urban planners in identifying street concerns, and decision-makers in comparing and quantifying various development options. This study intends to promote sustainable practices in urban street design, assessment, and evaluation in Indian metropolitan cities.

Keywords-evaluation; sustainable; urban streets; weightage; framework

I. INTRODUCTION

Streets are a fundamental element of the urban system. Effective spatial design and planning ensures the sustainable development of the streets, as well as a livable and aesthetically appealing environment [1]. This research investigates the main principles of SUS and proposes a set of design guidelines and an assessment framework, following a design-oriented methodology characterized by the sequence of "vision-parameters-design toolkit-evaluation-design." It emphasizes the overall sustainability of the urban streets rather than providing specific technical answers. The four elements of sustainability— social, environmental, economic, and design sustainability—have been examined with equal significance, and the assessment framework is developed based on these parameters [2].

Bengaluru is the main focus of the research. Its specific geographical location, climatic conditions, economic growth, and social and cultural context were considered, recognizing their role in the evolution of the street network. Analyzing the network radius-based characteristics of street configurations can elucidate spatial disparities in pedestrian activity across multi-scale walkable zones, thereby assisting planners in enhancing urban livability [3]. The influence of roadside friction on urban arterial streets is another important factor, and includes, among others, land-use activities, animals in motion, pedestrians crossing or traveling along the road, street sellers, and parking on the street [4]. The applied study on SUS must take into account all these parameters.

Bengaluru, once known as Bangalore, is the capital and largest city in the southern Indian state of Karnataka. With 8.4 million inhabitants, according to the 2011 census, the city ranked as the third most populated in India and the most populated in South India. In 2025, the Bengaluru metropolitan region is expected to have a population of about 14.4 million. The city's parks and vegetation led to it being recognized as India's "Garden City". Bengaluru has grown to be the financial hub of the state. It is known as a worldwide metropolis with varied urban forms, rich cultural interaction, and multiple forms of street design. Thus, the research of SUS in Bengaluru may offer extensive references both locally and globally. The case of Bengaluru serves as a basis for evaluating the theoretical framework of the SUS in the metropolitan cities of India. This work can offer vital comments and data for researchers to ascertain the evolution and study path of SUS design. Furthermore, it may provide an insightful analysis for those in charge of the SUS design decisions, and residents, helping them acquire better knowledge, evaluate, and participate actively in the evolution of SUS.

II. METHODOLOGY

The field survey constitutes a suitable and efficient strategy, since it incorporates representativeness, structure, and practicality for data collection and aggregation. Moreover, it may substantially enhance the understanding of Bengaluru's streets through the collection of relevant primary data that are unavailable through current records or research. The following is a brief outline of the objectives of the Site Survey:

- To understand the features of the streets in Bengaluru.
- To assess the applicability of the SUS evaluation framework within a specific context.
- To establish a functional Indicator System for the evaluation framework.

A set of questionnaires is prepared for the field survey against each parameter listed for SUS (Table I). The survey techniques used are structured observations, photography, field notes, and site measurements. The result will be a collection of pragmatic Indicator Systems for the assessment framework of SUS. Developed from the results of [2], this grading system takes into account four dimensions of sustainability: social, economic, environmental, and design. The established rating system, commencing at 0 and comprising a four-level grading scale, effectively facilitates an objective sustainability assessment and enhances the direct conversion of quantitative evaluations into numerical values. The ratings of 1, 2, and 3 indicate mediocre, great, and exceptional sustainability performance, respectively, while 0 shows no development and perhaps deterioration. The Indicator System was built through user surveys, calculating the weights with first-hand data. Fifty user comments were gathered through questionnaires, regarding the relevance of nineteen attributes in the Indicator System. The survey was conducted over a one-year period, to ensure a thorough comprehension of the changes in the street activities and the performance of the street throughout the seasons. Furthermore, each street was surveyed at least five times every season, leading to extended study duration.

A. Normalization Method

In order to calculate a composite index, normalization is used to transform an indication into a standard unit-less form. The Categorical Scale Normalization technique was selected for its superior flexibility and numerical attributes regarding the characteristics of the chosen indicators and assessment properties [21-23]. Utilizing Categorical Scales, irrespective of whether the raw data are qualitative or quantitative, and regardless of the measurement units of the different indicators, the scores are allocated based on established scoring criteria.

TABLE I. LIST OF ATTRIBUTES AND INDICATORS FOR SUS DESIGN

Aspect layer	Attributes	Indicators		Sources
Environmental Sustainability (EnSu)	Adaptability (E1)	Resorting to mobility after a storm/ hurricane	E1-1	[5]
		% of flood risk area	E1-2	[6-7]
		Adaptability capacity to withstand extreme weather conditions	E1-3	[8-11]
	Urban heat island mitigation (E2)	Cool pavement	E2-1	[12]
		% of street tree shading	E2-2	[8-11]
		Air temperature difference	E2-3	[8-11]
	Comfort (E3)	Outdoor thermal comfort	E3	[13-14]
	Pollution reduction (E4)	Average noise emission	E4-1	[15]
		Air quality index	E4-2	[16]
	Ecological balance (E5)	Permeable pavement and bioswales	E5-1	[12]
		Site vegetation	E5-2	[12]
		Rainwater management	E5-3	[8-11]
	Green lifestyle promotion (E6)	Public campaigns for traffic safety	E6-1	[5]
		Green lifestyle promotion	E6-2	[8-11]
		Green travel support	E6-3	[8-11]
Social Sustainability (SoSu)	Equality (S1)	Tactile pavement for the blind	S1-1	[8-11]
		Barrier-free facilities	S1-2	[8-11]
	Safety (S2)	Traffic fatality	S2-1	[5]
		Coverage proportion of street cameras	S2-2	[5]
		Street lights	S2-3	[8-9, 17]
	Accessibility (S3)	Pedestrian access	S3-1	[12]
		The variety of arrival ways	S3-2	[8-11]
		Clear sign and guidance system	S3-3	[8-11]
	Diversity (S4)	Diversity of street activities	S4-1	[16]
		Diversity of street functions	S4-2	[16]
	Cultural inheritance (S5)	Aesthetic quality of urban art	S5-1	[5]
		Aesthetic quality of street furniture	S5-2	[8-11]
Economic Sustainability (EcSu)	Intensive land utilization (C1)	Mixed-use of street land	C1	[8-11]
	Efficiency (C2)	Parking smart program	C2-1	[5]
		Intelligent transportation system	C2-2	[12]
	Business creation (C3)	Types of shop/ business	C3	[8-11, 18]
	Job creation (C4)	Employment generation	C4-1	[15]
		Types of employment	C4-2	[8-11]
	Value addition of property (C5)	Increase in commercial price/ rent	C5-1	[16]
		Increase in housing price/ rent	C5-2	[16]
Design Sustainability (DeSu)	Design (D1)	Sidewalks	D1-1	[19]
		Street corners	D1-2	[19]
		Kerbs and kerb ramps	D1-3	[17]
		Street Furniture	D1-4	[9, 17, 20]
		Trees, landscape strips and planters	D1-5	[19]
		Kiosk spaces	D1-6	[19]
		Dustbins	D1-7	[17]
	Urban principles (D2)	Attractiveness	D2-1	[19]
		Liveliness	D2-2	[19]
	Encroachment (D3)	Types of temporary businesses/ hawkers	D3-1	[18, 20]
		Electric poles/ trees on sidewalks	D3-2	[18, 20]

Source: [2]

This framework employs a three-point scale (a score ranging from 0 to 3) due to its simplicity and clarity. Furthermore, it was necessary to compare the evaluation score of every single attribute with the evaluation data from the street surveys of the users. The respondents were advised to evaluate each sustainable criterion by selecting the most relevant option from a set of four options: exceptional (three points), great (two points), mediocre (one point), and terrible (zero points). Their responses were in accordance with the four-tier grading system.

B. System for Weighting

The weights are assigned to the variables based on their importance, dependability, significance, or other qualities of the indicators. The arrangement of the Weighting System must be in accordance with the assessment framework that has been provided for the Indicator System. There are four distinct layers that make up the structure of the assessment framework (Table II):

- Objective Layer: The primary goal of sustainability.
- Aspect Layer: The "four pillars" of sustainability: environmental, social, economic, and design sustainability.
- Attribute Layer: Comprising 19 attributes; and
- Indicator Layer: Consisting of 46 indicators.

The primary purpose of the theoretical framework is to ensure that all four components of sustainability are held to the same level of importance and significance. Therefore, if the overall aim was given a weight coefficient of 1.0, then the four aspects of sustainability each shared the same weight, which is equivalent to a 0.25 weight. For each evaluation factor for the attribute layer, the specific formulae used to determine its weighting coefficient (Cx) are [24]:

If x= 1,2,3,4,5,6

$$Cx = \frac{0.25 \times AvgCx}{Avg.E1+Avg.E2+Avg.E3+Avg.E4+Avg.E5+Avg.E6} \quad (1)$$

If x= 7,8,9,10,11

$$Cx = \frac{0.25 \times AvgCx}{Avg.S1+Avg.S2+Avg.S3+Avg.S4+Avg.S5} \quad (2)$$

If x= 12,13,14,15,16

$$Cx = \frac{0.25 \times AvgCx}{Avg.C1 + Avg.C2 + Avg.C3 + Avg.C4 + Avg.C5} \quad (3)$$

If x= 17,18,19

$$Cx = \frac{0.25 \times AvgCx}{Avg.D1 + Avg.D2 + Avg.D3} \quad (4)$$

Note: The average Cx represents the mean value of Cx derived from the questionnaire responses.

After the weights for the attribute layer were determined, the weights for each indicator could be easily calculated using the Equal Weight notion. The indicator calculations used:

Weighting Coefficient (Cx-1) = Weighting Coefficient (Cx-2) = Weighting Coefficient (Cx-n) = [Weighting Coefficient (Cx)]/ n (5)

Note: n is the total number of indicators under each category of the Attribute layer.

TABLE II. COMPREHENSIVE OUTLINE OF THE WEIGHTAGE SYSTEM WITHIN THE FRAMEWORK FOR SUSTAINABILITY ASSESSMENT

Objective layer	Aspect layer		Attribute layer		Indicator layer	
SUS total weight: 1.0	EnSu	Equal Weights (EW): 0.25	E1	Using a questionnaire (participatory approach) to specify the weights for each criterion	E1-1-E1-3	EW
			E2		E2-1-E2-3	EW
			E3		E3	EW
			E4		E4-1-E4-2	EW
			E5		E5-1-E5-3	EW
			E6		E6-1-E6-3	EW
	SoSu	EW: 0.25	S1		S1-1-S1-2	EW
			S2		S2-1-S2-3	EW
			S3		S3-1-S3-3	EW
			S4		S4-1-S4-2	EW
			S5		S1-1-S1-2	EW
	EcSu	EW: 0.25	C1		C1	EW
			C2		C1-1-C2-2	EW
			C3		C3	EW
			C4		C4-1-C4-2	EW
			C5		C5-1-C5-2	EW
	DeSu	EW: 0.25	D1		D1-1-D2-7	EW
			D2		D1-1-D2-2	EW
			D3		D1-1-D2-2	EW

Consequently, the maximum score for SUS will be 10, as per the design of the system. Scores ranging from 0 to 2 indicate a destitute assessment; scores from 2 to 4 denote poor; scores between 4 and 6 signify a medium evaluation; scores from 6 to 8 represent good; and scores from 8 to 10 reflect an excellent rating. The evaluators can identify areas for improvement for the street under assessment with the help of these scores, which provide a clear framework for understanding the performance levels. By utilizing this grading scale, organizations can foster a culture of growth and accountability. The weighting scheme of the indicator scheme was developed based on the calculation formulae (Table III).

The evaluation Indicator System was then used to assess a selected street of Bengaluru, Srinivagilu Main Road, 1.6 km long, for a pilot survey (Figures 1 and 2). This sub-arterial street stretches from Sony World Junction to the Wipro signal in Koramangala, Bengaluru. It is a mixed land-use street surrounded mostly by retail shops, office buildings, and commercial complexes, along with restaurants. For the Indicator System, a subject expert and street user evaluated the street based on the detailed questionnaire. For the questionnaire survey, 50 respondents were randomly selected. The researcher's time and ability constraints were considered when determining the sample size.

TABLE III. THE SUSTAINABILITY EVALUATION FRAMEWORK'S WEIGHTING SYSTEM

Objective layer	Aspect layer	Attribute layer	Indicator layer
1	0.25	0.08	0.027
			0.027
			0.027
		0.05	0.017
			0.017
			0.017
		0.06	0.060
		0.05	0.025
			0.025
		0.02	0.007
			0.007
			0.007
		0	0.000
			0.000
			0.000
	0.25	0.02	0.010
			0.010
		0.06	0.020
			0.020
			0.020
		0.05	0.017
			0.017
			0.017
		0.07	0.035
			0.035
		0.04	0.020
			0.020
	0.25	0.01	0.003
		0	0.003
			0.003
		0.08	0.080
		0.08	0.040
			0.040
		0.08	0.040
			0.040
	0.25	0.08	0.011
			0.011
			0.011
			0.011
			0.011
			0.011
			0.011
		0.11	0.055
			0.055
		0.06	0.030
			0.030

The primary objectives and findings of the survey are:

- Survey schedule verification: Data were acquired on-site at the designated time and day successfully and precisely represented the usual efficiency of the selected streets. The survey responses showed that the suggested timing was appropriate.
- Comprehensive survey methodology design: It involves a detailed questionnaire that will give more precise answers, refining the survey procedure, which entails data collection techniques and the order of site measurements, improving the data efficiency.
- An evaluation of the Indicator System: This research served as a crucial assessment of the Indicator System, confirming its practicality and functionality.

Fig. 1. Selected street for the survey.

Fig. 2. Srinivagilu main road.

III. RESULTS

Concerning the sustainability of Srinivagilu Main Road, two sets of assessment data were derived from the Indicator System and the Questionnaire Study of the street users. The comparison of the results is depicted in Figures 3, 4, and 5, whereas the full data are included in Table IV.

However, the discrepancies between the two datasets were evident: EnSu, SoSu, and EcSu derived from the Indicator System results were all lower than the Questionnaire Survey results, with differences of 3.7%, 1.4%, and 0.4%, respectively; conversely, the DeSu from the Indicator System data was 3.1% higher than that from the Questionnaire Survey.

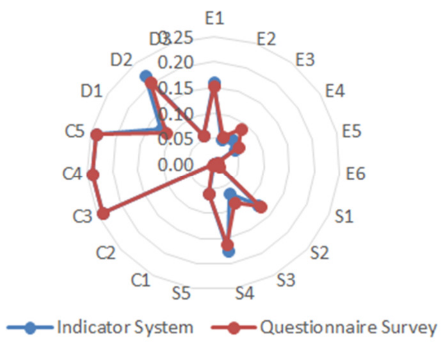

Fig. 3. Radar chart comparing datasets from the Indicator System and Questionnaire Survey.

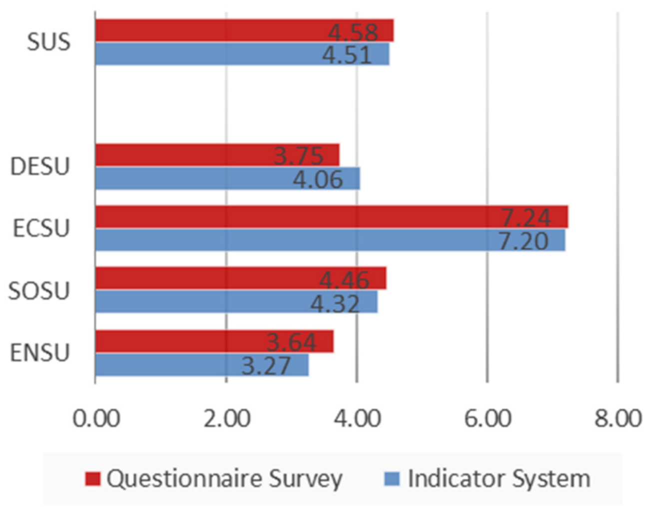

Fig. 4. Comparative graph of the Questionnaire Survey and Indicator System for the objective and aspect layers.

The assessment results of the Indicator System can accurately reflect the street's reliable functioning. The results clearly illustrated the differing performance across the environmental, social, economic, and design aspects of a single street, highlighting both its advantages and drawbacks. The questionnaire survey conducted with 50 users reinforces the weightings derived from the Indicator System, since the overall discrepancy between the two distinct assessment frameworks used to generate the sustainability number of the specified street is just 0.7%.

IV. CONCLUSION

The objective of the Sustainable Urban Streets (SUS) assessment is to identify issues and develop sustainable strategies rather than just to provide a numerical ranking of urban streets. The study addresses the lack of a practical evaluation toolkit necessary for comprehensive and effective design work and establishes a basis for future research directions.

A set of Indicator Systems is established to evaluate the sustainability in the metropolitan cities of India. It consists of four layers, 19 assessment criteria, and 46 indicators, in addition to standardization procedures, a Weighting System, and a compilation of calculation formulae. It outlines an evaluative approach for a comprehensive observation and analysis of the street. The assessment outcomes, consisting of numerical ratings across four layers, objectively and thoroughly represent the street's performance. The examination of the evaluation findings clarifies the street's attributes, including its qualities, benefits, and drawbacks, enabling more focused optimization methods.

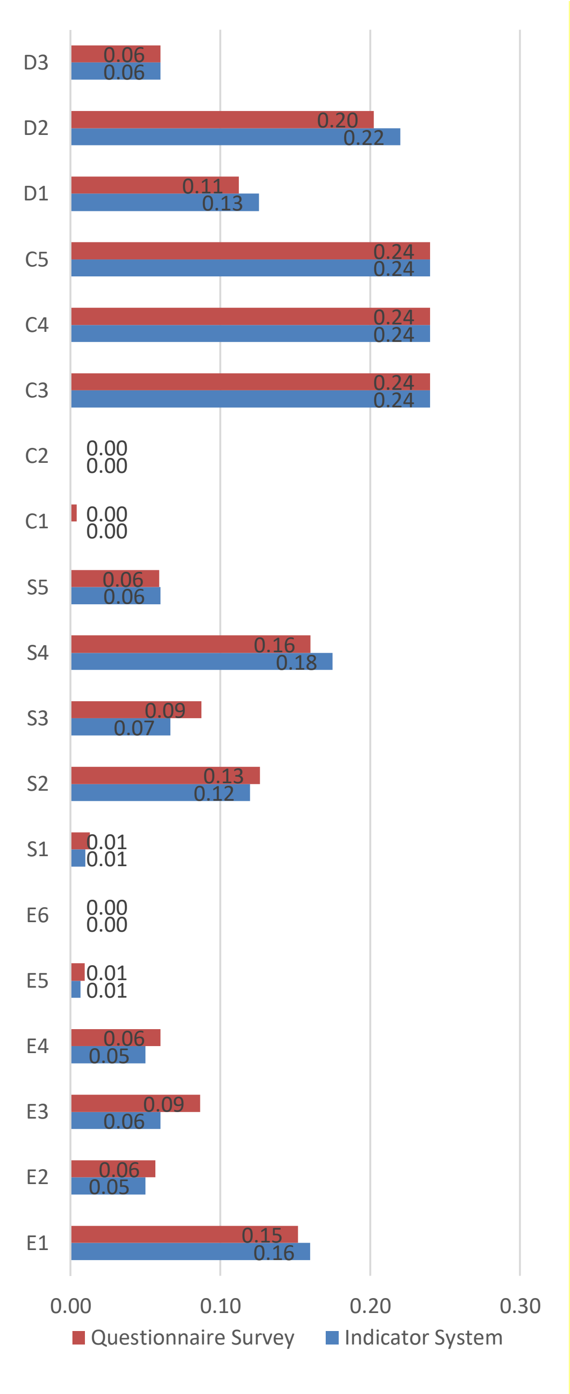

Fig. 5. Comparative graph of the Questionnaire Survey and Indicator System for the attribute layer.

TABLE IV. ANALYSIS OF SUSTAINABILITY EVALUATION FOR INDICATOR SYSTEM AND QUESTIONNAIRE FINDINGS

Evaluation framework				**Indicator System**					**Questionnaire Survey**				
Objective layer	**Aspect layer**	**Attribute layer**	**Indicator layer**	**Weights**	**Indicator layer**	**Attribute layer**	**Aspect layer**	**Objective layer**	**Weights**	**Indicator layer**	**Attribute layer**	**Aspect layer**	**Objective layer**
SUS	EnSu	E1	E1-1	0.03	3.00	0.16	3.27	4.51	0.08	1.90	0.15	3.64	4.58
			E1-2	0.03	2.00								
			E1-3	0.03	1.00								
		E2	E2-1	0.02	0.00	0.05			0.05	1.13	0.06		
			E2-2	0.02	1.00								
			E2-3	0.02	2.00								
		E3	E3-1	0.06	1.00	0.06			0.06	1.44	0.09		
		E4	E4-1	0.03	0.00	0.05			0.05	1.20	0.06		
			E4-2	0.03	2.00								
		E5	E5-1	0.01	0.00	0.01			0.02	0.47	0.01		
			E5-2	0.01	1.00								
			E5-3	0.01	0.00								
		E6	E6-1	0.00	0.00	0.00			0.00	0.00	0.00		
			E6-2	0.00	0.00								
			E6-3	0.00	0.00								
	SoSu	S1	S1-1	0.01	0.00	0.01	4.32		0.02	0.65	0.01	4.46	
			S1-2	0.01	1.00								
		S2	S2-1	0.02	2.00	0.12			0.06	2.11	0.13		
			S2-2	0.02	1.00								
			S2-3	0.02	3.00								
		S3	S3-1	0.02	1.00	0.07			0.05	1.75	0.09		
			S3-2	0.02	2.00								
			S3-3	0.02	1.00								
		S4	S4-1	0.04	2.00	0.18			0.07	2.29	0.16		
			S4-2	0.04	3.00								
		S5	S5-1	0.02	2.00	0.06			0.04	1.48	0.06		
			S5-2	0.02	1.00								
	EcSu	C1	C1-1	0.00	0.00	0.00	7.20		0.01	0.42	0.00	7.24	
		C2	C2-1	0.00	0.00	0.00			0.00	0.18	0.00		
			C2-2	0.00	0.00								
		C3	C3-1	0.08	3.00	0.24			0.08	3.00	0.24		
		C4	C4-1	0.04	3.00	0.24			0.08	3.00	0.24		
			C4-2	0.04	3.00								
		C5	C5-1	0.04	3.00	0.24			0.08	3.00	0.24		
			C5-2	0.04	3.00								
	DeSu	D1	D1-1	0.01	2.00	0.13	4.06		0.08	1.41	0.11	3.75	
			D1-2	0.01	2.00								
			D1-3	0.01	2.00								
			D1-4	0.01	1.00								
			D1-5	0.01	2.00								
			D1-6	0.01	2.00								
			D1-7	0.01	0.00								
		D2	D2-1	0.06	2.00	0.22			0.11	1.84	0.20		
			D2-2	0.06	2.00								
		D3	D3-1	0.03	1.00	0.06			0.06	1.00	0.06		
			D3-2	0.03	1.00								

The assessment outcomes of the Indicator System must include a detailed report that specifies not only the scores for SUS, Environmental Sustainability (EnSu), Social Sustainability (SoSu), Economic Sustainability (EcSu), and Design Sustainability (DeSu), but also strategies to improve the sustainability of the streets. These strategies should focus on enhancing community engagement, promoting green infrastructure, and implementing the best practices for urban planning. Moreover, the report should highlight successful case studies and recommendations tailored to the specific needs of each area assessed. Therefore, the sustainable assessment does not aim to identify an ideal street. Each street possesses distinctiveness due to its historical context, geographical location, and the characteristics of its users. Instead of referring to an ideal state, the term "sustainability" describes a state that is well-balanced. By achieving a high SUS score, a street demonstrates a pattern of health and longevity in the areas of design, economics, society, and the environment.

The sustainability assessment functions as an open system. It must be adjusted according to the deployment site and refined in response to the current advancements. Therefore, it is categorically unfeasible to assess diverse streets with varying social contexts and climatic conditions using a singular approach. Nevertheless, within the identical geographic region marked by comparable climate, social circumstances, and economic growth, the built system can evaluate street performance and discern the attributes of the assessed streets.

The identified challenges highlight the necessity for intervention in the urbanization of the developing nations. Collaborative initiatives that involve a variety of stakeholders require the involvement of communities, experts, and policymakers in the development of strategies for SUS. Informed decision-making is crucial for improving environmental and economic sustainability amidst urban challenges, especially through design considerations and collaborations with pertinent experts. It is anticipated that this research will improve the urban planning strategies that are in line with the global sustainability objectives, facilitating the development of SUS for future generations [25].

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