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# Comparative Analysis of Neighborhood Sustainability Assessment Systems from the USA (LEED–ND), Germany (DGNB–UD), and India (GRIHA–LD)

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**Abstract:** Neighborhood sustainability assessment systems support the planning of sustainable and resilient cities. This research analyses, compares, and evaluates three neighborhood sustainability assessment systems (NSA) of (i) the German Sustainable Building Council for Urban Districts (DGNB–UD), (ii) the USA Leadership in energy and environmental design for Neighborhood Development (LEED–ND), and (iii) the Indian Green Rating for Integrated Habitat Assessment for Large Developments (GRIHA–LD). The theoretical background, certification types, process, and evaluation methods of the three NSAs are discussed. The qualitative and quantitative comparative analysis and evaluation methods of the NSAs included identifying and assessing ten weighted essential urban sustainability themes. Indicators under each theme were identified and compared in the NSAs. The comparison showed the importance of particular themes based on assigned weights. LEED–ND focuses on "transportation" and "site planning", while DGNB–UD addresses all dimensions of sustainability in a balanced manner. GRIHA–LD has limitations concerning social, economic, and governance concerns. The research results define differences and similarities in international neighborhood sustainability assessment and illustrate the quality and quantity differences of sustainability and resilience aspects addressed by the three existing NSA systems as a starting basis for the future improvement of existing and development of new land sustainability and resilience assessment systems.

**Keywords:** sustainability; resilience; urbanized land; neighborhood; assessment systems

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## 1. Introduction

Land use changes through urbanization and the construction and operation of cities are profoundly altering the relationship between society and the environment at accelerated rates, with hazardous effects, such as excessive nonrenewable resource consumption, resulting in polluting emissions and climate change. As per the UN Habitat, more than 68% of the world's population will be accommodated in cities by 2050, mainly in developing countries [1]. Urban expansions will put pressure on potable water supplies, energy, food, urban mobility, air condition, health, quality of life, and waste treatment [2]. Moreover, urbanization leads to social, environmental, economic, institutional, and cultural transformations; therefore, it is necessary to understand the form and content of urbanization to reduce carbon emissions. Climate change is contributing to increasing the frequency and intensity of natural hazards. Concerns regarding public health implications of urbanization have arisen with recent COVID-19 outbreaks [3]. Consequently, a range of urban risks is accumulating, and cities in the developing world urgently need a mechanism for risk reduction and resistance planning [1].

The concept of "sustainability" was initiated in the 17th century [4]. The concept of sustainable development was articulated by the World Conservation Strategy of the International Union for Conservation of Nature and Natural Resources (IUCN, 1980).

In 1987, the United Nations Brundtland report defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [5,6]. Sustainability in urban areas refers to planning for the future of urban development, as well as redeveloping existing settlements in an ecofriendly and resource-efficient manner [4]. Resilience can be defined as the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions [7–9]. Resilience and sustainability are also associated with global political trends, where global frameworks and multilateral agendas are being developed to promote sustainability and resilience in urbanization [10]. Strong sustainable development needs to address ecological, social, and economic challenges in a balanced way [11]. The need for a sustainable urban form at the local level has been advocated by the United Nations through its "Local Agenda 21" programs [12]. The 2030 Agenda for sustainable development discussed the determination to take the bold and transformative steps that are urgently needed to shift the world onto a sustainable and resilient path [13]. Sustainable development at the local level has also been recognized through the formulation of a separate goal under the Sustainable Development Goals for 2030, specifically Goal 11: "Make cities and human settlements inclusive, safe, resilient, and sustainable" [13,14]. To overcome the challenges of sustainable development, the understanding of sustainability in a holistic sense requires proper understanding of the concepts, approaches, methods, tools, and techniques used to evaluate the sustainability of urban development [15–17].

### *1.1. Neighborhoods and Urban Districts*

A neighborhood or an urban district is urbanized land of a specific size, accommodating multiple buildings with single or different uses, such as housing, education, and commercial. According to the UN, the neighborhood is an area where people can easily meet their daily needs, socialize, and feel safe [18]. Leadership in Energy and Environmental Design for Neighborhood Development (LEED–ND) 2009 states that the neighborhood is an area of dwellings, employment, retail, and civic places and their immediate environment that residents and employees identify in terms of social and economic attitudes, lifestyles, and institutions [19,20]. According to the German Sustainable Building Council–Urban Districts (DGNB–UD) system, an urban district is an urban area of a minimum of two hectares consisting of a number of buildings and at least two development sites having public and publicly accessible spaces and related infrastructure and has a gross floor residential area that should not be less than 10% and not more than 90% [21]. In the Green Rating for Integrated Habitat Assessment for Large Development (GRIHA–LD) the term "Large Development" is used, specifying that the area of development be equal to or greater than one hectare. Various typologies of "Large Development" are stated in GRIHA–LD as per land use and building use, including mixed-used township, institutional campuses, and special economic zones [22].

Sustainability principles suggest that the neighborhood scale is an appropriate level to better analyze socioeconomic impacts, and more easily and meaningfully facilitate citizen involvement. Neighborhoods have gained considerable attention, since they are small enough to efficiently and effectively experiment with innovative sustainable planning and design initiatives, while they are simultaneously large enough to take account of complex interrelationships with different urban components [23]. When the focus is only on smaller scales, such as buildings and building blocks, such complexities are often not considered [24].

Neighborhoods are subdivisions of cities. All neighborhoods within a city form the city with all developments, activities, and processes. Therefore, the overall sustainability of a city depends on the sustainability of its neighborhoods [25]. An urban neighborhood can be defined by the utilization of multiple themes and indicators referring to topics such as social, economic, and ecological, topography, land use, infrastructures, and administration [26]. The most sustainable neighborhoods tend to exhibit high levels of walkability, a sense of place, social cohesion and stability, and neighborhood resiliency amidst changing economic and sociopolitical conditions. With regard to the urban environment, investigating sustainable and resilient urban neighborhood principles are crucial, as they provide general insights into the desirable development paths for neighborhoods [27].

A seminal work on the perceptual form of urban environments found that sustainable neighborhoods are defined by limits having various community mixed housing, offices, retailers, leisure activities, civic centers, schools, medical care centers, and parks interconnected by a network of streets that assigns priority to public spaces, and to the appropriate placement of institutional structures [18]. Neighborhood sustainability can be investigated using various assessment methods and techniques. A neighborhood sustainability assessment (NSA) system is a tool that facilitates neighborhood sustainability and resilience capacity identification.

### *1.2. Neighborhood Sustainability Assessment (NSA) Systems*

NSA systems are standards that evaluate the surrounding environment of buildings, and indicators that are associated with various themes, such as society, transportation, water, waste management, and the economy on larger scale [28]. In 1990, the Building Research Establishment Environmental Assessment Method (BREEAM) system was the first multicriteria system developed for the sustainability assessment of buildings [29]. Multicriteria sustainability assessment systems allow a stepwise implementation for each theme [30] and provide a third-party evaluation based on several predefined sustainability themes, providing credibility for the planning project. NSA systems provide a common platform and standardized terminology for various stakeholders involved in urban development projects [31–33]. NSA systems were designed to assist decision-makers in evaluating global to local integrated nature–society systems in the short and long term to assist them in making appropriate decisions to make society sustainable [34]. Assessment systems facilitate decision-making and outcome evaluation, and guide future development [35]. Therefore, NSA systems support the improvement of neighborhood sustainability. A certified neighborhood can gain recognition, and developers can promote certified projects, which results in potential increase of the project's value. Among various NSA systems, some exemplary and well-known systems—the Comprehensive Assessment System for Built Environment Efficiency (CASBEE–UD) of Japan [36], DGNB–UD of Germany [21], LEED–ND of the USA [37], BREEAM communities of the United Kingdom [38], Green Mark of Singapore [39], and The Ecological Community Evaluation System (EEWH–EC) of Taiwan, are used for assessment and certification.

Based on research and developments progress and expert input, NSA systems are generally regularly updated, further developed, and improved. However, update periods are inconsistent among NSA systems. Comparing and evaluating the most actual versions of comprehensive NSA systems facilitated this up-to-date neighborhood sustainability and resilience assessment research. Further research is needed to investigate if and how regular updates of NSA tools have resulted in structural and procedural improvements [23]. The NSA systems selected for the comparative analysis in this research address social, environmental, economic, and institutional dimensions of sustainability and resilience. Quantitative assessment by scoring or weighting is part of the evaluation process of comprehensive and recognized NSA systems. Furthermore, these systems' assessment methods and manuals are publicly accessible.

This research selected the LEED–ND and DGNB–UD for comparative analyses because LEED–ND and DGNB–UD are the most comprehensive and internationally recognized second- and third-generation neighborhood and urban district assessment systems developed in the USA and Germany, respectively. Literature studies on comparative analysis of NSA systems proved that LEED–ND and DGNB–UD have the most comprehensive, established sustainability assessment framework [40,41]. In contrast, GRIHA−LD is a system designed to assess extensive developments' environmental performance, developed in and used exclusively in India. In this research, the authors aimed to compare the Indian NSA system GRIHA–LD with the most recognized, globally used neighborhood sustainability assessment systems. Literature studies confirmed missing research about developing countries' NSA systems. [42,43]. GRIHA–LD was formulated to develop a consolidated framework for assessing the environmental impacts of large-scale urban developments [22], but comparative analysis demonstrates that the NSA system should encompass economic, social, and institutional aspects equitably, in addition to environmental impact evaluation. This comparison could contribute to the improvement of existing systems, and the analysis will assist in the development of new neighborhood sustainability assessment systems.

### *1.3. General Description of LEED–ND, DGNB–UD, and GRIHA–LD*

#### 1.3.1. LEED–ND

In 2009, the United States Green Building Council (USGBC), Congress for New Urbanism (CNU), and National Resources Defense Council (NRDC) launched the Leadership in Environmental Design for Neighborhood Development (LEED–ND) as a voluntary sustainability assessment system to guide sustainable neighborhood development [20].

The LEED–ND for the "neighborhood development built project" is applicable for a fully completed neighborhood or one in the completion stage, whereas the LEED–ND for the "neighborhood development plan" can be applied to a neighborhood in the construction phase when less than 75% of the area is constructed. In this research, the latest version of "LEED v4" for neighborhood development built project was considered for the analysis. Table 1 shows that the LEED–ND is assessed on the basis of five credit categories, the most important of which are "smart location and linkage (SLL)", "neighborhood pattern and design (NPD)", and "green infrastructure and buildings (GIB)", which are assigned prerequisites and credit points, while the "innovation and design process (IDP)" and "regional priority (RP)" categories are also assigned importance in the LEED–ND v4 version with credit point allocation [37,44]. Table 1 shows the score allocation in LEED–ND to all five credit categories: "SLL" receives 25% points, "NPD" receives 37% points, and "GIB" receives 28% points. "IDP" receives 6% of the total points, while "RP" receives 4% of the total points [37].

**Table 1.** Assessment and structure of the LEED v4 for neighborhood development with the specification of credit categories, credits and prerequisites, absolute and normalized credit points, and credit categories percentages [44].

| Credit Categories | Credits and Prerequisites | Credit Points/110 | Normalized Credit Points/100 | Credit Categories (%) |
|---|---|---|---|---|
| Smart location and linkage | Smart location | Required | - | 25.42 |
| | Imperiled species and ecological communities | Required | - | |
| | Wetland and water body conservation | Required | - | |
| | Agricultural land conservation | Required | - | |
| | Floodplain avoidance | Required | - | |
| | Preferred locations | 10 | 9.1 | |
| | Brownfield remediation | 2 | 1.82 | |
| | Access to quality transit | 7 | 6.35 | |
| | Bicycle facilities | 2 | 1.82 | |
| | Housing and job proximity | 3 | 2.69 | |
| | Steep slope protection | 1 | 0.91 | |
| | Site design for habitat or wetland and water body conservation | 1 | 0.91 | |
| | Restoration of habitat or wetlands and water bodies | 1 | 0.91 | |
| | Long-term conservation management of habitat or wetlands and water bodies | 1 | 0.91 | |

**Table 1.** *Cont.*

| Credit Categories | Credits and Prerequisites | Credit Points/110 | Normalized Credit Points/100 | Credit Categories (%) |
|---|---|---|---|---|
| Neighborhood pattern and design | Walkable streets | Required | - | 37.28 |
| | Compact development | Required | - | |
| | Connected and open community | Required | - | |
| | Walkable streets | 9 | 8.18 | |
| | Compact development | 6 | 5.45 | |
| | Mixed used neighborhood | 4 | 3.64 | |
| | Housing types and affordability | 7 | 6.36 | |
| | Reduced parking footprint | 1 | 0.91 | |
| | Connected and open community | 2 | 1.82 | |
| | Transit facilities | 1 | 0.91 | |
| | Transportation demand management | 2 | 1.82 | |
| | Access to civic and public space | 1 | 0.91 | |
| | Access to recreation facilities | 1 | 0.91 | |
| | Visitability and universal design | 1 | 0.91 | |
| | Community outreach and involvement | 2 | 1.82 | |
| | Local food production | 1 | 0.91 | |
| | Tree-lined and shaded streetscapes | 2 | 1.82 | |
| | Neighborhood schools | 1 | 0.91 | |
| Green infrastructure and building | Certified green building | Required | - | 28.2 |
| | Minimum building energy performance | Required | - | |
| | Indoor water use reduction | Required | - | |
| | Construction activity pollution prevention | Required | - | |
| | Certified green buildings | 5 | 4.55 | |
| | Optimize building energy performance | 2 | 1.82 | |
| | Indoor water use reduction | 1 | 0.91 | |
| | Outdoor water use Reduction | 2 | 1.82 | |
| | Building reuse | 1 | 0.91 | |
| | Historic resource preservation and adaptive reuse | 2 | 1.82 | |
| | Minimized site disturbance | 1 | 0.91 | |
| | Rainwater management | 4 | 3.63 | |
| | Heat island reduction | 1 | 0.91 | |
| | Solar orientation | 1 | 0.91 | |
| | Renewable energy production | 3 | 2.73 | |
| | District heating and cooling | 2 | 1.82 | |
| | Infrastructure energy efficiency | 1 | 0.91 | |
| | Wastewater management | 2 | 1.82 | |
| | Recycled and reused infrastructure | 1 | 0.91 | |
| | Solid waste management | 1 | 0.91 | |
| | Light pollution reduction | 1 | 0.91 | |
| Innovation and design process | Innovation | 5 | 4.55 | 5.46 |
| | LEED®-accredited professional | 1 | 0.91 | |
| Regional priority credit | Regional priority credit: region defined | 1 | 0.91 | 3.64 |
| | Regional priority credit: region defined | 1 | 0.91 | |
| | Regional priority credit: region defined | 1 | 0.91 | |
| | Regional priority credit: region defined | 1 | 0.91 | |
| - | Total credit | 110 | 100 | 100 |

The "prerequisites" are mandatory to achieve certification, while the credit measures are optional, and measured by the allocation of weighted point values that signify the relative importance of each measure. Prerequisite and credit measures are described through supporting information in the documentation. The "intent" of each indicator identifies the main goals of the measure. "Requirement" indicates the specifications that are needed to fulfil the goals.

As a result of the assessment, neighborhood development is certified using LEED–ND, with four certification levels based on points earned. Certified status can be achieved with a score of 40–49 points; silver certification with 50–59 points; gold certification with 60–79 points; and platinum certification with more than 80 points [37].

#### 1.3.2. DGNB–UD

The German Sustainable Building Council assessment system for urban districts, DGNB–UD, was launched in Germany by DGNB in 2011 and consists of a complex point impact factor and percentage-based assessment criteria certification system for urban districts. Table 2 shows the structure of the DGNB–UD system, assessment criteria, and the scores of respective criteria. In the DGNB–UD system, the concept of sustainability is defined and extended beyond social, environmental, and economic sustainability, as the DGNB–UD includes "process quality" and "technical quality" [45]. Table 2 also illustrates the distribution of credit score percentages in each domain of the most recent version, 2020 of DGNB–UD [46], used for this research.

**Table 2.** Assessment and structure of the DGNB–UD system with the specification of domains, criteria groups, criteria, and weighting of the urban district assessment criteria [46].

| Domain | Criteria Group | | Criteria | Relevance Factor | Share of Total Score (%) | Domain Score (%) |
|---|---|---|---|---|---|---|
| Environmental quality (ENV) | Effect on global and local environment (ENV1) | ENV1.1 | Lifecycle assessment | 8 | 6.4 | 20 |
| | | ENV 1.2 | Pollutants and hazardous substances | - | - | |
| | | ENV 1.5 | Urban climate | 5 | 4.0 | |
| | Resource consumption (ENV2) | ENV 2.2 | Water cycle systems | 4 | 3.2 | |
| | | ENV2.3 | Land use | 4 | 3.2 | |
| | | ENV 2.4 | Biodiversity | 4 | 3.2 | |
| Economic quality (ECO) | Life-cycle costs (ECO1) | ECO1.1 | Lifecycle costs | 4 | 5.6 | 20 |
| | Economic development (ECO2) | ECO2.1 | Resilience and adaptation | 3 | 4.3 | |
| | | ECO2.3 | Land Use efficiency | 3 | 4.3 | |
| | | ECO2.4 | Value stability | 2 | 2.9 | |
| | | ECO2.5 | Environmental risks | 2 | 2.9 | |
| Sociocultural and functional quality (SOC) | Health, comfort, and user satisfaction (SOC1) | SOC1.1 | Thermal comfort in open space | 3 | 2.6 | 20 |
| | | SOC1.6 | Open space | 4 | 3.5 | |
| | | SOC1.8 | Workplace comfort | - | - | |
| | | SOC1.9 | Noise, exhaust, and light emission | 3 | 2.6 | |
| | Functionality (SOC2) | SOC2.1 | Barrier-free design | 3 | 2.6 | |
| | Sociocultural quality (SOC3) | SOC3.1 | Urban design | 3 | 2.6 | |
| | | SOC3.2 | Social and functional mix | 4 | 3.5 | |
| | | SOC3.3 | Social and commercial infrastructure | 3 | 2.6 | |
| Technical quality (TEC) | Technical infrastructure (TEC 2) | TEC2.1 | Energy infrastructure | 4 | 4.4 | 20 |
| | | TEC2.2 | Resource management | 2 | 2.2 | |
| | | TEC2.4 | Smart infrastructure | 2 | 2.2 | |
| | Mobility (TEC3) | TEC3.1 | Mobility infrastructure—motorized transportation | 5 | 5.6 | |
| | | TEC3.2 | Mobility infrastructure—pedestrians and cyclists | 5 | 5.6 | |
| Process quality (PRO) | Planning quality (PRO1) | PRO1.2 | Integrated planning | 3 | 5.0 | 20 |
| | | PRO1.7 | Participation | 2 | 3.3 | |
| | | PRO1.8 | Project management | 2 | 3.3 | |
| | | PRO1.9 | Governance | 2 | 3.3 | |
| | | PRO1.10 | Safety concepts | - | - | |
| | Construction quality (PRO 2) | PRO2.1 | Construction site/construction process | 1 | 1.8 | |
| | Quality assurance in the use phase (PRO3) | PRO3.5 | Quality assurance and monitoring | 2 | 3.3 | |
| | | | Total | 92 | 100 | 100 |

In the DGNB–UD system, the evaluations are always based on the entire life cycle of a district. The DGNB system uses quantitative performance indices to grade a neighborhood. The overall performance index is calculated from the five topic areas, according to their weights. The total performance index is insufficient to gain the certification. To receive the respective award; the performance index must reach the minimum performance index in the result-relevant topic areas. The maximum percentage that can be achieved by a project is 100%. Assessment through certification is based on three certification categories: silver, gold, and platinum. Platinum is the highest certification level which requires a minimum performance index for each domain of 65% and a total performance index of 80% and above. The DGNB certificate in gold is awarded for a minimum domain-related performance index of 50% and a total performance index of 65% and above. The basic silver DGNB certification requires a minimum domain-related performance index of 35% and a total performance index of 50% [46]. NSAs, which were developed as important part of the sustainable development goals (SDGs) at global scale, cannot be developed independently from neighborhood conditions [28]. The DGNB–UD supports achieving the SDGs [14–16] and demonstrates the system's constructive contribution to achieving SDGs [46].

### 1.3.3. GRIHA−LD

In 2008, The Energy and Resources Institute (TERI) and GRIHA Council, in association with the Ministry of New and Renewable Energy (MNRE), launched the Green Rating for Integrated Habitat Assessment (GRIHA) and Simple Versatile Affordable GRIHA (SVA GRIHA) to address and promote green buildings in India. The GRIHA system was limited to the building rating and assessment. Due to the need to formulate the framework for the assessment of sustainability at a larger scale, in 2013 the GRIHA council, along with TERI, developed the certification system entitled "GRIHA–LD for Large Developments". In this research, the revised version GRIHA–LD 2015 is used [47].

A GRIHA–LD rating can be applied for a project with a site area of 1–50 hectares. Projects of more than 50 hectares need to pay extra assessment charges. The assessment is made to the ongoing development stage of neighborhood development and is evaluated in six different sections: 1. site planning, 2. energy, 3. water and waste water, 4. solid waste management, 5. transport, and 6. social. Figure 1 shows the percentage assigned to each of the subsections.

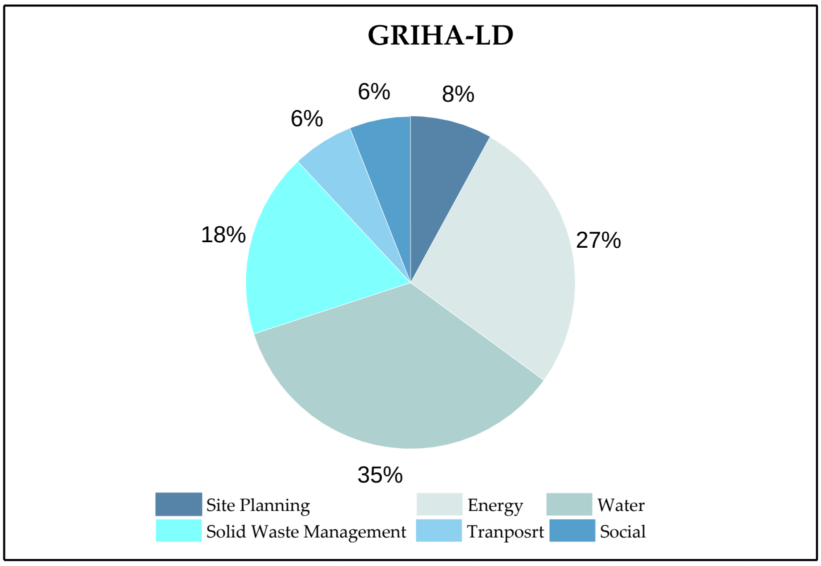


**Figure 1.** Pie chart showing the distribution of credit score percentage to each subsection (site planning, energy, water, solid waste management, transport, social) as per the GRIHA–LD.

The GRIHA–LD is a scoring-based system; a score can be awarded out of a total score of 100. Each section is evaluated using both quantitative and qualitative parameters. Table 3 shows the evaluation subsections of GRIHA–LD. Qualitative parameters for evaluation are designated as "development quality", while quantitative are designated as "self-sufficiency". The social aspect is only evaluated based on qualitative parameters. The rating is based on the overall evaluation of the subsections "development quality" and "self-sufficiency". Each subsection received a maximum score out of 100. The overall weights assigned to the subsection demonstrate the impact of that subsection's sustainability contribution. Figure 1 shows the distribution of credit score percentage to each subsection. The "process" section describes the method used to obtain the masterplan and phased development certified by an external evaluator. The "commitment" section of the GRIHA–LD document discusses the issues and future vision for sustainability of large developments. The "compliance" section contains a list of documents that must be submitted during the certification process. Each subsection has "appraisal-development quality" specifications, which represent the "mandatory" and "optional" indicators. It is necessary to fulfill "mandatory" indicators before the assessment of optional indicators [47]. A weighted score is calculated for each subsection by multiplying the maximum score of 100 by the overall weights. The total score is 100, which is the addition of all subsection scores. The overall rating for the project is awarded based on the overall assessment of all appraisals from all sections. Certification is awarded as a "rating" in the GRIHA–LD. Scores greater than 85 receive a 5-star rating, a 4-star rating is awarded for a score of 71–85, a 3-star rating for a score of 56–70, a 2-star rating for a score of 41−55, and a 1-star rating for a score of 25–40.

**Table 3.** The evaluation subsections of GRIHA–LD for the subsections self-sufficiency appraisals and development quality with the specification of overall weights, maximum subsection score, weighted score, and subsection score [47].

| Subsection | Subsection | Overall Weights (A) | Maximum Subsection Score (B) | Weighted Score (C) = (A) × (B) | Subsection Score (%) |
|---|---|---|---|---|---|
| Self-sufficiency appraisals | Energy | 0.18 | 100 | 18 | - |
| | Water | 0.23 | 100 | 23 | - |
| | Organic solid waste Treatment | 0.12 | 100 | 12 | - |
| Development quality | Site Planning | 0.08 | 100 | 8 | 8 |
| | Energy | 0.09 | 100 | 9 | 27 * |
| | Water | 0.12 | 100 | 12 | 35 * |
| | Solid waste management | 0.6 | 100 | 6 | 18 * |
| | Transport | 0.06 | 100 | 6 | 6 |
| | Social | 0.06 | 100 | 6 | 6 |
| | Total | 1 | 100 | 100 | 100 |

* Addition of percentage score of self-sufficiency and development quality for respective categories.

The GRIHA–LD rating can be awarded to various large-scale development typologies: (i) large (mixed-use) townships: housing complexes by builders, housing complexes by urban development organizations, housing boards and public sector undertaking townships; (ii) smart city neighborhoods; (iii) educational, medical, and institutional campuses; (iv) special economic zones; and (v) hotels and resorts.

## 2. Materials and Methods

Various sustainability assessment methods have been proposed [48–50]. Therefore, a comparative literature analysis of NSA systems was conducted between the most recognized and comprehensive systems from developed and emerging systems from developing countries [43], including the application and comparison of neighborhood sustainability rating systems in areas with diverse local conditions [15,51], and the analysis of NSA systems' success factors [24].

This research on comparative NSA system analysis contributed to defining and understanding differences and similarities in assessing the sustainability and resilience of neighborhoods in different countries. Urban sustainability is an integral part of urban resilience, and resilience-oriented actions need to be integrated into sustainable development [11]. As climate change advances, resilience becomes an even more important topic in the science and policy circles that influence future urban development. Resilience indicators, in particular, will be essential for helping planners and decision-makers to understand the resilience capacities of neighborhoods and develop strategies and action plans for creating more resilient cities. Therefore, urban sustainability and resilience assessment tools were developed with both single and multisectoral approaches and addressing different environmental, social, economic, and institutional aspects of urban sustainability and resilience [52].

NSA systems were reviewed and compared based on the available literature. Further analysis was performed by formulating of a number of matrices to examine the themes and indicators covered in selected NSA systems. Kaur et al. [15] developed three levels of matrices: (i) Twenty-three themes were selected, and indicators associated with all dimensions of sustainability under the twenty-three themes were identified. Afterward, (ii) all indicators and their percentage weights amongst identified themes were redistributed and compared. Finally, (iii) a context-specific matrix of six themes and indicators was developed. Additional studies analyzing and comparing NSA systems were carried out with variations in the type and number of themes and indicators. [32,43,53].

This research investigated the framework of the three NSA systems: LEED–ND, DGNB–UD, and GRIHA–LD, using analysis of the literature and online databases [20–22,37,44–47]. This study demonstrates that the neighborhood sustainability was evaluated based on the measurement of the indicators under various themes, as seen in Tables 1–3. The LEED–ND, DGNB–UD, and GRIHA–LD use "categories", "criteria", and "subsections", respectively, to define the term "themes" used in this research. Indicator-based systems are useful in the process of planning, assessing, and managing urban development [54,55]. The selection of appropriate sustainability themes and indicators for monitoring sustainable urban development is a challenge for policymakers [14]. A theme evaluates the objectives of NSA systems, while the indicator is a variable providing specific measurement [43]. Tables 1–3 illustrate the lack of homogeneity in themes and indicators of the three NSA systems. Hence, the authors identified the most common and essential assessment themes covering all dimensions of sustainability and resilience of neighborhoods based on literature analysis on urban sustainability and resilience and the investigation of the three NSA systems. As the evaluation of NSA is based on the measurement of the indicators, the indicators also need to be normalized. Normalizing measures different units, bringing them into a similar range for comparison [56]. The normalization of indicators was conducted in two parts: (i) The existing indicators of each theme in the original documentations of the systems were rearranged according to the 10 identified themes, and (ii) the original indicator's weights were normalized to be out of 100. The summation of normalized weights of all indicators under the identified theme of one system was compared with the total weight of similar themes of the other systems.

Figure 2 shows a schematic of the overall method of analysis of the NSA system.

*Selection of Themes for Comparative Analysis*

The authors identified themes for comparison from (i) the literature study on the sustainability dimensions; (ii) the literature studies on urban sustainability, urban resilience, and comparison of NSA systems. The literature on sustainability explores the sustainability dimensions (social, environmental, economic, and institutional) using different models. Ali-Toudert et al. reviewed the dimensions of sustainability using the twelve different models and concluded that the conceptualization and categorization of the NSA systems follow the four sustainability dimensions [57,58]. UNEP's integrated guidelines for the sustainable neighborhood 2021 described the synergies of governance, economic, environmental, and social context for a sustainable neighborhood [18]. According to the literature and the LEED–ND, DGNB–UD, and GRIHA–LD NSA systems' analysis, ten themes for comparative NSA system analysis associated with the four dimensions of sustainability were identified and selected within this research. The selection of ten themes for the comparative analysis was identified from the thematic categories of LEED–ND, DGNB–UD, and GRIHA–LD and the comparison studies of NSA Systems. The literature on the comparative analysis of NSA systems was reviewed, and the number and type of themes are summarized in Table 4.

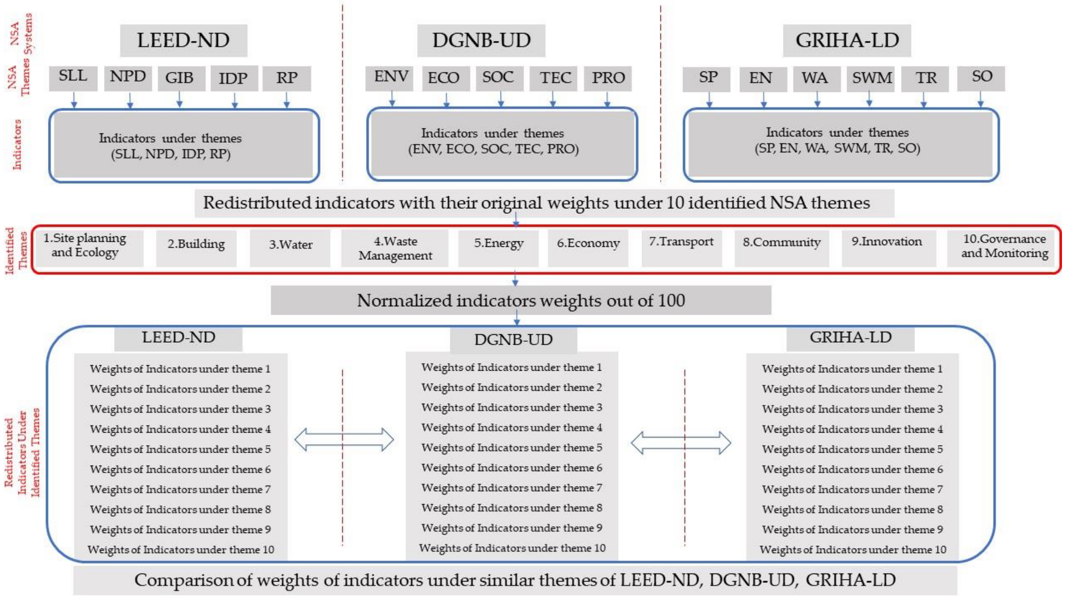


**Figure 2.** Schematic representation of the overall method of comparative analysis of the three NSA systems. SLL—smart location and linkage; NPD—neighborhood pattern and design; GIB—green infrastructure and building; IDP—innovation and design process; RP—regional priority; ENV—environmental quality; ECO—economic quality; SOC—sociocultural and functional quality; TEC—technical quality; PRO—process quality; SP—site planning; EN—energy; WA—water; SWM—solid waste management; TR—transport; SO—social.

As indicated in Table 4, most of the comparative studies were conducted with the environment, social and cultural aspects, economy, transport, site planning, energy, building, and resource management themes of sustainability. In contrast, less preference was assigned to the themes of governance and innovation. However, in this research, the authors included "innovation" and "governance and monitoring" as individual themes. Energy, water, and waste management themes were addressed as one theme, for instance, by Happio and Sharifi et al., as resource or infrastructure themes. In the present research, the authors aimed to assess the sustainability and resilience indicator themes "energy", "water," and "waste management" separately. Furthermore, essential themes for urban development sustainability assessment were included to facilitate the assessment of specific relevant indicators and keep the number of themes as small as possible. Accordingly, "site planning and ecology" were included as one theme, and "buildings", "economy", "transport," and "community", were addressed as separate themes. Accordingly, the following 10 themes for the comparative analysis of the three NAS systems were selected:

1. Site planning and ecology
2. Buildings
3. Water
4. Waste management
5. Energy

6. Economy
7. Transport
8. Community
9. Innovation
10. Governance and monitoring

**Table 4.** Number and specification of themes used in the associated literature on urban sustainability, urban resilience, and comparative analysis of NSA systems.

| Author/Authors Year | Number of Themes | Themes |
|---|---|---|
| Orova, M.; Reith, A. 2019 [59] | 10 | 1. Healthy environment, 2. pollution and risks, 3. water efficiency and waste management, 4. material, 5. energy efficiency, 6. ecology, 7. the sustainable site, 8. management and quality of services, 9. economic aspect, and 10. community |
| Hamedani, A.Z; Huber, F. 2012 [41] | 13 | 1. Social and cultural aspects, 2. innovation, 3. design and planning, 4. process and construction management, 5. infrastructure, 6. business and economy, 7. transportation, 8. ecology and environment, 9. buildings, 10. location of new and existing communities, 11. resource efficient use, 12. water, 13. management energy efficiency |
| Lee, J.; Park, J.; Schuetze, T. 2015 [40] | 10 | 1. Smart green site, 2. smart green transportation, 3. smart green economy, 4. smart green building, 5. smart green infrastructure, 6. smart green community, 7. smart green ecology, 8. smart green program, 9. smart green water, and 10. smart green innovation |
| Kamble, T.; Bahadure, S. 2021 [43] | 8 | 1. Social, 2. site and site planning, 3. energy, 4. water and wastewater, 5. material and resources, 6. environmental, 7. transportation, 8. others (innovation and design, stakeholder's engagement, historic preservation, etc.) |
| Sharifi, A.; Murayama, A. 2013 [53] | 6 | 1. Resource and environment, 2. transportation, 3. social, 4. economic, 5. location site selection, 6. pattern and design |
| Ali-Toudert, F.; Ji, L. 2017 [58] | 9 | 1. Site location/site ecology; 2. land use, urban form-building; 3. infrastructure, transport; 4. urban climate, climate change; 5. resources (energy, water, materials); 6. society, culture; 7. economy; 8. management, quality of services; 9. bonus |
| Deng, W. 2011 [33] | 9 | 1. Environmental quality within site, 2. neighborhood layout and facilities, 3. infrastructure, 4. transport, 5. economy, 6. resources and energy, 7. environmental impact, 8. site ecology, 9. sustainable management |
| Haapio, A. 2012 [32] | 7 | 1. Infrastructure; 2. transportation; 3. location; 4. resources and energy; 5. ecology; 6. business, economy, and employment; 7. wellbeing |
| Yıldız, S.; Yılmaz, M.; Kıvrak, S.; Gültekin, A.B. 2016 [28] | 6 | 1. Environment and land usage, 2. economic development, 3. transportation, 4. social development, 5. design and management, 6. resources and energy |
| Sharifi, A.; Yamagata, Y. 2016 [52] | 5 | 1. Materials and environmental resources, 2. society and wellbeing, 3. economic, 4. built environment and infrastructure, 5. governance and institution |

## 3. Results and Discussion

### *3.1. Theme-Based Comparison of LEED–ND, DGNB–UD, and GRIHA–LD*

#### 3.1.1. Site Planning and Ecology

Sustainable approaches to site planning attempt to minimize the negative development impacts both onsite and offsite. Ecology and site have a complex and inevitable relationship.

During site planning, the primary concern is to conserve the ecosystems [60]. Existing ecological conditions are significantly altered during the site planning process.

Table 5 illustrates that the DGNB–UD and LEED–ND both assign importance to the "site planning and ecology" theme, with around 21%, but the GRIHA–LD only assigns 8%, which is less than the former two NSAs. Nevertheless, the LEED–ND emphasizes this theme by creating a separate category, called "site planning". The LEED–ND has five prerequisite indicators that need to be fulfilled before the assessment, of "wetland and waterbody conservation", "agriculture land conservation", "floodplain avoidance", "imperiled species and ecological communities", and "construction activity pollution prevention". LEED–ND focuses more on "preferred location" and "housing and job proximity" because the site location is regarded as important from connectivity and compact development points of view. DGNB–UD emphasizes the importance of "land use and land use efficiency", "water and soil protection", "energy-efficient development layout", "urban design", and "resource-efficient infrastructure earthwork management" in the site planning theme. Indicators included in "land use" and "urban design" facilitate the assessment of resource security and resource management and resilience against impacts caused, for instance, by extreme weather events such as flooding, droughts, and heat waves [61]. GRIHA–LD focuses mostly on the existing environmental condition of the site, with emphasis on the "existing trees", "site features", and "construction activities on site", etc., because mostly large greenfield urban developments are established by appropriating agriculture land or environmentally sensitive areas. Environmental issues are a prime concern in the GRIHA–LD. Environmental resources play a significant role in enhancing the resilience of communities. Wetlands are necessary for absorbing the impacts of disasters such as floods and improving recovery [48]. LEED–ND, DGNB–UD, and GRIHA–LD systems address environmental sustainability and resilience-related issues by including indicators associated with site planning and the ecology theme.

#### 3.1.2. Buildings

Buildings are an integral component of neighborhoods. A sustainable and resilient neighborhood cannot be realized without sustainable and resilient buildings. Throughout their entire lifecycle, buildings are the main contributors to the global consumption of resources, and the generation of waste and pollution of the environment, associated with their construction, operation, maintenance, and demolition. Accordingly, "buildings" is an important theme for the NSA evaluation process.

Table 6 shows that DGNB–UD has only one indicator, "noise, exhaust, and light emission", which is associated with sustainable and resilient building and surrounding has been assigned a score of 2.6%; but the indicator "life cycle assessment", which is part of the site planning and ecology theme, includes sub-indicator "special construction", which discusses "sustainable buildings" and "sustainable building materials" in the DGNB–UD. The LEED–ND places more emphasis on the sustainable buildings in a neighborhood by assigning a 10% score that includes "certified green buildings" and "minimum building energy performance" as prerequisite sub-indicators. The sub-indicator "certified green building" is also included in the optional scoring. Similarly, "building reuse", "optimizing building energy performance", "historic resource preservation", and "adaptive reuse" are included in the "building" theme of the LEED–ND. In contrast, the GRIHA–LD has no building-specific credits. One of the reasons for assigning less credit to the "building" theme is that LEED, DGNB, and GRIHA developed separate building sustainability assessment systems. The NSAs focus mainly on neighborhood-level indicators.

#### 3.1.3. Water

Accessibility and the protection of safe, clean, and freshwater resources and proper sanitation is crucial for human survival, socioeconomic development, and healthy ecosystems. This plays a significant role in reducing the global burden of disease, and improving the health, welfare, and productivity of populations. Water is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society, and the environment. Strategies for the conservation, recycling, and reuse of water resources at the neighborhood level are vital contributions at the city level, and ultimately at the global scale. Resilient water system construction, operation, and maintenance must be based on iterative, inclusive, and integrated planning, engaging multiple stakeholders [62].

**Table 5.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD, based on the theme "site planning and ecology".

| No. | LEED-ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Wetland and water body Conservation | Pre * | Pre | Land use | 4 | 3.2 | Clearance for construction | Ma * |
| 2 | Agricultural land conservation | Pre | Pre | Lifecycle assessment | 8 | 6.4 | Storm water management | Ma |
| 3 | Floodplain avoidance | Pre | Pre | Urban design | 3 | 2.6 | Tree cover on site | Ma |
| 4 | Imperiled species and ecological communities | Pre | Pre | Urban climate | 5 | 4 | Storm water management | 3 |
| 5 | Construction activity pollution prevention | Pre | Pre | Biodiversity | 4 | 3.2 | Maintain existing site features | 3 |
| 6 | Preferred locations | 10 | 9.1 | Construction site solar orientation/ construction process | 1 | 1.7 | Manage construction activities in management to reduce environmental damage | 2 |
| 7 | Steep slope protection | 1 | 0.91 | - | - | - | - | - |
| 8 | Solar orientation | 1 | 0.91 | - | - | - | - | - |
| 9 | Site design for habitat or wetland and water body conservation | 1 | 0.91 | - | - | - | - | - |
| 10 | Housing and job proximity | 3 | 2.72 | - | - | - | - | - |
| 11 | Brownfield eemediation | 2 | 1.82 | - | - | - | - | - |
| 12 | Long-term conservation management of habitat or wetlands and water bodies | 1 | 0.91 | - | - | - | - | - |
| 13 | Heat island reduction | 1 | 0.91 | - | - | - | - | - |
| 14 | Restoration of habitat or wetlands and water bodies | 1 | 0.91 | - | - | - | - | - |
| 15 | Minimized site disturbance | 1 | 0.91 | - | - | - | - | - |
| 16 | Regional priority credit: Region defined | 1 | 0.91 | - | - | - | - | - |
| | Total | 23 | 20.92 | Total | 25 | 21.1 | Total | 8 |

Pre *: prerequisite indicator; Ma *: mandatory indicator.

Table 7 compares all three rating systems under the "water" theme. In defining the "water" theme, the LEED–ND includes the prerequisite indicators "indoor water use reduction" and "rainwater management", which are associated with closing the water cycle of a neighborhood. Meanwhile, the DGNB–UD includes the "water cycle systems" indicator. The GRIHA–LD includes the "water self-sufficient development" and "capturing and storing rainwater on site for reuse" mandatory indicators. Moreover, the GRIHA–LD places emphasis on maintaining the "natural water cycle", "monitoring water use", and "using efficient fixtures" indicators. During the analysis, the GRIHA–LD received the highest score of 35%, followed by the LEED–ND and DGNB–UD, which received scores of 6.36% and 3.2%, respectively.

**Table 6.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "buildings" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Certified green buildings | Pre | Pre | Noise, exhaust, and light emissions | 3 | 2.6 | - | - |
| 2 | Minimum building energy performance | Pre | Pre | - | - | - | - | - |
| 3 | Certified green buildings | 5 | 4.54 | - | - | - | - | - |
| 4 | Optimize building energy performance | 2 | 1.82 | - | - | - | - | - |
| 5 | Building reuse | 1 | 0.91 | - | - | - | - | - |
| 6 | Historic resource preservation and adaptive reuse | 2 | 1.82 | - | - | - | - | - |
| 7 | Regional priority credit: region defined | 1 | 0.91 | - | - | - | - | - |
| | Total | 11 | 10.00 | Total | 3 | 2.6 | Total | 0 |

**Table 7.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "water" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Indoor water use reduction | Pre | Pre | Water cycle systems | 4 | 3.2 | Water self-sufficient development | Ma |
| 2 | Indoor water use reduction | 1 | 0.91 | - | - | - | Capturing and storing rain water on site for reuse | Ma |
| 3 | Outdoor water use reduction | 2 | 1.82 | - | - | - | Monitoring and audits and operation and maintenance | - |
| 4 | Rainwater management | 4 | 3.63 | - | - | - | Reduction of the total amount of water required from the local municipal grid/ground water by 25 percent | - |
| 5 | - | - | - | - | - | - | Rainwater falling on site (besides that is being stored for use) is recharged using appropriate filtration measures | - |
| 6 | - | - | - | - | - | - | All low flow fixtures | - |
| 7 | - | - | - | - | - | - | Remote monitoring, operation and maintenance | - |
| | Total | 7 | 6.36 | Total | 4 | 3.2 | Total | 35 |

3.1.4. Waste Management

Increase in population and living standards accelerate the waste generation in a developing country [63]. Waste reduction, separation, and recycling are the most preferred practices in sustainable waste management. Sustainable waste management solutions help to reduce pollution and energy consumption, and conserve natural resources. Local waste management solutions reduce the burden of waste transportation costs and the infill area. Therefore, the waste management theme is essential for assessing neighborhood sustainability.

Table 8 shows that the waste management theme is covered in the DGNB–UD under the "resource management" indicator, including the "use of recyclable materials" and "waste management facilities", but is only assigned a 2.2% score. Meanwhile, in the LEED–ND, the "waste management" theme accounts for about 3.64% of the total score, and includes "wastewater management", and "recycled and reused infrastructure", as well as "solid waste management". In the GRIHA–LD, "waste management" is represented by the highest score 18%, which shows the waste management theme has more impact on the overall score of the GRIHA–LD. The GRIHA–LD has an indicator specifying that "centralized or decentralized STP on site" and "recycling of STP water" are mandatory indicators.

**Table 8.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD in the "waste management" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Wastewater management | 2 | 1.82 | Resource management | 2 | 2.2 | Centralized or decentralized STP on site. | Ma |
| 2 | Recycled and reused infrastructure | 1 | 0.91 | - | - | - | Recycling STP water for reuse on site. | Ma |
| 3 | Solid waste management | 1 | 0.91 | - | - | - | STP/wastewater treatment facility should meet the CPCB norms. | - |
| | Total | 4 | 3.64 | Total | 2 | 2.2 | Total | 18 |

#### 3.1.5. Energy

Energy conservation and generation are important indicators that play a main role in establishing the sustainability and resilience of a neighborhood. Energy consumption and energy prices have a direct relationship with the economic growth of an area. Developing countries are facing high growth rates along with high urbanization. This results in high energy demands, making energy a prime objective for nations [64]. The expanding urban infrastructure has contributed to high energy needs, and existing energy systems are insufficient, which has turned the goal of sustainable energy cycle development into a necessity [28]. A sustainable and resilient urban energy system needs to develop effective strategies to ensure the availability, accessibility, affordability, and acceptability of energy over time and under uncertain conditions [65].

Table 9 demonstrates that the DGNB–UD emphasizes the energy efficiency of the neighborhood with an integral energy concept, such as the establishment of coherent supply structures, synergies between generation and use, energy management, and passive system design. Out of 100, the energy theme in the DGNB–UD received a 4.4% score, while the LEED–ND was allotted a 6.37% score, with the emphasis on "minimum building energy performance" as mandatory points, with evaluation, "renewable energy production", "district heating and cooling", "infrastructure energy efficiency", and "light pollution reduction", also counting in the credit designation for energy. While the GRIHA–LD assigned 27% of its score to the energy theme, it mostly focused on energy savings by specifying that the outdoor lighting should meet particular lux levels and use automatic switching and dimming controls. Similarly, energy can be generated using smart minigrids, heat island reduction, and other passive design strategies that should be used at the neighborhood scale to limit energy consumption.

**Table 9.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD in the "energy" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Minimum building energy performance | Pre | Pre | Energy infrastructure | 4 | 4.4 | Outdoor road lighting meets the required lux levels | Ma |
| 2 | Renewable energy production | 3 | 2.73 | - | - | - | Automatic switching/ dimming controls | Ma |
| 3 | District heating and cooling | 2 | 1.82 | - | - | - | Smart mini-grids | - |
| 4 | Infrastructure energy efficiency | 1 | 0.91 | - | - | - | Passive urban design strategies, heat island calculation | - |
| 5 | Light pollution reduction | 1 | 0.91 | - | - | - | Operation and maintenance | - |
| | Total | 7 | 6.37 | Total | 4 | 4.4 | Total | 27 |

### 3.1.6. Economy

Since the inception of the sustainability concept, the economy has been a key pillar of sustainability [57]. Job opportunities and sources of income for neighborhoods can contribute to the overall economic growth of a country. The key to long-term economic success lies in focusing on the microcosm of neighborhoods and subregions and addressing their needs and assets. By generating accurate information about neighborhood-based resources and capabilities, and about current and future demand, specific development initiatives can be launched that meet identified needs, create employment, improve residents' quality of life, and advance long-term sustainability. As a result, when assessing neighborhood sustainability, the economy theme must be considered. The economic resilience of a community depends on the capacity and skillfulness of its working population to support the dependent population. The availability of jobs within proximity can also be associated with resilience [66].

Table 10 compares the DGNB–UD, LEED–ND, and GRIHA–LD with one another to illustrate the economic aspects covered within all three systems. Differentiation shows that the DGNB–UD rating system prioritizes "economy" as its main assessment theme, allocating 20.5% of the district's overall score to it. The DGNB–UD emphasizes "lifecycle cost" as a major indicator under the "economy" theme to address the present challenges of climate change, while the "resilience and adaptability" indicator receives major focus in the economy theme of the DGNB–UD. The following sub-indicators define the "resilience and adaptability" indicator in DGNB–UD: "security of supply of drinking water", "security of supply of wastewater", "flexibility and expansion reserves of the technical district infrastructure and buildings, "redundancy and resilience of transportation system". Similarly, "land use efficiency" has received special attention. "Value stability" and "environmental risks" also receive priority during the sustainability and resilience of neighborhood assessments. Environmental risk indicators include sub-indicators associated with natural calamities. Hazard levels of earthquakes, volcanic eruptions, avalanches, storms, heavy rain, hail, landslides or soil subsidence, storm surge/tsunami, temperature extremes, forest fire, radon, and provision for compensation due to these calamities are also included.

The DGNB–UD prioritizes the district economy 20 times more than the other two systems. In comparison, the LEED–ND assigns a score of 1.82% to the economic aspect of neighborhood sustainability, while GRIHA–LD assigns only 1%. The lowest score assigned to the economy theme in both systems demonstrates that the economic sustainability needs at the neighborhood scale are not well considered. "Local food production" is the only indicator included in the economy theme of GRIHA–LD.

**Table 10.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "economy" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Local food production | 1 | 0.91 | Lifecycle cost | 4 | 5.7 | Food production onsite | (Score included in site planning) |
| 2 | Regional priority credit: region defined | 1 | 0.91 | Resilience and adaptability | 3 | 4.3 | - | |
| 3 | - | - | - | Land use efficiency | 3 | 4.3 | - | |
| | - | - | - | Value stability | 2 | 2.9 | - | |
| | - | - | - | Environmental risks | 2 | 2.9 | - | |
| | Total | 2 | 1.82 | Total | 14 | 20.1 | Total | 1 |

3.1.7. Innovation

Innovation is seen as a core element of all sustainability strategies [54,67]. Innovation improves adaptability, flexibility, and a tool's capability for incremental improvement [53]. The neighborhood sustainability assessment system is also one of the innovative approaches to formulating strategies for sustainable and resilient neighborhood development. Improvement of sustainability and resilience assessment systems has led to better consideration of locally specific issues, improved transparency, and further attention to promoting innovation [23]. In the near future, innovative approaches will be required to deal with upcoming stainability and resiliency challenges. The use of ICT was a significant innovation for neighborhoods.

Table 11 compares the LEED–ND, DGNB–UD, and GRIHA–LD with one another to illustrate the "innovation" theme impact within all three systems. The DGNB–UD and LEED–ND both include an innovation theme. Meanwhile, the GRIHA–LD has limitations on including the innovation theme in neighborhood sustainability assessments, because it was developed in 2015; at that time, advanced technology and an innovative approach were not implemented, and the mechanisms to apply technological aspects were at a primitive stage. In the DGNB–UD, around 2.2% of the score is assigned to "smart infrastructure", because it makes neighborhoods sustainable and resilient. A 5.46% score in the LEED–ND indicates that the "innovation" theme is important, as the LEED–ND includes "innovation" as a separate theme during evaluation. The LEED–ND system is also an innovation for sustainable and resilient neighborhoods, so we have included a "LEED-accredited professional" indicator in the innovation theme.

**Table 11.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "innovation" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score / 100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Innovation | 5 | 4.55 | Smart infrastructure | 2 | 2.2 | - | - |
| 2 | LEED®-accredited professional | 1 | 0.91 | - | - | - | - | - |
| | Total | 6 | 5.46 | Total | 2 | 2.2 | Total | 0 |

3.1.8. Transport

Transport is central to sustainable and resilient development, and provides universal access, enhanced safety, reduced environmental and climate impact, improved resilience, and enhanced efficiency [68]. Transportation and information sharing are fundamental for enhancing resilience. Transport offers accessibility to vital resources for daily activities, accessibility in emergencies, rescue operations, reconstruction, and recovery [69].

Apart from providing services and infrastructure for the mobility of people and goods, sustainable transport is a cross-cutting accelerator that can fast-track progress toward other crucial goals, such as eradicating poverty in all its dimensions, enabling access to jobs, reducing inequality, empowering women, minimizing carbon and other emissions, and combating climate change [68]. The spatial distributions of different land uses connect together with physical infrastructures and associated transport networks [70].

Table 12 illustrates that the overall score assigned to the "transport" theme in the LEED–ND is higher than in the DGNB–UD and GRIHA–LD. LEED–ND assigns approximately 27% to the "transport" theme, while the DGNB–UD gives 11% and GRIHA–LD only 6%. The comparison shows that the LEED–ND assigned more than twice the percentage compared to the DGNB–UD. The importance of the transport theme in LEED–ND emphasizes the need for compact neighborhood developments in US American cities, which are mostly car-dependent, have poor public transport connectivity, and are facing the issue of urban sprawl.

**Table 12.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "transport" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Walkable streets | Pre | Pre | Mobility infrastructure—motorized transportation | 5 | 5.6 | Provision of footpaths and bicycling tracks and safe interaction of NMT traffic with motorized traffic | Ma |
| 2 | Compact development | Pre | Pre | Mobility infrastructure—pedestrian and cyclists | 5 | 5.6 | Supporting infrastructure: bicycle parking, landscaping, public conveniences, etc. | - |
| 3 | Connected and open community | Pre | Pre | - | - | - | Safety measures: railing, non-slippery surfaces | - |
| 4 | Walkable streets | 9 | 8.18 | - | - | - | Parking for two-wheelers | - |
| 5 | Compact development | 6 | 5.45 | - | - | - | Road network planning | - |
| 6 | Reduced parking footprint | 1 | 0.91 | - | - | - | - | - |
| 7 | Transit facilities | 1 | 0.91 | - | - | - | - | - |
| 8 | Transportation demand management | 2 | 1.81 | - | - | - | - | - |
| 9 | Bicycle facilities | 2 | 1.81 | - | - | - | - | - |
| 10 | Access to quality transit | 7 | 6.36 | - | - | - | - | - |
| 11 | Tree-lined and shaded streetscapes | 2 | 1.81 | - | - | - | - | - |
| | Total | 30 | 27.24 | Total | 10 | 11.2 | Total | 6 |

### 3.1.9. Community

Creating an inclusive community is another crucial factor in a sustainable neighborhood development. The community can be formed though social ties and interaction, communal involvement, community cohesion, security and safety, etc. [71]. The objective is to create a vibrant social community with active public participation [72]. The social dimension has a strong influence on the achievement of community self-sufficiency and resilience. Indicators associated with safety and wellbeing improve the stability of communities. Safe and healthy communities are more capable of withstanding and responding to shocks [73].

The DGNB–UD, LEED–ND and GRIHA–LD assign scores of 18.1% and 17.28%, and 6% to the "community" theme, respectively. Table 13 illustrates that the DGNB–UD and LEED–ND both assign importance to the "community" theme. Nevertheless, the DGNB–UD emphasizes this theme by including "thermal comfort in open spaces", "open spaces", "barrier-free design", "social and functional mix", and "social and commercial infrastructure" participation indicators. The LEED–ND assigns more importance to indicators to develop the mixed-use neighborhood with various housing typologies to develop a versatile and inclusive community that can be livable for all age groups, genders, and income groups. The LEED–ND also includes indicators such as "neighborhood schools", "historic resource preservation and adaptive reuse", "access to civic and public space", "access to recreational facilities", "visitability and universal design", and "community outreach and involvement". The GRIHA–LD contributes to improving inclusion and the conditions of vulnerable and marginalized communities by including the indicators "facilities for construction workers", "social infrastructure in development", and "planning for low-income group populations".

**Table 13.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "community" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Mixed-use neighborhoods | 4 | 3.64 | Thermal Comfort in open spaces | 3 | 2.6 | Facilities for construction workers | Ma |
| 2 | Housing types and affordability | 7 | 6.36 | Open space | 4 | 3.5 | Social infrastructure in development | - |
| 3 | Neighborhood schools | 1 | 0.91 | Barrier-free design | 3 | 2.6 | Planning for low-income group population | - |
| 4 | Historic resource preservation and adaptive reuse | 2 | 1.82 | Social and functional mix | 4 | 3.5 | - | - |
| 5 | Access to civic and public space | 1 | 0.91 | Social and commercial infrastructure | 3 | 2.6 | - | - |
| 6 | Access to recreation facilities | 1 | 0.91 | Participation | 2 | 3.3 | - | - |
| 7 | Visitability and universal design | 1 | 0.91 | - | - | - | - | - |
| 8 | Community outreach and involvement | 2 | 1.82 | - | - | - | - | - |
| | Total | 19 | 17.28 | Total | 19 | 18.1 | Total | 6 |

### 3.1.10. Governance and Monitoring

Governance is one of the domains in the definition of sustainability [9]. Monitoring is necessary to ensure the proper implementation of the project, and to evaluate its impact in achieving sustainability. The governance theme is included in the assessment process, as it plays a significant role in decision making, and policy formulation, implementation, and monitoring. The literature on NSAs illustrated that there were limitations in assessing the performance of governmental and nongovernmental neighborhood institutions in many NSA systems. Accordingly, assessment indicators associated with governance, decentralization, legal framework and instrumentation, information systems, research, and education need to be revised and improved [53].

Effective governance can create progressive change in urban development. Local governance at the neighborhood level involves public participation, understanding, and the conveying of grassroot-level issues. To create effective policies and actions to steer cities toward sustainability, cooperation between various governance levels is necessary. Government and institutional regulations communicate about the various activities and mechanisms, formulated a contingency and mitigation plan, and make sure to implement it in case of any emergency situations. Strong governing capacity and leadership enhance resilience by strengthening linkages between various elements of the systems and empowering social bonding [74].

Table 14 shows that the DGNB–UD assigns importance and a total score of 14.9% to the "governance and monitoring" theme by including specifically a "governance" indicator along with "integrated design", "project management", and "quality assurance and monitoring". The "project management" indicator in DGNB–UD includes the "risk management" sub-indicator associated with resilient construction management practices. The LEED–ND and GRIHA–LD do not assign scores to the governance and monitoring theme. However, In the comparative assessment of the three NSA systems, a score for the "regional priority" credit was assigned to LEED–ND because regional governance plays a crucial role in urban development. The GRIHA–LD does not assign a score to this theme, showing its limitations in addressing the governance and monitoring theme.

**Table 14.** Comparative analysis of the LEED–ND, DGNB–UD, and GRIHA–LD based on the "governance and monitoring" theme.

| No. | LEED–ND | Weighted Score/110 | Score /100 | DGNB–UD | Weighted Score/92 | Score /100 | GRIHA–LD | Score /100 |
|---|---|---|---|---|---|---|---|---|
| 1 | Regional priority credit: region defined | 1 | 0.91 | Integrated design | 3 | 5 | - | - |
| 2 | - | - | - | Governance | 2 | 3.3 | - | - |
| 3 | - | - | - | Project management | 2 | 3.3 | - | - |
| 4 | - | - | - | Quality assurance and monitoring | 2 | 3.3 | - | - |
| | Total | 0 | 0.91 | Total | 9 | 14.9 | Total | 0 |

The three NSA systems overall comparison was carried out by comparing the summation of the total weight of all indicators obtained for each theme of the three NSA systems. Table 15 lists the specific percentage scores for each sustainability domain and associated theme for the three NSAs. The resulting scores assigned to each theme by the three NSAs are illustrated in a bar chart in Figure 3.

**Table 15.** Comparison of the percentage score assigned to all 10 themes in terms of the LEED–ND, DGNB–UD, and GRIHA–LD.

| No. | Sustainability Domain | Themes | LEED–ND | DGNB–UD | GRIHA–LD |
|---|---|---|---|---|---|
| 1 | Environmental | Site planning and ecology | 20.92 | 21.1 | 8 |
| 2 | Social | Building | 10.00 | 2.6 | 0 |
| 3 | Environmental | Water | 6.36 | 3.2 | 35 |
| 4 | Environmental | Waste management | 3.64 | 2.2 | 18 |
| 5 | Environmental | Energy | 6.37 | 4.4 | 27 |
| 6 | Economic | Economy | 1.82 | 20.1 | 0 |
| 7 | Institutional | Innovation | 5.46 | 2.2 | 0 |
| 8 | Environmental | Transport | 27.24 | 11.2 | 6 |
| 9 | Social | Community | 17.28 | 18.1 | 6 |
| 10 | Institutional | Governance and monitoring | 0.91 | 14.9 | 0 |
| | | Total | 100 | 100 | 100 |

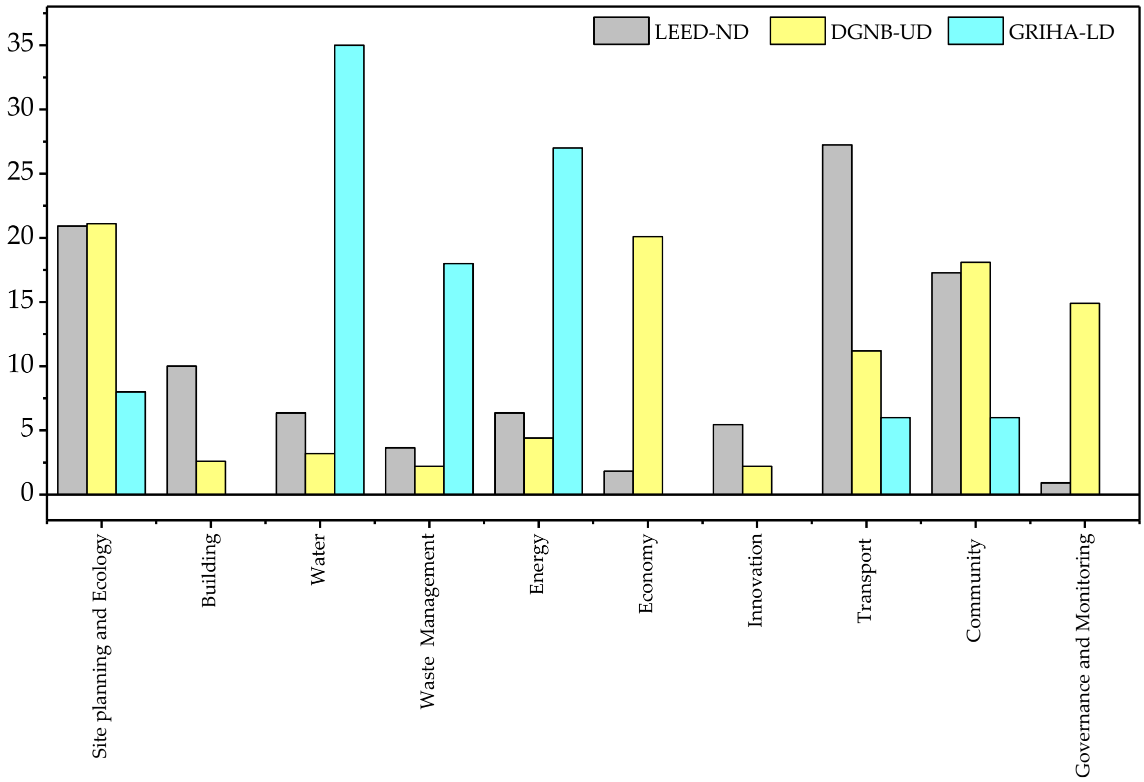


**Figure 3.** Bar chart showing the comparative analysis of the three LEED–ND, DGNB–UD, and GRIHA–LD NSA systems with the percentage score assigned to all 10 sustainability themes.

### *3.2. General Comparison of the LEED–ND, DGNB–UD, and GRIHA–LD*

The indicators under each theme needed to be analyzed while comparing the systems. A detailed study of the systems demonstrated that the LEED–ND and GRIHA–LD only have indicators with their respective assigned weights. However, the DGNB–UD has a structural framework, including indicators and sub-indicators. In the DGNB–UD, the overall weightage of indicators is determined by the assessment of sub-indicators having their separate score. Indicators "life cycle assessment", "life cycle cost", "land use", "value stability", "environmental risk", "urban climate", "participation", "neighborhood safety", "quality assurance and monitoring", and "smart infrastructure" are included in the DGNB–UD, but the LEED–ND and GRIHA–LD are limited in addressing all these indicators. The LEED–ND and GRIHA–LD include the "urban heat island" indicator, which is not included in the DGNB–UD system. The indicators and their assigned weights vary from system to system and are, accordingly, difficult to compare. Furthermore, it is required to investigate the NSA systems' indicators and their interrelation and potential synergies referring to resilience, health, climate change mitigation, and climate adaptation [23]. Critical analysis and comparison based on the indicators and sub-indicators involved in systems are also crucial to analyzing the efficiency of the NSA system, considering present and future urban sustainability and resilience challenges.

## 4. Conclusions

Achieving neighborhood sustainability is indispensable for the development of sustainable and resilient cities. NSA systems were developed to assess the sustainability and resilience of the neighborhood both qualitatively and quantitatively by measuring specific indicators. The three NSA systems, LEED–ND (USA), DGNB–UD (Germany), and GRIHA–LD (India), were analyzed and compared. Even though the general goal of achieving neighborhood sustainability and resilience is the same in the three NSAs, the assessment and certification of neighborhood sustainability and resilience varies between the three systems. The comparison between LEED–ND, DGNB–UD, and GRIHA–LD shows that the scoring assigned to indicators was based on the importance of distinct indicators. The decisions about the significance of the indicators were subjective and varied from system to system. The overall weight of the specific theme was based on the number of indicators and the individual weights of indicators assigned under the theme. "Site planning and ecology" had more indicators, so the score received for the site planning and ecology theme was comparatively higher than other themes. The overall weight assigned to the "innovation" theme was relatively minor, as "innovation" has few indicators in LEED–ND and DGNB–UD. The prerequisite indicators from LEED–ND and mandatory indicators from GRIHA–LD were difficult to evaluate or compare during comparative analysis. If sustainability and resilience dimensions were not addressed comprehensively and balanced, a certified neighborhood might acquire the certification without adequately addressing all dimensions of sustainability and resilience. Themes not addressed in the comparative analysis indicated that improvements in the missing thematic areas were required in the respective assessment system. The interrelationship and interdependencies between various themes and indicators are complex to interpret. Along with the themes and indicators, sub-indicators were also essential to evaluate the qualitative aspects of indicators and themes.

The LEED–ND prioritizes "transportation" (27.24%), "site planning and ecology" (20.92%), "community" (17.28%), and "building" (10%) themes. Meanwhile, the DGNB–UD prioritizes "site planning and ecology" (21.1%), "economy" (20.1%), and "community" (18.1%) themes. Additionally, "transport" (11.2%) and "governance and monitoring" (14.9%) receive considerable scores in the DGNB–UD. The themes "water" (35%), "energy" (27%), and "waste management" (18%), receive the highest scores from the GRIHA–LD, while "site planning and ecology" (8%), "community" (6%), and "transportation" (6%) have less significance in defining a neighborhood's sustainability. Moreover, the GRIHA–LD has limitations in considering indicators related to the "building", "economy", "innovation", and "governance" themes.

The DGNB–UD is the only NSA system that was designed by analyzing the multidimensional aspects of sustainable neighborhood development based on the 10 identified themes. Core issues, such as climate action, climate adaptation, and resilience to climate change, are addressed by the DGNB–UD through the inclusion of bonus points, indicators, and sub-indicators associated with core issues, while the LEED–ND has limited indicators associated with resilience, and GRIHA–LD has limitations in addressing resilience-associated issues. LEED–ND and GRIHA–LD do not have any provisions for bonus points. In comparing the systems, the content and qualitative aspects of the indicators and sub-indicators are also crucial to understanding the efficiency of the NSA systems.

NSA systems require statistical indicator-related data as input for sustainability evaluation. Hence, international standard protocols need to be provided for data collection, measurement units, and data output, increasing the reliability of data input, update, and result interpretation and comparison. NSA systems are formulated with a top-down approach. Successful application of NSAs in various contexts requires a bottom-up approach with the participation of local stakeholders. NSAs require the involvement of third parties and investment in human and financial resources. Hence, the application is unpopular among building owners and investors, unaware of the benefits and profits achievable by NSA application and certification during the planning phases. In particular, governing authorities in developing countries are not encouraging the application of NSAs. Incentive schemes need to be introduced in the assessment mechanism to encourage the application of NSAs. Integration of NSAs into planning systems is crucial for applying NSA systems with inclusive governance mechanisms to ensure appropriate indicators and methods for funding neighborhood development.

The future development of the three NSA could address the differences and limitations identified within this research by redefining and extending the sustainability and resilience assessment themes and indicators. Accordingly, a new international context-based system could be developed by taking into account the limitations of the existing assessment systems to evaluate and compare urban neighborhood sustainability and resilience, particularly in and between developing countries.

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