A Study on the Environmental Sustainability Assessment of Multi-Family Housing Estates in Korea

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Abstract
The objective of the present study is to assess the environmental sustainability of multi-family estates in Korea, and based on the assessment, to consider the best future direction for the further promotion of environmental sustainability. In this study, 111 representative multi-family housing estates in Korea were selected and assessed for their sustainability, based on sustainability indicators and standards, and the following conclusions were drawn.

In assessment by sectors, the sustainability of landuse and transportation appeared high, but the sustainability of energy and resource use was assessed to be quite low. Indicators such as sunlight use, heavy water use, construction waste recycling and biotop development showed achievement as low as 10%. Thus, these areas will require further efforts.

In assessment by estates, the sustainability of landuse appeared high in estates of large-scaled systematic development, but low in those of disordered development or redevelopment. Therefore, the promotion of large-scaled systematic development is recommended. Estates developed under the slogan of environmental-friendliness were found to be superior in both ecological environment and indoor environment, so they should be promoted as well. In addition, estates constructed in the turnkey system attained good marks in several sustainability indicators including energy, which suggests that the turnkey system has advantages.

Keywords: sustainable development; multi-family housing estate; sustainability assessment; sustainability indicator

1. Background and Objective
Since the United Nations Conference on Human Environment in Stockholm in 1972, the discussion of how to secure the future of the planet has come to focus on sustainable development. The United Nations World Commission on Environment and Development defined sustainable development in 1987, and in 1996, HABITAT II was held in Istanbul. In the years since, discussion on sustainable human settlements has progressed rapidly, and much effort is being exerted to establish planning goals and develop planning indicators and assessment standards. In particular, the sustainability assessment of human settlements is considered to be a critical task in that the correct evaluation of current levels of sustainability are needed in order to determine how to improve sustainability in the future.

Emphasizing sustainability, the Korean government has established a national committee for sustainable development, and performed research for the development of sustainable housing estates. This research has set the goals for sustainable housing estates and established sustainability indicators and standards for attaining these goals. The results of the research are the basis for the housing estate environment certificate system in Korea. Therefore, the objective of this study is to assess the level of sustainability of multi-family housing estates in Korea by sectors and indicators, and to propose recommendation for the future improvement of sustainability. For these purposes, drawing analyses and field surveys were carried out on 111 multi-family housing estates in Korea to assess their sustainability. Because assessment indicators and standards for socioeconomic sustainability have not yet been developed, this study focused on environmental sustainability.

2. Methods of Sustainability Assessment of Multi-Family Housing Estates
In this study, the assessment indicators and standards developed by the House Research Institute of Korea National Housing Corporation were adopted. The assessment method used here was developed as a part of a three-year national policy study of the Ministry of Construction and Transportation and is currently the official Korean assessment model. This assessment model groups assessment sectors into basic sectors and additional sectors; basic sectors include the four sectors suggested in Habitat II Agenda: landuse and transportation, energy and resource use, ecological environment, and indoor environment. Additional sectors include indicators applied to special cases and socioeconomic indicators applied empirically. A total of 33 assessment indicators were established, and assessment standards were divided into minimum ones and ideal ones. For minimum standard, marks allotted...
to landuse and transportation, energy and resource use, ecological environment and indoor environment were 32: 29: 24: 15 respectively, and for ideal standard, marks allotted to landuse and transportation, energy and resource use, ecological environment, indoor environment and additional sectors were 69: 39: 48: 19: 25 respectively.

Therefore, if an estate fully satisfies the minimum standard its score is 100, and if it fully satisfies the ideal standard, its score is of 200 (see Table 1 and 2).4

This method can be applied not only for the relative assessment of the general sustainability of housing estates but also for sustainability assessment by sectors. In addition, sustainability can be assessed by each assessment indicator to analyze the level of sustainability of multi-family housing estates and to find directions for future development.

2.1 Assessment Indicators and Standards

As shown in Table 1, the sector of landuse and transportation has 10 indicators, including volume ratio, and the number of marks allotted to each indicator is different for the minimum and ideal assessment standards. For example, with regard to the indicator measuring the average distance between the local center and the estate center, the minimum criterion is 1km while the ideal criterion is 500m, and marks given are 2 and 4 respectively. In assessment, the local center is identified from drawings and field surveys, its distance to the estate center measured, and then marks given according to each standard.

2.2 Selecting Estates To Be Assessed

To select representative multi-family housing estates in Korea by typical characteristics, this study included major estates such as Jamsil, Gwacheon, Mokdong, and Sanggye, as well as estates in five new towns including Bundang, Ilsan, and Suwon Yeongtong and Ansan Gojan. It included estates expected to have relatively favorable residential environment such as those developed through

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Table 1. Assessment Indicators and Standards for Assessing the Sustainability of Multi-Family Housing Estates (basic sectors)

| Sectors                        | Assessment Indicator                                                                 | Assessment Standard | Marks               |
|--------------------------------|--------------------------------------------------------------------------------------|---------------------|---------------------|
| Landuse and transportation     | Volume ratio (%)                                                                     | Y = 0.125X + 31.5   | Less than 100% (Y = 0.125X + 31.5) |
|                                | Average distance between city center and estate center (m)                            | Within 3km           | 2                   |
|                                | Average distance between local center and estate center (m)                           | Within 5km           | 4                   |
|                                | Roads exclusively for pedestrians within estate                                      | Y = 0.025X + 46.5    | 8                   |
|                                | Link between pedestrian roads inside estate and outside                               | Link to green roads  | 2                   |
|                                | Number of pedestrian crossings to elementary school                                  | 1                   | 2                   |
|                                | Roads for cycling                                                                    | Inside estate        | 4                   |
|                                | Bicycle parking capacity per 100 households                                         | Over 15 bicycles     | 2                   |
|                                | Average distance between subway station (bus stop) and estate center (m)              | Within 2km           | 6                   |
|                                | Width of roads around estate (lane)                                                  | Two-way 2,4 lane     | 8                   |
| Subtotal                       |                                                                                      | 22                  | 69                  |
| Energy and resource use        | Total quantity of carbon dioxide produced within estate                              | EPI3: marks 80-89: 90-99: 100-109: 110-119: 120-129 | EPI3: marks 80-89: 90-99: 100-109: 110-119: 120-129 |
|                                | Solar energy use (% of households)                                                   | Less than 3%         | 3                   |
|                                | Rainwater, heavy water recycling facility                                            | Over 5%              | 6                   |
|                                | Water saving equipment                                                               | 0                   | 2                   |
|                                | Permeable pavement area ratio (%)                                                   | 1%                  | 4                   |
|                                | Using waste disposal facility within estate                                          | 0                   | 3                   |
|                                | Recycling of construction wastes                                                    | 0                   | 3                   |
| Subtotal                       |                                                                                      | 29                  | 39                  |
| Ecological environment         | Green area ratio (%)                                                                | Over 35%             | 10                  |
|                                | Small brooks, ponds, etc                                                             | Over 1%              | 5                   |
|                                | Vegetable gardens, fts, nature learning centers, etc                                | Over 10%             | 10                  |
|                                | Accessibility to neighboring parks, rooms, forests (m)                               | Within 500m          | 8                   |
|                                | Interconnection among green areas within estate                                      | Link to green areas outside the estate | 8                   |
| Subtotal                       |                                                                                      | 24                  | 48                  |
| Indoor                         | Ratio of southern exposure (%)                                                       | Over 70%             | 4                   |
|                                | Restriction of the use of harmful materials                                          | 0                   | 3                   |
|                                | Court-like balcony                                                                  | 0                   | 4                   |
|                                | Flexible plan design                                                                | 0                   | 4                   |
| Subtotal                       |                                                                                      | 15                  | 19                  |
| Total                          |                                                                                      | 100                 | 175                 |

Table 2. Assessment Indicators and Standards for Assessing the Sustainability of Multi-Family Housing Estates (additional sectors)

| Sector                      | Assessment Goal                                      | Assessment Indicator                  | Assessment Standard | Marks |
|-----------------------------|-----------------------------------------------------|--------------------------------------|---------------------|-------|
| Landuse                     | Preserving & restoring existing natural resources   | Nature-restoring slope face method   | O                   | 3     |
|                             |                                                     | Preserving natural landform          | O                   | 5     |
|                             |                                                     | Utilizing surface soil               | O                   | 2     |
|                             | Planned landuse                                     | Planned development (housing site, development area, etc.) | O | 5     |
|                             | Information Infra                                  | Information communication network    | O                   | 4     |
| Social Sustainability       | Promoting community                                 | Plans for community centers or spaces | O                   | 5     |
|                             |                                                     |                                      |                     |       |
| Total                       |                                                     |                                      |                     | 25    |
prize contests by the Korea National Housing Corporation and the Seoul Urban Development Corporation, and in the turnkey system, as well as estates expected to have relatively poor residential environments, such as those of disorderly development and redevelopment. However, most of the estates selected were in or around Seoul or Kyunggi Province, for the sake of convenience in conducting field survey. Estates without drawings were excluded because drawings analysis was essential. Ultimately, 111 multi-family housing estates were selected. Representative estates are shown in Table 3.

Table 3. Estates to Be Assessed

| Selection Standard          | Estate                                                                 |
|-----------------------------|----------------------------------------------------------------------|
| Major estates by decade     | 1970’s: Jamsil, Gwacheon, etc.                                       |
|                             | 1980’s: Gaepo, Mokdong, Sanggye, Changdong, etc.                      |
|                             | 1990’s: Junggye, Neunggok, Osan Uham, Suwon Gwoneun, Gheung Sanggil, Yeongdeok, etc. |
| New towns                   | Bundang, Ilsan, Sanbon, Pyeongchon, Jungdong, Suwon Yeongdong, Ansan Gojang |
| Prize contest & turnkey     | Sinsaeng, Banghwa, Gayang, Sinmae, Yangcheon, Changdong, Sinsaeng, Incheon Mansu, Juyongbu, Kumho, Daedeon Gwanjoo, Masan Samgye, Busan Asian Game Village, Gwangju Yongdong, Ulsan Gullha, H-Housing etc. |
| Development / redevelopment | Yongin Sui, Gugal, Jukjeon, Jongamdong, Banghokdong redevelopment, etc. |

3. Results of Sustainability Assessment

3.1 Sustainability Assessment by Sector

3.1.1 Assessment of landuse and transportation

According to the results of the landuse assessments, volume ratios were evenly distributed from 50% to 360%, which showed that the samples were diverse (Figure 1), but the average volume ratio was 162.9%. The average mark was 10.8 out of 19, so the average achievement was 56.8%. The distance between the city center and the estate center varied (Figure 2), but the average distance was 2km, so the achievement was relatively high at 77.6%. Except in some cases of disorderly development or redevelopment, it was within 2.5 km in most estates. The distance between the local center and the estate center averaged approximately 400m, which is a walkable distance; the achievement was 90%, the highest among indicators.

On the other hand, while pedestrian roads within the estate were satisfactory in about half the samples, the number of estates with roads linked to external green roads was only 34, and the achievement was a very low 15%. However, the number of pedestrian crossings to an elementary school is one on average, which was relatively satisfactory. 42 estates had cycling roads, and the mark for this indicator was 1.5 out of 4, so the achievement was 37.5%. However, bicycle parking capacity was only 8.2 bicycles per 100 households, so this achievement was only 25%.

Meanwhile, the distance to a subway station (or a bus stop) was relatively short at 823m on average, and the achievement was 67.5%, but 72 estates had roads with four or more lanes around them, which suggested that the road structure of many multi-family housing estates was vehicle-oriented rather than pedestrian-oriented.

Therefore, the achievement in landuse and transportation was a relatively high 50.2% but the results indicate that pedestrian roads need to be in a systematic way, and the width of roads around estates must be reduced.

Table 4. Assessment Results in the Sector of Landuse and Transportation

| sectors                | Assessment Indicator                  | Average | Points | Achievement (%) |
|------------------------|---------------------------------------|---------|--------|-----------------|
| Landuse and Transportation | Volume ratio (%)                      | 162.9   | 10.8   | 56.8            |
|                        | Average distance between city center and estate center (m) | 2.114   | 3.1    | 77.6            |
|                        | Average distance between local center and estate (m) | 417.1   | 3.6    | 90.0            |
|                        | Roads exclusively for pedestrians within estate                            | 59      | 2.1    | 26.2            |
|                        | Link between pedestrian roads inside estate and outside                      | 34      | 0.6    | 15.0            |
|                        | Number of pedestrian crossings to elementary                                  | 0.9     | 2.2    | 55.0            |
|                        | Roads for cycling                                                             | 42      | 1.5    | 37.5            |
|                        | Bicycle parking capacity per 100 households                                    | 8.2     | 1.0    | 25.0            |
|                        | Average distance between subway station (bus stop) and estate center (m)      | 823.1   | 8.1    | 67.5            |
|                        | Width of roads around estate (m)                                              | 39(2)   | 1.6    | 26.6            |
|                        | Total                                                                     | Average | 34.7   | 50.2            |

Fig.1. Distribution of Volume Ratio of Housing Estates Assessed (%)

Fig.2. Average Distance between City Center and Estate Center(m)

Fig.3. Average Distance between Local Center and Estate Center
3.1.2 Assessment of energy and resource use

The quantity of carbon dioxide produced in housing estates was excluded from indicators because it is impossible to measure in existing estates. Combined heating systems were in service at 82 estates, and the achievement in combined heating systems was 74%. This showed that most large-sized housing estates had established combined heating systems. However, only six estates had installed solar heating facilities, so the achievement for this indicator was a mere 2.6%. The marks for rainwater or heavy water recycling systems were even worse; only one housing estate had installed such a system.

On the other hand, relatively many housing estates had installed water-saving equipment, so the achievement for this indicator was 38%. However, permeable pavement was attempted at only eight estates, living waste disposal facilities at only six estates, and construction waste recycling at only one estate; the achievement was a mere 0.6%. Accordingly, in the sector of energy and resource use, most indicators scored low achievements except for combined heating systems and water-saving equipment, and the average achievement was only 13%.

| Table 5. Assessment Results in the Sector of Energy and Resource Use |
|-----------------------------------------------|
| sectors                                      | Assessment Indicator | Estates Points Achievement (%) |
| Energy and resource use                      | Combined heating system | 82 3.7 74.0 |
|                                             | Solar energy use 1% of households | 0 0.16 2.6 |
|                                             | Rainwater, heavy water recycling facility | 1 0.05 2.5 |
|                                             | Water-saving equipment | 42 0.76 38.0 |
|                                             | Permeable pavement area ratio | 3 0.22 7.3 |
|                                             | Living waste disposal facility within estate | 6 0.21 5.2 |
|                                             | Recycling of construction wastes | 1 0.02 0.6 |
| Total                                       | Average 5.1 13.0 |

3.1.3 Assessment of ecological environments

In the sector of ecological environment, the green area ratio was satisfactory at 33.95% on average, and the achievement was 63.3%. However, only ten estates created biological habitats on part of their green spaces, and the achievement was only 5%. Meanwhile, the distance to natural resources outside estates was 250m on average, and the achievement was as high as 61.2%. Furthermore, green spaces within the estate were interconnected in 49 estates but the quality of interconnection was poor, so the achievement was only 21.2%. Therefore, the results indicate an urgent need for better biological habitats in order to ecological environments.

Table 6. Assessment Results in Ecological Environment

| sectors                                    | Assessment Indicator                   | Average Points Achievement (%) |
|--------------------------------------------|----------------------------------------|--------------------------------|
| Ecological Environment                     | Green area ratio (%)                   | 33.95 7.6 63.3                |
|                                            | Small brooks, ponds, etc.              | 11 0.52 5.2                   |
|                                            | Vegetable gardens, hills, nature learning centers, etc. | 15 0.65 6.5 |
|                                            | Accessibility to neighboring parks, rivers, forests (m) | 253.7 4.9 61.2 |
|                                            | Interconnection among green (form a green network centering on base green areas within estate) (areas within estate) | 49 1.7 21.2 |
| Total                                      | Average                                | 15.4 32.0                     |

3.1.4 Assessment of indoor environments

The ratio of southern exposure in the sector of indoor environment was 87.4% on average, and the achievement was 73.7%. This showed that most houses in Korea are still constructed facing south. However, only seven housing estates used non-toxic materials such as natural paints for interior finishing. In addition, only one housing estate attempted to make court-like balconies to contribute to the development of ecologically sound indoor spaces. Flexible design plans such as changeable floors were employed by only four estates, all of which were recently constructed. Accordingly, achievements in the sector of indoor environment were generally low, except in the southern exposure.

Table 7. Assessment Results of Indoor Environment

| sectors                                | Assessment Indicator                           | Average Points Achievement (%) |
|----------------------------------------|-----------------------------------------------|--------------------------------|
| Indoor Environment                     | Ratio of southern exposure (%)                | 87.4 5.9 73.7                  |
|                                        | Restriction of the use of harmful materials   | 1 0.2 5.0                      |
|                                        | Court-like balcony                            | 0.04 1.0                       |
|                                        | Flexible plan design                          | - 0.14 3.5                     |
| Total                                  | Average                                       | 6.3 33.3                       |

3.1.5 Assessment of additional sectors

Only four housing estates were found to have preserved the natural landform, and none had used nature-restoring slope face methods. In addition, no estate had reused surface soil. On the other hand, 94 of the sample estates were built under somewhat organized development plans such as new town plans or housing site development plans; only 17 were developed in disorder. Information communication networks were established in 46 estates, and 20 estates, most of which were recently constructed, had a community center or a resident square. Putting the

Table 8. Assessment Results in the Additional Sectors

| sectors                                | Assessment Indicator                           | Average Points Achievement (%) |
|----------------------------------------|-----------------------------------------------|--------------------------------|
| Additional sectors                     | Nature-restoring slope face method             | 0 0 0                           |
|                                        | Preserving natural landform                    | 4 0.3 5.0                       |
|                                        | Utilizing surface soil                         | 0 0 0                           |
|                                        | Planned development (housing site development area, etc.) | 94 4.2 84.0 |
|                                        | Information communication network              | 46 1.6 40.0                     |
|                                        | Plans for community centers or spaces          | 20 0.9 18.0                     |
| Total                                  | Average                                       | 7.0 28.0                        |
results together, planned development and information communication network scored high achievements, but achievements related to the construction of nature restoring slope faces, the preservation of natural landforms, and the utilization of surface soil were low.

3.2 Analysis of Sustainability Assessment by Sector

This sustainability assessment of multi-family housing estates in Korea has shown that achievement in the sector of landuse and transportation is the highest at 50.8%, and that in the sector of energy and resource use is the lowest at 13%. Achievements in the ecological environment and indoor environment sectors slightly exceed 30%, and that in additional sectors is just 28%. The general achievement is 31.4%.

Because housing estates assessed in this study were mostly developed under large-sized housing site development projects, they had favorable location and accessibility, but their achievement in energy and resource use, which requires special designs and facilities, was significantly low, indicating limited in investment for improving sustainability.

Meanwhile, the strong trend toward environmentally friendly housing estates in Korea since the late 1990s has had a positive influence on the sectors of ecological environment and indoor environment because residents have become to be interested in outdoor biological habitats and indoor environments, which are easily to developed and have visible effects. However, the overall achievement is still only slightly over 30%, so the sustainability of multi-family housing estates in Korea is considered to be low.

4. Analysis of Sustainability Assessment by Indicator

As for achievement by indicator, achievement was over 50% for numerous indicators in the landuse and transportation sectors: volume ratio, distance between the city center and the estate center, distance between the local center and the estate center, number of pedestrian crossings to an elementary school, distance to a subway station, and planned development. In energy and resource use, only the combined heating system indicator’s achievement was over 50%. In ecological environments, green area ratio and accessibility to neighboring natural resources exceeded 50% achievement rates, and in indoor environments, only southern exposure exceeded 50%. These indicators are being popularized as factors enhancing the sustainability of housing estates. In particular, the distance between the local center and the estate center achieved 90% of the target, the highest achievement among all indicators.

Another group of indicators is those with achievements ranging from 10% to 50%: pedestrian roads within the estate, linkage of pedestrian roads to external roads, cycling roads, bicycle parking capacity within the estate, the width of roads around the estate, interconnection of green spaces within the estate, information communication networks, and community centers and squares. It was found that there were many attempts made related to these indicators. Because these indicators are not yet well-established in Korean housing estates, it is important that supportive policies are put in place to accelerate their establishment.

Indicators such as solar energy use, recycling of rainwater and heavy water, permeable pavement, living waste recycling, construction waste recycling, aquatic biotops, land biotops, suppression of the use of harmful materials, court-like balconies, nature- restoring slope face construction, preservation of natural landforms, and the utilization of surface soil scored achievements of less than 10%. Because these indicators are costly or have insignificant visible effects, leadership in the public sector and strong political support will be required to increase their use in housing estates.

The results of detailed indicator analysis are as follows.

First, volume ratio has increased continuously from around 100% in the 1970s~1980s to 150% in the 1980s~1990s and 200% in the 1990s~2000s, excluding some extreme cases of over 300%, but recently there are complexes constructed at volume ratio below 200% with increasing recognition of the importance of the environment, which is an encouraging tendency. In general, if volume ratio goes high, outdoor spaces and green areas are narrowed. Thus it is an indicator that must be monitored with regard to sustainability in the first place.

As for indicators related to accessibility to the central area, there are complexes that are increasingly distant from the city center as housing sites are run out in cities. With a few exceptions, nevertheless, accessibility appeared to be satisfactory as the average distance to the local center is 417 m.

Concerning pedestrian road, this study found a number of complexes, which were among those constructed in or after the mid 1990s, that planned pavements exclusively for pedestrians, but few of them linked the roads to the outside systematically. Even when green roads for pedestrians were constructed along urban trunk roads, there were few cases of organic connection to surrounding pedestrian passages. This problem should be solved in the future. On the other hand, the safety of pedestrian roads to elementary schools appeared to be satisfactory as the average distance to the local center is 417 m.

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| Indicators / Estates (Score) | minimum | maximum | mean | Summary of contract contents |
|-----------------------------|---------|---------|------|-----------------------------|
| **Landscape / Transportation** |
| Volume Ratio                | 59.3    | 369.2   | 162.9| Have increased but recently tend to decrease due to the construction of environment-friendly residential complexes |
| Average distance between city center and estate center (m) | 190 | 10000 | 2114 | Tend to become more distant as development in outer areas is increasing |
| Average distance between local center and estate center (m) | 80 | 2100 | 417.1 | In case of planned development, the district center is generally situated at a place that can be accessed on foot |
| Roads exclusively for pedestrians within estate | n(52) | y(59) | | Generally planned in complexes constructed in or after the mid 1990s |
| Link between pedestrian roads inside estate and outside | n(77) | y(34) | | Not connected systematically on a urban level until recently |
| Number of pedestrian crossings to elementary school | 0 | 0 | 0.9 | Relatively satisfactory because of consideration in the plan of housing site development |
| Roads for cycling | n(69) | y(42) | | Reflected in recently constructed complexes but insufficient on a urban level |
| Bicycle parking capacity per 100 households | 0 | 34 | 8.2 | Gradually increasing |
| Average distance between subway station (bus stop) and estate center (m) | 100 | 10000 | 823 | With the increase of subway lines, more complexes have high accessibility |
| Width of roads around estate (lane) | 2 | 6 | | As urban structure is still driveway-oriented, many wide roads separate urban spaces |
| **Energy / Resource use** |
| Combined heating system | n(29) | y(82) | | Applied to most large-sized development |
| Solar energy use (% of household) | n(105) | y(6) | | Applied experimentally and quite partially since Gwacheon Complex I |
| Rainwater, heavy water recycling facility | n(110) | y(1) | | Begin to be considered in planning stages but is reflected in few cases |
| Water-saving equipment | n(68) | y(42) | | Gradually expanded (some facilities are mandatory) |
| Permeable pavement area ratio(%) | n(103) | y(8) | | Reflected in residential areas as people recognize the importance of permeable pavement |
| Living waste disposal facility within estate | n(105) | y(6) | | Attempted not only for new complexes but also existing ones, but cause problems such as bad smell, noise and excessive production of compost |
| Recycling of construction wastes | n(110) | y(1) | | Encouraged strongly by the government but attempted quite limitedly |
| **Ecological environment** |
| Green area ratio (%) | 15.5 | 24.4 | 33.9 | Shrunk due to high-density development in the 1990s but is increasing in response to consumers demand |
| Small brooks, ponds, etc. | n(100) | y(11) | | Some complexes professing environment-friendliness are found to allot 0.5% of the land size, |
| Vegetable gardens, hills, nature learning centers, etc. | n(96) | y(15) | | Some complexes professing environment-friendliness are found to allot 0.1% of the land size, |
| Accessibility to neighbouring parks, rivers, forests (m) | 10 | 1300 | 253.7 | In many cases, accessibility is found favorable because of a lot of mountains and hills |
| Interconnection among green areas within estate | n(62) | y(49) | | Recently the linkage of green areas is dealt with as a weighty matter in planning |
| **Indoor Environment** |
| Ratio of southern exposure (%) | 36 | 100 | 87.4 | Increasingly strengthened |
| Restriction of the use of harmful materials | n(104) | y(7) | | The use of natural materials (wood, natural paint, etc.) are attempted |
| Court-like balcony | n(110) | y(1) | | Considered recently in environment-friendly complexes but seldom applied |
| Flexible plan design | n(107) | y(4) | | There are an increasing number of attempts |
| **Additional sectors** |
| Nature-restoring slope face method | n(111) | y(0) | | Do not go beyond the erection of existing breast walls yet |
| Preserving natural landform | n(107) | y(4) | | Emerge as the most important issue in recent complex development |
| Utilizing surface soil | n(111) | y(0) | | Have never been attempted |
| Planned development | n(17) | y(94) | | Recently systematic development plans are being established |
| Information communication network | n(65) | y(46) | | Introduced more widely |
| Plan for community center or spaces | n(91) | y(20) | | Community space planning is increasing but actual construction of community centers is rare |
planned for efficient car traffic, so many of their roads have six or more lanes, which is a point to be improved.

According to the result of analysis on indicators related to energy and the use of resources, most large-sized complexes adopt district heating systems, and more than 70% of apartment complexes investigated in this study benefit from district heating. District heating is efficient in generating and supplying heat and superior to other heating systems in the costs of house heating and hot water, so is recommendable for a future heating system.

Solar energy facilities were used first in a solar energy model complex in Gwacheon Complex I as Gwacheon New Town was constructed in the early 1980s under the oil shock, but since then there has been no attempt. With increasing interest in natural energy and according to governmental policies, however, solar cells and solar collections have been installed in some apartment complexes since the late 1990s. Although such attempts may be understood as a positive start, the use of solar energy is extremely meager compared to the whole energy consumption.

As their necessities have been recognized, the reuse of rainwater and the utilization of heavy water have been actively pursued but there are few cases of introduction of such systems. Because spaces inside apartment complexes in Korea are paved, they are dry and extremely poor for plants to grow, so it is one of important tasks to utilize rainwater and heavy water in the future. Water-resource saving facilities are becoming gradually popular and some of them are mandatory. The importance of permeable pavement has been widely acknowledged, but not many complexes have tried it. It is because the cost of permeable pavement is much higher than general pavement.

Facilities to convert living wastes to compost were found not only in new complexes but also in old ones, but side effects such as bad smell, noise and vermin as well as difficulties in using produced compost hinder the popularization of the facilities, so it is necessary to take measures for these problems. The recycling of construction wastes has hardly been executed despite the government’s strong encouragement.
As for indicators related to ecological environment, green rate appeared to go higher as consumers get tired of high-density development and demand more green areas. Aquatic biotopes such as small brooks and ponds are increasing recently, and in some cases 0.5% of the land size was allotted for an aquatic biotope. Terrestrial biotopes as well are in the same tendency, so those occupying 1% of the land size were found.

Accessibility to surrounding natural resources appeared to be high in most cases because Korea has many mountains and rivers. The average distance to natural resources was merely 253m. Many of recently developed complexes consider the linkage of green areas within complexes in response to the necessity of eco-corridor.

As for indicators related to indoor environment, the rate of apartments facing the south appeared to increase. On the other hand, natural materials such as wood and natural paint are used more than before to inhibit the use of harmful materials.

Court-like balcony was found only in housing complexes constructed by H Construction under the slogan of environment-friendliness aiming at the introduction of indoor green spaces. The plan is to create a green space like a flower garden at part of balcony in front of the living room. The size of the green space was approximately 4m². Recently the government enforced a system that expands the limit of balcony width form 1.5m to 2m for garden-typed ones, so it is expected for garden-typed balconies to be gradually popularized.

There was no case that adopted re-vegetation technology for ecological restoration of cut-slopes. The conservation of natural topography has emerged as an important issue and, encouragingly, complexes that preserve hills inside the complexes are appearing in Korea. However, no complex that practiced surface soil conservation was found.

In addition, the enforcement of planned development appeared to result in the gradual reduction of disordered development, and the construction of information telecommunication network appeared to become common. Lastly, as for community facilities and spaces, there have been positive attempts to install community spaces but the construction of community centers was rare yet. Thus it is necessary to pay attention to them with efforts.

5. Analysis of Assessment by Housing Estate

The results of assessment of representative complexes are as follows. First, Jamsil Complex constructed in the mid 1970s has a low volume ratio and is located in a secondary center of Seoul, though the place was a suburb of the city when it was constructed, so it is highly accessible from the downtown and close to subway stations. In addition, its high green rate and closeness to the Han River makes it get high score of 76.2 in assessment though it is an old complex. Therefore, the main factors of the high evaluation of Jamsil Complex are its low density and high accessibility.

Gwacheon, which got the highest mark among assessed complexes, is a new town developed as a satellite city of Seoul in the early 1980s under the motto of ‘Garden City.’ Most apartment buildings in the city are medium-high and have a low volume ratio. Furthermore, the size of the city was designed so that residents can access the city center from their apartments on foot. What is more, a subway line from Seoul passes through the city center, so public transportation is quite favorable. The residence is supported by ecological environments including high green rate and other surrounding natural resources. Therefore, Gwacheon can be a model for the development of future residences and new towns in terms of size, location, density, etc.

Sanggye Complex, which was constructed in 1980 to solve ordinary people’s housing problem, is a new town situated in the northwestern Seoul. The complex includes a well-developed subway network connected to the city center as well as well-designed pavements and green roads and a high rate of green areas. In addition, its ecological condition is fine thanks to nearby Mt. Bukhan. Furthermore, the complex is equipped with district heating systems and is advantageous to heating energy saving because a large part of apartments face the south. Therefore, Sanggye Complex scored a high mark in sustainability due to the systematic planning and connection of public transportation means and pavements, district heating system, etc.

Like Sanggye Complex, Bundang New Town, which is one of the five new towns developed in the early 1990s, also has well-developed subway line to Seoul and public transportation means as well as district heating systems covering the whole town. It also has a high rate of green areas and is surrounded by hills and mountains (Mt.

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Table 12. Sustainability Marks of Representative Housing Estates and by Area (average marks by area in parentheses)

| Score | Estates |
|-------|--------|
| 80– | Gwacheon, H-Housing, Ansan, Bundang, Ilsan, Sanggye |
| 60–79 | Jamsil, Gaepo, Giheung Sanggul, Yeongdeok |
| 40–59 | Yongin Suji, Sinjeong, Banghwa, Jungdong, Suwon Kwonseon, Banghuldong redevelopment |
| ~ 39 | Jukjeon Kilhoon, Yongin Gugal, Jongamdong redevelopment |

Fig.5. Distribution of Sustainability Marks of Multi-Family Housing Estates
Fig 6. Distribution of Sustainability Marks of Multi-Family Housing Estates
### Table 13. Contents of Plans and Assessment Marks by Complexes

| Indicators / Estates (Score) | Jamsil (mean) | Gwachoeon (mean) | Ssanggye (mean) | Bundang (mean) | Yongsan Sugi (mean) | Yongsan Sugi (mean) | Jangnam Re-development (mean) | Ansan Gojan (Turn Key) (mean) | H Housing (mean) |
|-----------------------------|---------------|-----------------|-----------------|---------------|-------------------|-------------------|-----------------------------|-----------------------------|-----------------|
| Volume Ratio                | 99.6 (19)     | 90.9 (19.3)     | 154.1 (12)      | 148.6 (13.1)  | 193.9 (17.2)      | 39.2 (0)          | 127.1 (15.6)               | 107.0 (7.3)                  |                 |
| Average distance between city center and estate center (m) | 342(4)        | 734(4)          | 796(4)          | 3170(2)       | 3830(2)           | 4100(2)           | 2000(4)                    | 5000(0)                    |                 |
| Average distance between local center and estate center (m) | 306(4)        | 2500(4)         | 416(4)          | 380(4)        | 336(4)            | 400(4)            | 500(4)                     | 100(4)                     |                 |
| Roads exclusively for pedestrians within estate | n             | y(4)            | y(4)            | y(4)          | y(4)              | y(4)              | y(4)                        | y(4)                        |                 |
| Link between pedestrian roads inside estate and outside | n             | y(2)            | y(2)            | y(2)          | y(1)              | n                 | n                           | y(2)                        |                 |
| Number of pedestrian crossings to elementary school | 0.2(4)        | 1.2(2)          | 1.1(2)          | 0.7(2)        | 0.7(3)            | 2.0                | 0.4(2)                      | 1.2(2)                      |                 |
| Roads for cycling | y(4)          | y(4)            | n               | y(4)          | n                 | n                 | y(2)                        | y(2)                        |                 |
| Bicycle parking capacity per 100 households | n             | 18(2)           | 15(2)           | 14(2)         | 4(1)              | n                 | 15(2)                       | 15(2)                       |                 |
| Average distance between subway stations (bus stops) and estate center (m) | 3300(12)      | 434(5.9)        | 447(12)         | 850(10)       | 1797(3)           | 400(12)           | 100(12)                     | n                           |                 |
| Width of roads around estate (lane) | 6(0)          | 2.3(4)          | 2.4(5)          | 4(1)          | 4(1)              | 6(0)              | 8(0)                        | 8(0)                        |                 |
| Combined heating system | n             | n               | y(5)            | n             | n                 | n                 | n                           | n                           | y(5)            |
| Solar energy use (% of households) | n             | y(5)            | n               | n             | n                 | n                 | n                           | n                           | n               |
| Rainwater, heavy water recycling facility | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| Water-saving equipment | n             | n               | n               | y(2)          | y(2)              | y(2)              | y(2)                        | y(2)                        | y(2)            |
| Permeable pavement area ratio (%) | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| Living waste disposal facility within estate | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| Recycling of construction wastes | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| Green area ratio (%) | 53.4(12)      | 41.6(10)        | 43.9(12)        | 34.9(8)       | 30(0)             | 30(0)             | 31(0)                       | 42.3(12)                    |                 |
| Small brooks, ponds, etc. | n             | y(2)            | n               | n             | y(2)              | n                 | n                           | n                           | n               |
| Vegetable gardens, hills, nature learning centers, etc. | n             | y(2)            | y(2)            | n             | n                 | n                 | n                           | y(10)                       |                 |
| Accessibility to neighboring parks, rivers, forests (m) | 369(3.2)      | 46(6.4)         | 262(4.4)        | 186.3         | 157.5(6)          | 150(4)            | 100(10)                     | near(60)                    |                 |
| Intercorssion among green areas within estate | n             | y(4)            | y(2)            | y(1)          | n                 | n                 | y(4)                        | y(1)                        |                 |
| Indoor Environment | 89(6)          | 80(5)           | 94(8)           | 88(5)         | 100(8)            | 83(4)             | 92(5)                       | 100(8)                     |                 |
| Ratio of southern exposure (%) | y(2)          | y(3)            | n               | y(3)          | y(3)              | y(3)              | y(3)                        | y(1)                        |                 |
| Restriction of the use of harmful materials | y(2)          | y(3)            | n               | y(3)          | y(3)              | y(3)              | n                           | y(1)                        |                 |
| Court-like balcony | n             | n               | n               | n             | n                 | n                 | n                           | y(1)                        |                 |
| Flexible plan design | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| nature-restoring slope face method | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| preserving natural landform | n             | n               | n               | n             | n                 | n                 | n                           | y(6)                        |                 |
| utilizing surface soil | n             | n               | n               | n             | n                 | n                 | n                           | n                           | n               |
| planned development | y(5)          | y(5)            | y(5)            | y(4)          | y(3)              | y(5)              | y(5)                        | y(5)                        |                 |
| information communication network | n             | n               | n               | y(4)          | y(4)              | y(4)              | y(4)                        | y(3)                        |                 |
| plan for community center or spaces | n             | y(2)            | n               | y(1)          | y(1)              | n                 | y(4)                        | y(3)                        |                 |
| Total Score | 76.2          | 94.6            | 91.8            | 85.2          | 59.7              | 35.0              | 90.6                        | 90.8                        |                 |

* As for green rate, marks were given based on the ratio of exceeding 15% for public complexes that are composed of small-sized houses according to the law and 30% for private complexes that are composed of medium and large-sized houses.

Bulgok). A river (Tancheon) is flowing across the city, giving all areas of the city high accessibility to nearby natural resources. The city has an advanced information telecommunication network. Bundang New Town made a good score because of its well-planned outstanding public transportation network, district heating system, fine surrounding natural environment and advanced information telecommunication system.

Yongin Sugi Complex, which is branded as a representative example of disordered development in the capital area, was mainly developed by private developers in the mid 1990s. It has been under controversy continually even after development due to lack of convenience and education facilities. The result of analysis showed that its volume ratio is relative high and the green rate is low compared to other new towns. Its accessibility to the city center and public transportation means are also poor. Such poor location conditions and unsystematic development resulted in a low mark for Yongin Sugi Complex.

Another complex is Jongam-dong Redevelopment Apartment District. It is a super high-density complex, which floor area ration is 369.2%, four times higher than Gwacheon and 2.5 times higher than Bundang. With such a high development density, its green rate is lowest and environmental considerations are hardly found. As a result, its score was as low as 35. Jongam-dong Redevelopment Apartment District evidences that excessively dense development lowers sustainability.

On the other hand, Ansan Gojan District, which was developed under turn-key base contracts in the late 1990s, has a low volume ratio, is close to subway stations and includes bicycle stations and public transportation means. In addition, although it is a public complex populated with small-sized houses, its green rate is high and environmental condition is favorable.

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thanks to natural environment close at hand. What is more, the district is equipped with fine community spaces for residents. Because of these factors, Ansan Gojan District got a mark over 90. Turn-key base contracts are design-construction bids systems, so apartments are constructed as they are designed. This may contributed to the high mark of the district.

Lastly, according to the result of analyzing the residential complex constructed by H Construction Co., Ltd., which recently adopted the slogan of ‘Environment-Friendly Residential complex’, it received scores higher than 90 despite its poor transportation condition and accessibility to the city center as it is situated in the outskirts of the city. Such a high score came from the following factors. First of all, it has a high rate of green areas as well as biotopes within the complex and links them in a systematic way. Next, the complex installed district heating systems and water-saving equipment to save energy and resources, and made efforts to create ecological indoor environment by restraining the use of harmful materials and making gardens using the balconies. Besides, it preserved natural environment in the complex, constructed information telecommunication networks, erected community centers, etc. These factors are considered to raise the score. Such analysis results show the potential of recent environment-friendly apartments under construction.

Achievements of sustainability by sector for the sectors of landuse and transportation, energy and resource, ecological environment, and indoor environment, varied from 28 to 97. As for the average mark of representative residential areas, Gwacheon scored the highest mark of 94.6. It is probably because the city has a low housing density, good public transportation and high pedestrian accessibility to the city center from each housing estate. In addition, the mountains surrounding the city are thought to contribute to its fine ecological environment.

Multi-family housing estates scoring over 80 include such new towns as Ilsan, Bundang and Sanggye.

Meanwhile, housing estates scoring over 70 include Jamsil, Gaepo, and Mokdong, which are large-sized urban housing sites. Housing estates scoring low marks are mostly those developed in a disorderly fashion on semi-farmlands, or redeveloped in midtown areas. They characteristically have high volume ratios and low green area ratios. Estates scoring high marks, such as Gwacheon, received a large portion of their marks in the sectors of landuse and transportation and ecological environment (Figure 6). However, newer housing estates developed under turnkey projects received a more even distribution of marks throughout all sectors including energy and resource use, rather than in one or two particular sectors. Also, housing estates developed under the slogan of environmental friendliness appeared to be score very well in the sectors of ecological environment, indoor environment and additional sector. These results suggest that the turnkey system is effective in enhancing sustainability, and that policies promoting the development of environmentally friendly housing estates are desirable.

6. Conclusions

As presented above, this study selected 111 representative multi-family housing estates in Korea, assessed their sustainability using sustainability indicators and standards, and drew the following conclusions from the assessment results.

First, according to the sustainability assessment by sector, sustainability in terms of landuse and transportation appeared high with regard to the distance between the local center and estate center, the distance between the city center and the estate center, and the distance to a subway station or bus stop, but low with regard to pedestrian roads and their linkage to external roads, cycling roads and bicycling parking capacity. Another problem found was that many wide roads made housing estates vehicle-oriented rather than pedestrian-oriented.

In the sector of energy and resource use, sustainability was satisfactory with regard to combined heating systems and water-saving equipment, but generally low. In the sector of ecological environment, green area ratio and accessibility to neighboring natural resources were favorable, but biotopes were poorly developed. As for indoor environments, only southern exposure was satisfactory, and other indicators were quite low in general. In additional sectors, planned housing site development and information communication networks were considered acceptable.

Second, we have seen that achievement in the sector of landuse and transportation was highest at 50.8%, and that in the sector of energy and resource use was lowest at 13%. This implies that, in designing housing estates in Korea, concerns over sustainability are mainly focused on location rather than on the use of natural energy or the circulation and recycling of resources, so special measures are necessary in this sector. However, due to the boom in environmentally friendly housing estate construction since the late 1990s, the sectors of ecological environment and indoor environment scored achievements over 32%. This shows that these sectors also receive more attention than the sector of energy and resource use.

Third, as for the achievement of each indicator, location-related indicators such as volume ratio, the distance between the city center and the estate center and the distance to public transportation, and indicators such as combined heating system, green area ratio, southern exposure and planned development scored achievements over 50%. These indicators are considered to be highly cost efficient or interesting to consumers. On the contrary, solar heat use, heavy water use, construction waste recycling, biotope creation, the suppression of the use of harmful materials, and the preservation of surface soil, which are costly or have low visible effects, scored achievements less than 10%. These areas require concentrated efforts in the future.

Fourth, in assessment by housing estates, Gwacheon,
which is environmentally friendly and of low density, got the highest overall mark of over 90 points. Next, large-scaled new towns such as Ilsan, Bundang, and Sanggye scored 80 points or higher. However, areas developed in a disorderly way or redeveloped scored 60 points or lower, which evidences the necessity for changing these development methods.

Fifth, large-sized new towns got high marks only in the sector of landuse and transportation, but newer housing estates developed under the slogan of environmentally friendliness or the turnkey system scored relatively high marks in the sectors of indoor environment as well as ecological environment, which is an encouraging trend.

In conclusion, the sustainability of multi-family housing estates in Korea has reached a certain level in the sector of landuse and transportation, and recently many new housing estates are making active attempts to improve sustainability in the sectors of ecological environment and indoor environment. However, the overall level of sustainability is still low. In particular, sustainability in the sector of energy and resource use is poor, so governmental support and efforts in all relevant areas are required. Achievements in assessment items such as solar energy use, the recycling of rainwater and heavy water, construction waste recycling, ecologically sound indoor environment, flexible design plans, natural restoration and the utilization of surface soil remain at less than 5%, so there should be special supportive measures.

This study is meaningful in that it diagnosed the current state of multi-family housing estates in Korea through assessment of their sustainability and proposed a direction for improving sustainability. However, this study has limits in that it confined subject housing estates to Seoul and the capital area. The generality of these results will be determined only through nationwide assessment in the future.

Acknowledgments

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Notes
1 Sustainable development is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”
2 Ministry of Construction and Transportation, A study on policies and systems for the development of sustainable human settlements (I), (II), (III), 1996-2000, Korea National Housing Corporation, Housing Research Institute, This study defined the concept of sustainable housing estates, created a planning model and developed an assessment method. This assessment method is being utilized as the official Korean model for assessing the environment-friendliness housing estates.
3 UNCHS(1996), HABITAT II Agenda
4 For detailed assessment method, see ibid, pp94-106
5 Ministry of Construction and Transportation(1999), Energy Performance Index
6 Achievement is the ratio of the attained mark to the possible full mark in percentage. Thus it shows the current level of the corresponding indicators in comparison with the target.
7 These diagrams are to compare the achievement of Gwacheon and Turnkey Projects by assessment sectors. Because the full mark of each sector is different, these diagrams used the ratio of the attained mark to the possible full mark in percentage to compare the sectors based on the same scales.

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