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Indicator for formulating and measuring the Urban Sustainability Index: A Review

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Abstract: *Urbanization and its effects on the environment are issues brought up by the rapid growth of the urban population. The need for addressing environmental issues has become critical as cities struggle with issues like carbon emissions, a lack of fresh water, and agricultural pollution. Urbanization presents a chance for progress by fostering the development of sustainable cities that can lessen the pressure on the environment in the future. Urban Sustainability has been emphasized to raise current and future generations living standards. The Urban Sustainability Index (USI) gives decision-makers a thorough evaluation of the integrated nature-society systems globally and locally. Urban Sustainability is assessed using a variety of indicators. This article reviews and discusses the frameworks and indicators used by various researchers to define and measure the USI, highlighting the significance of sustainable urban development, renewable energy, and urban water management.*

Keywords: Urban Sustainability; Urbanization; Sustainability Indicators; Content Analysis; Text Mining

1. INTRODUCTION

The proportion of the urban population keeps on increasing decade by decade. The population worldwide in cities is 55% presently, likely to rise to 68% by 2050. According to projections, urbanization, the steady movement in human residency from rural to urban regions, and global population increase might bring another 2.5 billion people to urban areas by 2050 [1], [2]. Migration of people from rural to urban cause a significant contribution to rapid urbanization rather than natural population increase in the statutory town itself [3]. The infrastructure-based allied service facilities, employment opportunities, and accessibility to Education are significant reasons for migration activities around developing countries.

The ecological impact of cities has become an increasingly critical concern. With the Earth already affected by carbon emissions, limited fresh water, and agricultural pollution, addressing environmental problems is challenging and demands technological advancements and behavioral changes [4]. Urbanisation has emerged as one of the most critical issues defining humanity's relationship with the environment. However, unprecedented urban growth also presents a chance for positive change. By creating sustainable cities, we have the potential to alleviate future environmental pressures.

Furthermore, this transformation towards self-sustaining urban living offers an opportunity to improve cities' overall quality of life. Urban Sustainability has been under lamp light for decades to plan and improve the city's quality of life for the present and future generations [5]. This concept provides the assessment framework for the term' sustainable city.' Expecting sustainability at urban parcels enhances and balances residents' social, economic, and environmental status [6]. Quantifying the degree to which urban development is sustainable or not with suitable sustainability indicators is necessary. Urban Sustainability Index (USI) is a function of various indicators that infer environmental, social, and economic aspects. This index gives decision-makers a short- and long-term evaluation of global and local integrated nature-society systems to help them decide whether activities should or should not be made to make society more sustainable [7].

This article discusses and reviews the various indicators for defining and measuring USI. Indicators directly measure the achievement score present phenomenon compared with any proposed target, which should be the benchmark or maximum achievable.

2. URBAN SUSTAINABILITY INDEX AND INDICATORS:

An indicator can be observed and measured and describes a theory in practical terms. An index is one score created by combining multiple separate scores, sometimes simply by adding them together but often in a more complex manner, to measure a specific variable. The index number of the base data is usually set to 100. Using indicators to assess sustainability is a suitable and suggested method of dealing with sustainable urban development [8]. The indicator system of the sustainability framework just presents the findings for each indicator separately, making it harder to compare cities and making data analysis more labor-intensive.
On the other hand, it is easier to adjust the sustainability framework to the unique characteristics of each city, and it is more difficult to miss the components of the urban system.

Indexes and scorecards frequently assign different weights to individual measures prior to aggregation to represent the relative value of the indicators. Indexes can be implemented to compare the performance of cities readily [9]. This practice requires each city under review to complete all required areas, limiting flexibility regarding public requirements and cities' own approach to sustainability. Urban Sustainability measures a specific component of sustainable development in a stra and understandable manner, enabling monitoring and, ultimately, implementing and administrating a public policy or management process [10].

This article aims to study the frameworks of index inclusive of indicators adopted by various researchers for Urban Sustainability assessment.

3. REVIEW METHODOLOGY

Due to the opportunity to measure, monitor and compare the cities through the sustainability index, several articles have been published under this theme, considering a few or many related indicators. A qualitative content analysis approach is adopted in this study. The process of converting raw data into categories or themes based on sound inference and interpretation is known as qualitative content analysis. This method employs inductive reasoning, in which themes and categories arise from data through meticulous examination and frequent comparison by the researcher [11].

The formation of systematic steps and workflow is vital for state-of-the-art articles. The workflow of sustainable indicators considered for USI in this study is presented in **Fig. 1.**

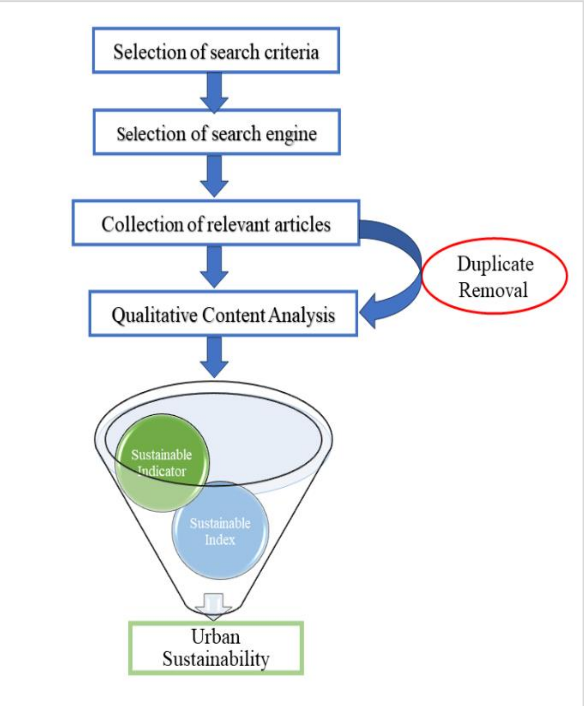

Fig. 1. Workflow of content analysis for sustainable city indicators.

The paper starts with collecting several articles published with the theme and keywords of urban Sustainability and US Index/Indicator. Even though standard bibliometric analysis and search options available with the Web of Science [12] and other publishers like Elsevier, Springer, Taylor and Francis, Willey, Emerald, IEEE, Frontiers, MDPI, and SAGE, Google Scholar was preferred. Google Scholar is nowadays considered a reservoir of journal articles due to quicker indexing in its database [13]. The related articles were collected from the corresponding publisher's site, and open-access articles were downloaded directly and checked for duplicates.

4. CONTENT ANALYSIS OF LITERATURE

Based on the literature study conducted on the collected paper, many researchers have formulated sustainability indexes specifically for a city. Some have measured the index value of the considered city alone. The indicators-wise content analysis in a category is presented below.

4.1 Integrated sustainability indicators

The integrated sustainability indicators aggregated as smart city index proposed by a researcher include indicators like air quality, water quality, and waste management under the Environment domain. Similarly, the smart society domain includes Education level, poverty rate, and healthcare. The author listed the domains of economy, governance, Energy, Infrastructure, and Pandemic resilience [14]. This index was applied to 20 cities worldwide. The smart environment and smart economy domains show a positive link. It was reported that Smart governance leads to a smarter economy. Grouping of indicators appeared very common during literature analysis. A study was conducted in three urban regions of the United Kingdom by Catalina Turcu. Here the indicators were grouped as Institutional, Environmental, Social, and Economic Sustainability. Through conducting face-to-face questionnaires to 134 urban residents of three regions, it was observed that schools, health services, and public transport were voted as critical indicators under service and facilities' based Environmental sustainability [15].

Cagliari City (Italy) was examined for urban sustainability through the derived quality indicators by Garau et al. The indicators were categorized as Use and fruition, Health and well-being, Appearance, Management, Environment, and Safety and security [16]. The point-rating system was developed by referring to indicators that match the master plan's standards, and an in-situ neighborhood analysis was performed to gather information on the area's characteristics.

Yigitcanlar et al. proposed a multiscalar urban sustainability strategy that connects two sustainability assessment models to evaluate performance on sustainability at the micro- and mezzo-levels and provide multiscalar answers at the macro-level. Natural and Built environments were a few significant indicators of 14 numbers included in the Micro-level Urban-ecosystem Sustainability Index (MUSIX). While, Transport, Urban form, and Externalities were the indicators used for measuring the Integrated Land-use and Transport Indexing Model (ILTIM) with a total of 24 indicators[17].

SAFE (sustainability assessment by fuzzy evaluation) to measure sustainability was modified by Phillis et al. with 46 basic inputs as indicators to rank 106 cities as per sustainability. Ecology and well-being were the indicator category considered. Water quality, soil quality, air quality, and land integrity to sea level rise are indicators considered for SAFE[18]. It was observed that European cities have the highest rankings, while African, Asian, and South American cities have the lowest. Waste generation and GHG (greenhouse gas) emissions are the primary challenges in developed cities; however, crime and poverty are the primary problems in cities of developing countries.

A multi-criteria approach to assess the performance of Uban Sustainability was conducted by Shmelev et al. with a panel of 20 indicators for 57 global cities, including London, Hong Kong, and New York [19]. This evaluation covered crucial elements of transitioning to cleaner energy, particularly emphasizing the factors influencing CO2 emissions in urban areas. These factors included the proportion of coal used in the energy mix, the patterns of public transportation and cycling, waste recycling practices, the interconnection between water and energy usage, and the impact of a smart and creative economy. According to the findings, San Francisco ranks highest in emphasizing economic growth and environmental preservation. At the same time, Stockholm takes the lead in prioritizing social well-being and developing innovative city initiatives. Also, It was found that no single city stands as the ultimate global leader that outperforms all others in every aspect.

Dizdaroglu. D introduced an indicator framework that assesses the sustainability performance of urban ecosystems based on three primary categories: the natural environment, built environment, and socio-economic environment. Each category was divided into nine sub-categories (Hydrology, Microclimate, Pollution, Location, Landscape Design, Energy efficiency, Demographic characteristics, Social stratification, and Lifestyle), totaling 23 indicators used for evaluation [20]. Urban ecosystem indicators track environmental shifts over a specific timeframe and offer insights into the dynamic interplay between the environment and human activities, highlighting emerging environmental, social, and economic concerns [21].

One can fit every sustainability indicator into one of three categories of sustainable pillars. Feleki et al. identified a set of indicators to assess Urban Sustainability, which were grouped into three pillars: Environment, Social, and Economic. Under the Environment pillar, the indicators encompassed Air Quality, Energy, Climate, Water, Nature & biodiversity, Transportation, Waste, and Land use. The Social pillar included indicators such as Health & well-being, Education & Culture, Equity & social cohesion, Governance, Labour, Housing, and Population. Lastly, the Economic pillar consisted of Macro-economic, Economic-environment, Socio-economic, Micro-economic, Investments, Business environment, and Socio-econ-environment as indicators. [22]. The author has also suggested a new sustainability dimension called the Spatial dimension. Also, these spatial dimensions strongly link culture, social patterns, heritage, and professional activities within urban geographic areas.

4.2 Specific indicator based sustainability

The above section of the literature analysis deals with how the indicators were clubbed together to form a sustainability index. This section deals with specific indicator-based sustainability assessments for a city as per the literature.

4.2.1 Renewable Energy

Kammen et al. shared their insights on the technical advancement of renewable energy for urban sustainability. The proposed goal was to create sustainable energy systems focusing on decreasing energy usage, particularly in buildings and transportation, while implementing strong, decentralized, and renewable energy sources [23]. These renewable sources should be capable of meeting the increasing energy demands of expanding urban areas. However, achieving this requires addressing various economic, technological, human behavior, and political challenges. Overcoming these obstacles will drive innovation and enhance urban sustainability. The scientific community emphasizes the critical significance of investigating renewable energy generation within cities to attain enhanced sustainability and cater to the needs of a growing urban population [24]. The increasing global focus on renewable energy, particularly in industrialized nations, as a pivotal measure to combat the impacts of climate change has further accelerated research in this domain [25]. Policymakers are vital in fostering improved urban conditions by implementing more stringent efficiency standards for buildings and promoting sustainable transportation options, thus facilitating sustainable urban development [26], [27].

4.2.2 Urban Water Management

Sustainability with water refers to a country's ability to achieve water self-sufficiency, ensuring an adequate water supply to fulfill various requirements, including agriculture, municipal, and industrial needs. Additionally, it entails maintaining a consistent water supply despite the adverse effects of climate change, such as droughts or floods, and being resilient in the face of these challenges. Odjegba et al. developed the Water Supply Systems Sustainability Index (WSSI), a practical evaluation tool designed to assess the sustainability of drinking water systems in various urban, peri-urban, and rural communities across Nigeria. This tool allows for a quick appraisal of these systems, enabling their classification into four categories based on their level of Sustainability: Highly Sustainable, Sustainable, Averagely Sustainable, and Unsustainable WSSI categories [28]. De Carvalho et al. developed a Sustainable Index for Integrated Urban Water Management, which consisted of 20 indicators related to water schemes. These indicators encompassed Social, Economic, Environmental, Political, and Institutional dimensions. The index was specifically designed to assess the sustainability of water-related initiatives in urban regions of South Africa. By utilizing this composite index, researchers could gauge the sustainability of water management practices in the selected urban regions, considering a comprehensive range of factors and dimensions [29].

Aydin et al. presented a methodology to calculate sustainability indices for water distribution systems (WDS) attributed to pressure and water age. The suggested approach can be valuable for monitoring current Water Distribution Systems (WDSs) sustainability [30]. This methodology makes it possible to assess the performance and effectiveness of existing

WDSs regarding Sustainability. Moreover, the methodology can aid in identifying potential areas for improvement and suggesting alternative solutions. These alternatives may involve adjusting pump operations to optimize efficiency and conserve resources [31]. Additionally, the methodology could propose modifications to the WDS infrastructure to enhance its sustainability, ensuring that water distribution remains reliable, efficient, and environmentally friendly.

4.2.3 Urban Transport

An Urban Transportation Sustainability Index has been developed by Ardekani et al. to evaluate the level of transportation sustainability in urban developments. The index comprises six categories of sustainability indicators: pedestrian infrastructure, bicycle infrastructure, transit infrastructure, mixed-use, transit-oriented developments, traffic calming measures, and sustainable operations. These categories help assess the effectiveness of sustainable transportation practices and facilities within the urban area [32]. Oses et al. have formulated a mathematical model designed explicitly for decision-making processes in urban transportation systems. This model utilizes multi-criteria analysis tailored to accommodate urban transportation's complexities. Unlike conventional approaches focusing solely on environmental factors, this model considers a broader range of criteria, including economic, social, and urban aspects [33].

Moreover, it considers the characteristics and conditions of the transport fleet and freight distribution vehicles. By integrating these diverse factors, the model generates a comprehensive sustainability index value for the urban transportation system. This sustainability index was a valuable tool for assessing and comparing the overall sustainability performance of urban transportation in different areas, guiding decision-makers to enhance sustainability and efficiency [34].

The above is evidence for sustainability assessment based on only one specific category of indicators. The literature collection also contains Land use [35], Construction [36], Wastewater reuse and Sewage system [37], Education [38], and so on as one category measure of Urban Sustainability.

5. TEXT MINING ANALYSIS

Text mining is a data analysis technique that involves exploring and examining extensive amounts of unstructured text data. This process is facilitated by specialized software that can efficiently identify and extract various elements from the data, such as concepts, patterns, topics, keywords, and other attributes [39]. The growth of big data platforms and advancements in deep learning algorithms have made text mining more accessible and feasible for data scientists and other users. These technologies enable the analysis of massive unstructured data sets, making it easier to derive valuable insights and patterns from text-based information [40].

5.1 Tag Cloud

Text Mining was performed with the literature collected for this study. In the field of text mining, a tag cloud is employed to visually emphasize the most frequently utilized keywords within a paragraph or a collection of research articles. The size and prominence of each keyword in the tag cloud are proportional to its frequency of occurrence, making it easier for readers to identify the most relevant and commonly mentioned terms at a glance. This visualization technique helps quickly grasp the text data's key themes and essential concepts. The tag cloud output for our study is presented in Fig. 2.

Fig. 2. Tag Cloud of collected literature

The text mining output indicates that "sustainable development" was the most frequently used term in the collected literature. This prominence can be attributed to the fact that a significant portion of the research is related to the sustainability index, closely linked to the indicators and targets of the 17 Sustainable Development Goals (SDGs) proposed by the United Nations. These SDGs aim to be achieved by 2030, and their implementation plays a crucial role in various studies concerning sustainability and development [41].

6. CONCLUSION

Modern urban development must prioritize urban sustainability because of the growing urban population's environmental effects. The articles examined for this study illuminated various frameworks and indicators for evaluating urban sustainability. Researchers have developed different strategies, with some emphasising integrated sustainability indicators and others highlighting particular elements like urban water management, renewable energy, and urban transportation.

Economic, social, and environmental factors can all be taken into account when assessing urban sustainability using indicators and indices. It gives decision-makers the information they need to support sustainable urban development. Researchers can also compare the sustainability performance of various cities by looking at different indicators, aiding in the identification of best practises and potential improvement areas. Renewable energy emerges as a key factor in achieving sustainable urban development, emphasizing the need to transition to cleaner energy sources. Urban water management and efficient transportation systems also play vital roles in enhancing urban sustainability by conserving resources and reducing environmental impact.

This study emphasizes how critical it is to evaluate urban sustainability holistically, considering a wide range of indicators and domains. As cities expand, adopting sustainable practises is essential to ensuring a higher standard of living for city dwellers while protecting the environment for future generations.

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