Indicators of Urban Underground Space Development for Implementing Sustainability*

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Abstract—‘Sustainable Development (SD)’ has become a guideline and value to be pursued for few decades. However, it is difficult to balance the development of economic, social and environmental sectors at the same time, especially in urban cities. Recently, underground development has been suggested as a solution to problems caused by rapid urbanization. In this study, the role of underground space in urban areas is evaluated as an effective method towards SD and 22 appropriate indicators are proposed as results. The use of underground structures can contribute to sustainability in four ways: by (a) creating additional open spaces above the ground, (b) consuming energy efficiently, (c) providing strong protection from severe weathers or natural hazards, and (d) enhancing overall environmental quality. Among the conventional approaches, measuring overall sustainability, indicators associated with underground development were identified, and also weights between them were calculated. Data were collected from interviews and the analytic hierarchy process conducted by experts including professionals and researchers in related fields. These research findings offer an alternative strategy considering underground space to achieve sustainable development as well as to provide an analysis tool for ongoing projects.

I. INTRODUCTION

Before the 1990’s, the concept of ‘development’ was considered as economic development with inevitable side effects, including environmental problems and exhaustion of natural resources. However, the concern about environmental pollution and destruction of ecological systems due to indiscriminate industrialization has been aroused globally and has led to a worldwide movement for countermeasures [19]. In 1992, ‘Sustainable Development (SD)’ began to be discussed as a solution at the United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro. The Rio Declaration, as well as a comprehensive plan of action, Agenda 21, created at the conference called for a paradigm change of ‘development’ and intended to guide SD around the world. In the last few decades the concept of SD has been instituted to improve the quality of human life as well as the global environment and has been established as a key subject for international agendas.

Despite these endeavors, the current condition of the earth is assessed as deteriorating in the publication of United Nations Environment Programme (UNEP)†. According to the report, environmental problems continue including the increase use of natural resource materials by over 40% between 1992 and 2005. At the same time, however, several successful cases such as the halt of further expansion of the ozone hole, regulation of unleaded fuel, and use of renewable energy, imply a promising future [27]. What economies worldwide need is an absolute decoupling of the environmental pressure associated with resource consumption from economic growth. To achieve this purpose, Rio+20 argued for Green Economy in 2012 and active solutions should be followed.

One of the seven critical issues at Rio+20 was sustainability of cities. Between 1992 and 2010, the world’s population grew from around 5500 million to close to 7000 million (a 26% increase), and half the population lived in urban areas. This unprecedented urban growth requires special attention because 75% of global energy consumption and 80% of global carbon emissions is generated there [22, 29]. Also, the largest 25 cities in the world create more than half of the world’s wealth. As a result solving the problems in urban areas can be an effective strategy for global issues [24, 25].

To overcome the challenges in cities, recent researches in United States and several regions in Europe have suggested underground space development as an effective solution. Underground space inheritably conserves energy and provides strong protection from natural hazards. It also frees spaces above the ground [9, 17, 18]. In this paper, the characteristics of underground space are studied, which would be established as effective roles for SD in cities. Unlike previous research analyzing the sustainability of cities, this work suggests development of underground space as an active solution for SD by assessing the capabilities and applicable indicators of related fields. Following four main approaches are conducted to gain information for setting up the roles of underground space and assessing the significance of indicators for SD: (a) a literature survey with content analysis, (b) data collection from Focused Group Interviews (FGI) by consulting various groups of experts, (c) Analytical Hierarchy Process (AHP) to calculate the weight of each indicator, and (d) application to case studies.

II. ESTABLISHMENT OF SUSTAINABLE DEVELOPMENT

A. Definition of Sustainable Development

In 1987 the World Commission on Environmental and Development (WCED) created the widely accepted definition of SD as “development that meets the needs of the present
without compromising the ability of future generations to meet their own needs.” This term was proposed in its final document, “Our Common Future,” which is generally known as the Brundtland Report, and has evolved to mean a balanced development of economic, social, and environmental sectors [13]. As illustrated in Figure 1a, the concept of ‘development’ had been considered as economic development which is unrelated to society and the environment. Environmental problems and exhaustion of natural resources by industrialization were accepted as unavoidable side effects. Recently, however, a three-dimensional concept of SD (economic, social, and environmental development) has been proposed (see Figure 1b). This concept employs complex synergies and trade-offs among the three sectors. Figure 1c illustrates the ultimate goal of SD which is the simultaneous fulfillment of its objectives. First, ‘Economy’ is assumed to be present inside ‘Society’ because all human economic activity is a result of interaction between social relationships. Society is a broader category than ‘Economy’ and includes cultural and religious activities between family and friends. Next, ‘Society’ is placed inside ‘Environment’ because all required elements of ‘Society’ are parts of ‘Environment’.

In spite of the trials to decouple the environmental pressure from economic growth [4], it has been noticed that a lack of detailed strategies and standards often results in the failure of integrated policy implementation as well as the interference of economic growth [8]. In June 2012, the United Nations Conference on Sustainable Development (UNCSD) was organized to mark the 20th anniversary of the 1992 UNCED in Rio de Janeiro. At this Rio+20 conference, not only was its current status examined, but also its future direction. Moreover, Green Economy and the institutional framework for SD were focused on in the final document, “The Future We Want” [26].

B. Indicators of Sustainable Development

To understand the paradigm objectively, many researchers over the last two decades have attempted to evolve indicators for implementing SD, that is, to identify those that are appropriate and meaningful to represent what needs to be measured and evaluated. It was decided that integrated frames covering economy, society, and environment to represent SD should be developed [5]. Although there are still notable limitations such as methodology and timing to apply [1], the indexes suggested by the United Nations Commission on Sustainable Development (UNCSD), Organization for Economic Cooperation and Development(OECD), and EU are generally utilized. UNCS6D originally introduced 132 sustainable development indicators (SDIs) and divided into themes and sub-themes collected in four columns: social, environmental, economic, and institutional. As evidenced by Agenda 21 [7], this model was revised in 2001 and reduced to a total of 15 themes, 38 sub-themes and 57 indicators. OECD provided 18 indicators in ‘Environment’ and 15 in ‘Society/Economy’. Based on the SDIs presented by UNCS6D, the EU selected 46 indicators and revised the total to 63 in 2001 [4]. By adding critical issues and removing unrelated items to the EU’s indicators, the final number was 22 social, 16 environmental, 21 economical, and 4 institutional. The indicators presented in Table 1 by major international organizations are applicable on a national level to provide information and evaluate the performance to generate SD policy. The Environmental Sustainability Index (ESI) was developed in 2006 to make the comparison between countries ease, [30, 31]. On the ESI, Korea was ranked 122nd among 146 countries, whereas Finland ranked first, Japan 30th, and United States is 44th [13]. However, a recent report in 2010 by the Ministry of Environment reveals that there has been improvement in most categories [12].

![Figure 1. Paradigm Change of SD](image_url)

**TABLE 1. MAJOR SD INDEX**

<table>
<thead>
<tr>
<th>Initiator</th>
<th>Application Level</th>
<th>Purpose</th>
<th>Scope &amp; Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNCSD</td>
<td>National/International</td>
<td>To provide information and evaluate performance for policy decision</td>
<td>4 dimensions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15 themes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>134 indicators</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>57 core indicators</td>
</tr>
<tr>
<td>OECD</td>
<td>National/International</td>
<td>To provide information and evaluate performance</td>
<td>2 dimensions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15 themes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>33 indicators</td>
</tr>
<tr>
<td>EU</td>
<td>National/Regional (EU members)</td>
<td>To evaluate performance for European region</td>
<td>4 dimensions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>63 indicators</td>
</tr>
<tr>
<td>Ministry of Environment (Korea)</td>
<td>National (Korea)</td>
<td>To evaluate performance for Korea</td>
<td>3 dimensions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14 themes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>77 indicators</td>
</tr>
</tbody>
</table>
III. URBAN UNDERGROUND SPACE DEVELOPMENT FOR SD

A. City problems and Underground Space as a Solution

As mentioned previously, more than half of the world’s population now lives in urban areas and this number is expected to increase to 70% in 2050. City problems created by this rapid urbanization must be resolved to achieve SD, and Rio+20 has highlighted ‘sustainable cities’ as one of the seven areas which need priority attention [27]. Table 2 presents the major facilities and related problems in urban areas [6]. Explosive growth in cities is directly linked to massive facilities and working and living conditions are deteriorating due to lack of maintenance. One of the major problems is shortages of green spaces and available land. This expands to a social problem for residents as well as an economic problem. Moreover, cars and industries are polluting city air and water, and CO2 emission, electricity, sanitation problems have also been reported.

“The Future We Want” addressed that a holistic approach is required to revitalize aging areas and improve the quality of life for residents [26]. It is also clear that an integrated method of planning and construction based on cooperation between experts and local communities is essential. Precedent studies have been introduced the SD concept in Europe, United States, and Canada, namely New Urbanism, Smart Growth, Compact City, Urban Village, and Urban Regeneration [14]. Urban Regeneration especially utilizes an integrated approach to the physical environment, economy, and society to revitalize distressed communities [20]. In Korea, central and local governments have pursued urban generation projects translates to a market breadth of approximately 2 billion dollars in 5 years [16]. A central part in the middle of city and a multipurpose complex are development in the projects [14].

Multidimensional space development, including underground space, is required to resolve the shortage of housing and infrastructures in city plans [11], and in 2008 the Ministry of Land, Transport, and Maritime Affairs also reported the importance of underground space to solve urban problems [6]. Reducing the problems addressed in Table 2 and achieving SD in cities is not only being addressed in the United States and Europe, but China has implemented urban underground space development more actively in its policy [28].

In this study, the characteristics and corresponding roles of underground space in urban area are established as an effective method toward approaching SD. Twenty-two appropriate indicators to be used in suggested policies as well as the evaluation and selection of projects are also proposed. A literature survey was performed first and groups of experts in the engineering fields of related to construction and city planning gathered to discuss the characteristics of underground space. The discussion also led to a written report.

<table>
<thead>
<tr>
<th>City Facilities</th>
<th>City Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural building</td>
<td>Degraded housing</td>
</tr>
<tr>
<td>Educational building</td>
<td>Green space shortage</td>
</tr>
<tr>
<td>Housing</td>
<td>Lack of disaster prevention control</td>
</tr>
<tr>
<td>Industrial building</td>
<td></td>
</tr>
<tr>
<td>Transportation system</td>
<td>Air pollution</td>
</tr>
<tr>
<td>Storage</td>
<td>Overcrowding/Space limitation</td>
</tr>
<tr>
<td>Information-communication</td>
<td>Lack of disaster prevention control</td>
</tr>
<tr>
<td>infrastructure</td>
<td></td>
</tr>
<tr>
<td>Infrastructure related to</td>
<td>Stability and Environment problem</td>
</tr>
<tr>
<td>electricity/gas/fuel</td>
<td>Energy problem</td>
</tr>
<tr>
<td>Waste treatment and disposal system</td>
<td>Lack of disaster prevention control</td>
</tr>
</tbody>
</table>

B. Characteristic and Use of Underground Space

Since ancient times, mankind has constructed underground cities to overcome weather conditions and natural hazards, and the need increases in modern cities as they grow. An underground space master plan was established in Seoul in order to solve the problem of overcrowding. The plan presented the idea of underground space as an important resource for future cities, and addresses that continuous maintenance and research are required to use this asset more efficiently [21].

Underground space is defined by the American Underground Space Association as a certain volume of resources that are naturally or artificially raised beneath the surface of the ground within a range of agreeable usage. This definition only considers physical characteristics and is based on a superficial concept. Thus, we need to understand the overall characteristics of underground space in order to lead us to strategies for its effective application. We must address recent issues that highlight the need for underground space and its corresponding potential and features that differentiate it from other strategies. First, the ground has a large heat capacity and slow rate of heat transfer; therefore, underground space inherently conserves energy and uses it efficiently. Because such space is removed from climatic influences, underground facilities provide significant energy savings. Because underground space is isolated it provides natural soundproofing and is easy to control. Moreover, underground space provides strong protection against natural hazards as well as radioactivity [6]. These characteristics can be used effectively to solve urban problems such as shortage of available land and space due to overcrowding, transportation, and environmental issues, as well as warding off the risks of disaster due to climate change [2]. The use of underground space utilizes energy efficiency and isolation for storage of food or waste and allows for the preservation of green space or cultural heritage above the ground [3, 15]. Finally, there are less requirements for maintenance, and the durability of the space also reduces the demand for resources [17].

As illustrated in Figure 2, six roles for underground space development for SD have been established for considering major facilities and corresponding issues as well as the characteristics of underground space. These roles involve three major sectors: social, economic, and environmental.
sustainability as follows: (a) provide secure city function, protection from natural hazards, and convenient and comfortable serviceability in economic and social sectors; (b) utilize land and space efficiently in economic and environmental sectors; (c) create green space above the ground in social and environmental sectors; and (d) preserve environment and scenery in environmental sector.

IV. SD INDICATORS RELATED TO URBAN UNDERGROUND SPACE DEVELOPMENT

As addressed earlier, underground space development can be a good intelligent approach for SD in cities. However, considering the expenses of multidimensional city construction including underground space, careful planning in accordance with policy and action plan is necessary. A quantitative framework such as employing indicators forms a solid foundation in achieving the SD concept. Many researches have been performed to develop SD indicators as an evaluative tool for projects or to act as a decision-maker for making policies. In this section, instead of creating new criteria, generally accepted standards are utilized to select indicators related to underground space development. Experts in identifying indicators as well as in underground construction from the academic and research community were consulted both in person and in writing.

A. Selection of Related SD Indicators

In the process of pursuing this research, SD indicators proposed by the OECD, PCSD, EU, and Ministry of Environment were provided to the experts by means of a questionnaire survey. In responding to the questionnaire, respondents were invited to indicate the level of significance of each SD indicator for addressing underground space development by assigning a score between 0 and 5. A score of ‘5’ indicated most related and ‘0’ not related. In addition to those general SD indicators, other factors were considered including sustainable land management indicators from the Korea Research Institute for Human Settlements, sustainable city indicators from the Urban China Initiative, and recommendations by the International Tunnel Association [10, 17, 23].

As illustrated in Figure 3, 22 indicators were selected and divided into social, environmental, economic sectors. Growth of framland in the environmental sector, energy efficiency in the economic sector, and environmental protection expenditures in the social sector are regarded as appropriate SD indicators to assess underground space development. On the other hand, gender equality, illiteracy rate, or the inflation rate is considered unrelated items.

B. Weight Calculation of Indicators

After the selection of the 22 indicators, AHP is applied to calculate weights of each indicator. Experts evaluated the selected indicators by comparing one to the other with respect to their impact on the urban underground development for SD. In making the comparisons, the decision makers used their professional judgments about the elements' relative meaning and importance. As illustrated in Figure 4, among the three major sectors, ‘environment’ (0.35) and ‘economy’ (0.38) are regarded as more critical than ‘society’ (0.27). In the environment sector, the weight of greenhouse gas emission is considered higher than other factors (Figure 5). Weights of energy efficiency, risk to human and natural capital, and use of renewal energy source are high in ‘economy’ (Figure 6). In
the society sector, population density and road fatality are considered as important (Figure 7). This analysis reveals that decision making based on the purpose of reducing air pollution, increasing energy efficiency, and dispersing concentrated population should be performed in underground space development to achieve SD in cities.

C. Case Study

It is important to benchmark other successful cases to use indicators properly, so weighted indicators calculated in the previous section were applied to Korea in comparison with Finland which is ranked first in ESI, 2006. Helsinki is one of the most successful cases using underground space effectively to improve the quality of city life. Helsinki has utilized underground space since the 1960’s: more than 400 sites and over 200km of tunnels have been built. Use of underground space contributes to the sustainability of the city [18].

There are several studies comparing sustainability between cities in Korea, and cities in Europe. However there is no official record of a SD indicator comparing cities in Korea and those overseas, especially by focusing on underground space development. Therefore, a comparison between Korea and Finland is attempted in this study. To reduce the uncertainty of the value calculation, the accepted ESI indicators are utilized. Among the 22 indicators selected in the previous section, 10 items are identified as the same as ESI. Weights newly calculated in this study are also applied. Figure 8 presents a radiation graph illustrating the 22 selected indicators. Ten items with ESI values for Korea and Finland are located in the graph color coded by weight. Color codes are used to easily see the importance of each item. According to the color codes, the gaps between Finland and Korea are small in energy efficiency and greenhouse gas emission indicators with high weights. However, Finland has a relatively lower score on those two indicators than others due to the heating systems necessary in severe weather condition. Also participation in international environmental agreements can be excluded since the weight of this indicator is low, though the gap is relatively big. Figure 9 shows the results after the weight is multiplied, and the largest difference occurs in property loss by disaster. In this highly weighted indicator, Finland shows a much higher score than Korea. This study implies that disaster prevention should be considered as the most important factor when underground space is developed for SD in cities.
V. CONCLUSION AND FURTHER DIRECTION

In this study, it was tried to establish the role of underground space toward SD and determine appropriate indicators to evaluate its potential. The 22 indicators designated and weighted in the three major sectors, ‘environment’ and ‘economy’ and ‘society’ show their possible application to assess SD of cities through a case study comparing Finland and Korea where underground spaces are developing. The result especially illustrated that underground space could play a role to solve city problems. For example, underground spaces are positively related to reduce the property damage and casualty from natural disasters.

Moreover, the indicators from this study could be applied to evaluate whether a city development policy or plan involving underground construction is in line with sustainability, and then select an appropriate program or project towards SD. The research findings could offer a use of underground space when a nation set up a SD policy to find a solution for urban problems. A national level strategy of sustainable cities should be established to overcome the
global problems from global warming, natural disaster, energy scarcity, urban concentration, and so on. Further studies are needed to supplement current results by enhancing validity and considering additional indicators in detail. Even with the limitations, this study could trigger the discussion on a role of underground space for SD in urban area with a practical case study assessed with the case-oriented indicators. This discussion would drive us better understanding about the characteristics of underground space and way to use it under a long-term vision of SD.

REFERENCES

[31] Yale University, "Environmental Sustainability Index," 2006.