# An Ecological Approach towards Building Knowledge Cities

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**Abstract**

**Purpose –** A knowledge-based urban development needs to be sustainable and, therefore, requires ecological planning strategies to ensure a better quality of its services. The purpose of this paper is to present an innovative approach for monitoring the sustainability of urban services and help the policy-making authorities to revise the current planning and development practices for more effective solutions. The paper introduces a new assessment tool–Micro-level Urban-ecosystem Sustainability IndeX (MUSIX) – that provides a quantitative measure of urban sustainability in a local context.

**Design/methodology/approach –** A multi-method research approach was employed in the construction of the MUSIX. A qualitative research was conducted through an interpretive and critical literature review in developing a theoretical framework and indicator selection. A quantitative research was conducted through statistical and spatial analyses in data collection, processing and model application.

**Findings/results –** MUSIX was tested in a pilot study site and provided information referring to the main environmental impacts arising from rapid urban development and population growth. Related to that, some key ecological planning strategies were recommended to guide the preparation and assessment of development and local area plans.

**Research limitations/implications –** This study provided fundamental information that assists developers, planners and policy-makers to investigate the multidimensional nature of sustainability at the local level by capturing the environmental pressures and their driving forces in highly developed urban areas.

**Originality/value –** This study measures the sustainability of urban development plans through providing data analysis and interpretation of results in a new spatial data unit.

**Keywords**

Ecological planning, Indicator-based sustainability assessment, Knowledge-Based Urban Development, Knowledge City.

## 1. Introduction

During the last several decades, the quality of natural resources and their services have been exposed to significant degradation from increased urban populations combined with the sprawl of

settlements, development of transportation networks and explosive advancement of information and communication technology [1;2]. As a result of this environmental degradation, in recent years, the concept of knowledge city has emerged as an effective action towards sustainable urban development. Knowledge city is a response to the changing global environment by generating, distributing and using knowledge in many ways to balance economic prosperity, human development, and socio-environmental sustainability [3].

While improving knowledge of the city, the capacity of natural resources to respond and adapt these activities constitutes an important factor to be considered. One of the important strategic approaches for developing sustainable knowledge cities is 'ecological planning'. Ecological planning is a multi-dimensional concept that aims to preserve biodiversity richness and ecosystem productivity through sustainable management of natural resources [4]. As stated by Baldwin [5], ecological planning is the initiation and operation of activities to direct and control the acquisition, transformation, disruption and disposal of resources in a manner capable of sustaining human activities with a minimum disruption of ecosystem processes.

Urban sustainability assessment plays an important role in amalgamating ecological planning into the urban development process. Over the past several years, there has been a significant increase in the development of sustainability assessment tools in order to provide guidance for the evaluation of the environmental impacts of existing and new urban developments. As stated by Karol and Brunner [6], even though they use different assessment themes and sub-themes, they outline the common sustainability principles, such as conservation of native vegetation, reduction of non-renewable energy use, waste reduction, water efficiency, high quality public transport and social safety. Therefore, they need to be integrated into the policy and decision-making to build sustainable urban environments.

A knowledge city needs to be sustainable and, therefore, requires innovative sustainability assessment tools to monitor the human impact on natural environment and help the decision-making authorities and actors to control it. As an innovative approach to this area, this paper introduces a new sustainability assessment tool entitled 'Micro-level Urban-ecosystem Sustainability IndeX' (MUSIX). MUSIX provides fundamental information and guidance that assists developers, planners and policy-makers to investigate the multidimensional nature of sustainability at the local level by capturing the environmental pressures and their driving forces in highly developed urban areas. Moreover, the outcomes of the model help in finding solutions for the environmental impacts in the urban area through proposing efficient policy recommendations.

The paper is organised into five major sections. Following this introduction, Section 2 provides a summary of the literature reviewed focusing on the concept of knowledge city and the role of ecological planning on knowledge based urban development. Section 3 presents the methodology of the MUSIX and outlines the preliminary findings of the pilot testing of the model in the Gold Coast City study. Section 4 consists of recommendations about the integration of the model outputs into sustainability policies. Lastly, the paper ends with some concluding remarks in Section 5.

## 2. Knowledge City and Ecological Planning

In the current literature, there are many definitions of knowledge city. According to Carrillo [7], knowledge city is a settlement which its citizens undertake a systematic approach to identify and develop its capital system in a balanced, sustainable manner. Tresman *et al.* [8] describes knowledge city as a dynamic and complex living organism exists within an environment composed of a network of integrated systems, processes and structures which are adaptable to internal and external changes. The Work Foundation [9] defines knowledge city as an "Ideopolis" which blends knowledge

with culture to form a rich and dynamic blend of theory and practice within its boundaries through a collective knowledge production. Amidon and Davis [10] call knowledge cities as "Knowledge Innovation Zones" which refers to geographic regions, economic sectors or communities of practice where knowledge flows from origin to the point of highest need or opportunity.

According to Yigitcanlar [11], knowledge city is shaped by four development areas: economy, society, management and environment. Firstly, it develops a strong local economy through providing technical knowledge for the innovation of products and services which can also be integrated with global economy. Secondly, it increases the skills and knowledge of residents and employees through developing effective education and skill building strategies to provide a good quality of life. Thirdly, it provides a transparent and democratic institutional management through developing long-term strategic planning and resources to give effect to policy decisions. Lastly, it provides an urban development that is ecologically sensitive and sustainable. Because change is an inevitable result of urban development, the capacity of natural resources to respond and adapt these changes is an important factor to take into consideration in developing knowledge cities.

As cities become increasingly knowledge-based, natural environment of the city changes due to economic activities required different conditions [12]. Advanced economies of the cities increase the level of consumption and waste generated by human-made environment (*e.g.* factories, buildings, roads and other physical artefacts). The degradation of natural environment and its services are irreversible and no type of human-made capital can substitute for them. There is a need to balance this increasing human demand on the natural systems [13;14]. Environmental responsibility is required for the protection and renewal of these resources; therefore, knowledge-based approach to the city needs to be sustainable. In this context, ecological planning plays an important role in adjusting urban environment and economic development in a sustainable manner.

As stated by Steiner [15], planning is a process that uses scientific and technical information to build consensus among a group of choices. Ecology is the study of interaction between living organisms and their environments. Ecological planning then is defined as the use of biophysical and socio-cultural information derived from this interaction as decision- making opportunities and constraints in the management of ecological systems. Ecological planning is a broad concept based on strategies and methods to create green, safe, vibrant and healthy urban environments [16]. It is an important planning tool in the establishment of sustainable knowledge cities. According to Shu-Yang *et al.* [17], the key characteristics of ecological planning can be summarised as below:

- City and its economic development have harmful impacts on natural systems. Ecological planning is an essential tool for enhancing the sustainability of human enterprise through finding environmentally friendly ways of manufacturing goods, constructing buildings and planning recycling-orientated enterprises to reduce ecological damage as much as possible.
- The sustainability of economic development is based on the wise use of renewable resources. Ecological planning promotes the urban form that requires minimum energy and resource input as well as minimises waste generation and ecological damage through efficient use, re-use and recycling.
- Maintenance of the integrity of ecosystems must be considered a key element of economic sustainability. Ecological planning integrates human activities with the dynamics of natural flows and cycles of materials and energy by developing solutions to particular planning issues. This can be achieved through defining the carrying capacity of ecosystems for the proposed human activities.
- Another goal of ecological planning is to emulate natural ecosystems when planning for anthropogenic activities, so that the resulting effects will be relatively 'natural'. For instance,

this can be achieved through developing a symbiotic industrial system that refers to an integrated process in which the waste of one process becomes a resource for another.

In brief, ecological planning is a fundamental approach to the sparing and efficient use of natural resources while adopting human activities in a less harmful way to the environment [18]. For a sustainable knowledge city, it is necessary to analyse the interactions between urban systems and the environment. Sustainability assessment tools ranging from indicators to comprehensive models provide an analysis of the current state of ecological urban systems by identifying the causes of the problem across a wide range of spatial scales. Moreover, they serve as a tool that helps policy-makers in improving their actions for creating more liveable and sustainable cities [19]. As an innovative approach to this area, the next section presents a new sustainability assessment tool entitled 'Micro-level Urban-ecosystem Sustainability IndeX' (MUSIX). MUSIX is an indicator-based sustainability-indexing model that investigates the human environment interactions in a local context and assesses the impacts of current development plans on natural environment. The next section introduces the methodology adopted for the MUSIX and presents the application and interpretation of the model in a pilot study.

## 3. An Ecological Approach: The MUSIX Model

MUSIX is constructed by following steps based on the Composite Indicators Methodology and User Guide developed by OECD [20]:

*Developing a theoretical framework:* This step identifies the main objectives of the model that underpin the methodological approach to be applied. Accordingly, it clarifies the relevant indicators and data sets that are related to the desirable outcomes followed by the development of policies. The theoretical framework of the MUSIX is based on environmentally sustainable city which is referred to a city that has an effective use of its resources while reducing ecological impacts and sustaining their ecological functioning, meanwhile providing higher living standards and a healthier urban environment for its citizens.

*Selecting indicators and data collection:* Environmental indicators represent the physical, chemical, biological or socio-economic measurements of a complex ecosystem or environmental issue [21]. They are able to reflect the changes over a period of time depending on the problem by providing information about its severity and draw attention to the effectiveness of current policies [22]. In order to measure environmental sustainability performance, a reliable set of indicators is required. A set of relevant indicators was developed through a comprehensive review of existing indicator initiatives [23;24;25;26;27;28;29]. For this study, data collection was a major problem due to the unavailability of data at the parcel scale. Therefore, indicators were also selected through consideration of the local context and data availability for the pilot test-bed city (see Appendix 1).

*Multivariate analysis:* As stated by Nardo *et al.* [30], if the indicators are chosen arbitrarily without investigating the interrelationships between them, the index result can lead to overwhelming, confusing and misleading decisions by policy-makers. This situation can be characterised as 'indicator rich but information poor'. Therefore, the underlying structure of the data needs to be examined before the construction of composite index. For the next step, a statistical analysis was employed. This step designates whether the theoretical framework of the index is well defined and the selected indicators are appropriate to describe the measured phenomenon [31]. As a result of the non-normal distribution of data set, the Spearman's rank correlation analysis was conducted to examine the relationship between the indicators.

*Spatial analysis:* As stated by Oluseyi *et al.* [32], in recent years, remote sensing and geographic information systems have become effective tools in the transformation of multi-spectral, multi-resolution and multi-temporal data into valuable information for monitoring environmental processes and impacts. Remote sensing provides information concerning the changes on the Earth's surface over a wide range of spatial (local to global) and temporal (years to decades) scales [33]. With an effectively integrated geographic information system, remotely sensed data offers resource managers and decision-makers storage and manipulation of information in spatial and non-spatial domains as well as assists in the measuring, mapping and modelling activities [34]. Spatial analysis of the study area was carried out through aerial remote sensing data with the use of ArcGIS software. From visual and digital interpretations of the aerial photo imagery derived from Google Maps, the total area of each land cover type within parcels were measured by using the ArcGIS Analysis tool.

*Normalisation:* A benchmarking normalisation method was employed to remove the scale effects of these different units by standardising the original indicator units to normalised units [31;35]. By reviewing various studies in the literature, benchmark values for each indicator were assigned according to their minimum and maximum impacts on environmental sustainability. A scale of 1 (extremely unsustainable situation) to 5 (target level of sustainability) was used where the values were indicating different levels of sustainability.

*Weighting:* In composite indices, indicator weighting reflects the importance given to the variables forming the index. For this study, expert opinion weighting was selected due to the spatial scale and scope of the research. First of all, MUSIX is developed to measure the local-level environmental performance of an urban area. In this sense, consultation of local expert's opinion helps to reflect the implications of the current planning policies, local environmental issues and needs of the study area. Secondly, MUSIX is developed as an assessment tool to serve in policy and decision-making processes. In this sense, the model results are highly benefited from the input from developers, planners and policy makers that consist of the expert survey participants.

*Aggregation:* Aggregation is necessary in order to combine multi-dimensional indicator scores to form a single meaningful composite index. This step is composed of two different aggregation stages. Firstly, an arithmetic aggregation was conducted. Additive aggregation is basically the arithmetic average of the weighted and normalised indicator scores. The composite index score was calculated by the following formula:

$$MUSIX\ score = \sum_{i=1}^{n} w_i . x_i$$

Where *n* is the number of indicators, $w_i$ is the weight for indicator *i,* and $x_i$ is the normalised indicator value.

The composite index score was presented in five comparative sustainability levels: as suggested by Yigitcanlar *et al.* [36], low (0.00-1.00), medium-low (1.01-2.00), medium (2.01-3.00), medium-high (3.01-4.00), and high (4.01-5.00). Secondly, a spatial aggregation was conducted. As defined by Rao [37], spatial aggregation is the process of grouping spatial data at a level of detail or resolution that is coarser than the level at which the data were collected. The study area was divided into 100 x 100 metre grid cells and ArcGIS software was used to transfer parcel-level aggregated composite index scores into grid cell scores. For this aggregation basically each parcel's composite index score is multiplied by its area percentage within the grid cell and then summed into a single composite score for each grid cell.

*Sensitivity Analysis:* Each composite index is constructed by several subjective steps, which include the calculation method, selection of indicators, choice of aggregation and weighting procedures that

are associated with some uncertainties in the methodology. Therefore, it is necessary to analyse the sensitivity of the index by using alternative methodological assumptions [38]. A sensitivity analysis was performed to assess the robustness of the model, and investigate the potential changes and their impact on the results derived from the model.

*Interpretation of model outputs:* Findings of the MUSIX and policy applications were presented in a clear and accurate manner through ArcGIS maps.

The model was tested in a pilot study site selected from the Gold Coast City (GCC). The GCC is located in the South East of the state of Queensland, Australia. The city is the sixth largest city in Australia and covers an area of 1,378 square kilometres with its rapidly growing population and urban settlements. The GCC is a linearly developed city running parallel to the ocean, which consists of a beach strip connected with high rise residential areas, highways, canal estates, suburbs and semi-rural hinterland [39]. The existing land use pattern of the city includes a coastline with a high density residential and tourism accommodation surrounded with low-density housing developments, industrial areas, commercial activity centres and developing knowledge precincts [40].

The pilot area is a residential canal-estate development located on Dalley Park Drive in the suburb of Helensvale at the GCC. The area consists of detached single and two storeys lot dwellings. There is parkland located in the area. The total size of the pilot area is approximately 40 hectares and the total number of parcels is 324. The area is highly dependent on motor vehicle use with poor walkability. Parcel-level findings of the model are presented and discussed below and the sustainability performances of the site are illustrated in Figure 1. The findings are expressed as a value between 1 and 5 indicating different levels of sustainability—1 being low, 2 medium-low, 3 medium, 4 medium high, 5 high. In addition to parcel-level findings, the outcomes of this study are also presented in grid cell level. Composite index maps of the case study sites are illustrated in Figure 2.

Briefly, analysis of the findings clearly shows that there are major environmental impacts in the study area arising from increased impervious surfaces due to urban development and population growth. For instance;

- The parcels located on the canal side are covered by large amounts of impervious surfaces. Thus, they yield lower performance in terms of surface runoff rates. The results indicate that canal parcels have the lowest levels of green area ratio due to the loss of their native vegetation cover from canal construction. This finding shows that the type of development has a direct and adverse impact on the urban habitat and ecosystems.
- The results show that the study area is highly dependent on car-based transport. There is no easy access to public services within walking distance or enough use of alternative modes of transportation, such as bicycles or buses. The results also demonstrate that the design of pedestrian ways and bikeways for the area need to be improved in order to improve the walkability of the streets.
- Passive solar design is an important part of lot design through the encouragement of energy efficiency in subtropical regions like the study area. Unfortunately, most of the parcel layouts do not meet the principles of passive solar design in terms of lot shape, building orientation or solar access. Additionally, there is a lack of interest about climate responsive landscape design in the study area which may cause significant effects on the microclimate, such as higher levels of temperature, humidity, air pressure, wind speed and energy usage.
- Another important aspect of climate responsive design, the implementation of energy and water saving strategies is not common in the study area. For instance, most of the houses have swimming pools, which have a major impact on water usage. Furthermore, waterfront

development is also not suitable for water conservation methods, such as underground rainwater tanks.

## 4. Integrating Ecological Knowledge into Sustainability Policies

A conceptual framework for the environmental assessment and reporting structure of the MUSIX, which is adapted from the Driving force-Pressure-State-Impact-Response (DPSIR) framework was developed in order to examine the linkages between human activities and ecosystems by clarifying the complex relationship between them (Figure 3). This framework provided a better understanding of the selection of indicators that are relevant to the environmental sustainability assessment of the study area and also provided a conceptual basis for the policy recommendations for sustainable urban development. As shown in Figure 3, each component of this framework represents the following aspects of the model: *Driving forces* are the bottom-line causes of environmental pressures on the urban ecosystem; *Pressures* are the environmental problems occurred as a result of driving forces; *State* variable refers to the selected indicators of the model that monitor the pressures and problems; *Impacts* refer to the indicator sub-category sets of the model that outlines the level of impacts on urban ecosystem, and; *Responses* are the actions that are taken in order to achieve a sustainable urban development.

In light of the model findings, the issues, related policy objectives and proposed ecological planning strategies were categorised based on the DPSIR framework. Afterwards, some key ecological planning strategies were recommended to guide the preparation and assessment of development and local area plans in conjunction with the Gold Coast Planning Scheme, which establishes regulatory provisions to achieve ecological sustainability through the formulation of place codes, development codes, constraint codes and other assessment criteria that provide guidance for best practice development solutions. These relevant strategies are as follows:

- *Establishing hydrological conservation* through sustainable stormwater management in order to preserve the Earth's water cycle and aquatic ecosystems;
- *Providing ecological conservation* through sustainable ecosystem management in order to protect biological diversity and maintain the integrity of natural ecosystems;
- *Improving environmental quality* through developing pollution prevention regulations and policies in order to promote high quality water resources, clean air and enhanced ecosystem health;
- *Creating sustainable mobility and accessibility* through designing better local services and walkable neighbourhoods in order to promote safe environments and healthy communities;
- *Sustainable design of urban environment* through climate responsive design in order to increase the efficient use of solar energy to provide thermal comfort, and;
- *Use of renewable resources* through creating efficient communities in order to provide long-term management of natural resources for the sustainability of future generations.

These recommended strategies contribute in so many ways to sustainability which can be summarised as follows:

- *Sustainable approaches need to be adapted to urban stormwater management in order to:*
    - Reduce the impact of urban development;
    - Manage surface runoff;
    - Reduce pollution, flooding and erosion risks;
    - Improve the green infrastructure, and;
    - Protect water and air quality.
- *Sustainable ecosystem management needs to be provided in order to:*

    - Preserve the existing native biodiversity and natural ecosystems;
    - Protect endangered and threatened species;
    - Promote urban green space network, and;
    - Reduce the urban heat island effect from impervious surfaces.
- *Pollution prevention regulations and policies need to be developed in order to:*
    - Provide environmental quality;
    - Reduce air emissions and stormwater discharges;
    - Prevent transport-related noise pollution, and;
    - Provide a healthy environment.
- *Sustainable mobility and accessibility need to be provided in order to:*
    - Minimise automobile dependency;
    - Promote walking, cycling as well as public transport;
    - Provide mixed-use neighbourhoods that are easily accessible, and;
    - Provide a safe and convenient environment for pedestrians.
- *Sustainable design of urban environment needs to be achieved in order to:*
    - Ameliorate the microclimate and improve thermal comfort;
    - Reduce the environmental impact of buildings and paved surfaces;
    - Encourage energy efficiency, and;
    - Provide a better visual effect on built environment.
- *The use of renewable resources needs to be encouraged in order to:*
    - Provide energy conservation;
    - Improve water use efficiency;
    - Provide sustainable waste management, and;
    - Achieve the long-term management of natural resources.

## 5. Conclusion

Results of the literature review have shown that human behaviour affects the functioning of the ecosystem and its dynamics irreversibly through population growth and rapid urbanisation. The increasing demand of productivity and consumption depletes and degrades the natural resources. Rapid urbanisation of populations is associated with the transformation of agricultural and forestland uses into built-up areas and large portions of impervious surfaces have been created through this conversion. Impervious surfaces are regarded as the imprint of human activities on the natural environment. Therefore, imperviousness is a key indicator of these environmental impacts on urban sustainability [41]. Remote sensing is a useful tool in order to detect the impact of impervious cover on the natural environment. Change detection on the natural land cover using remote sensing helps sustainability assessment by: discovering the changes that have occurred; establishing the nature of the change; measuring the extension of the change, and; assessing the spatial pattern of the change [42]. To analyse the land cover change in sustainability assessment, remote sensing data can be used in several ways.

In this study, a new local-level sustainability-indexing model (MUSIX) is developed to monitor the environmental impact of land cover change on the urban ecosystem. MUSIX evaluates current development plans; moreover, provides local and micro-level sustainability reporting guidance to help policy-making concerning environmental issues. The findings have shown that MUSIX has the potential to be used for measuring and benchmarking sustainability performances, particularly at the local level through the development of sustainability indicators and composite indices. On the other hand, MUSIX has limitations like other indices. The main limitation of this research was the lack of reliable data during the indicator selection of the MUSIX. At the beginning of the study, a comprehensive list of indicators was developed. However, the indicators which were related to socio-economic structure of the urban ecosystem had to be excluded due to problems with

individual or household level data collection and privacy issues. Furthermore, some challenges occurred during land cover detection through aerial remote sensing data. Because of poor data resolution, weather conditions or shadowing issues, the images were not detectable for some residential areas, hence; some practical and time-efficient solutions were implemented for the success of the study.

In conclusion, MUSIX measures the sustainability of a residential development through providing data analysis and interpretation of results in a new spatial data unit. With the pilot implementation in the Gold Coast City, this research validates that parcel-based spatial analysis collects reliable and accurate land use information for planners and policy-makers. The results confirm that the model can be used for benchmarking sustainability performance at the micro-level and that it also serves as a tool for different stakeholders in order to discuss and develop sustainability policies. As an extension of this study, further research can be carried out to adapt and apply the model to different land use patterns with some modifications. MUSIX is also planned to accommodate for evaluating alternative scenarios for the knowledge based urban development. In this manner, the model provides information to compare during the evaluation of proposed projects and plans. It also helps practitioners to choose the most appropriate plan that best accomplishes sustainability goals. Moreover, the model provides coordination and collaboration between different government ministries and bodies that are needed to ensure the creation of sustainable knowledge cities.

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