KSI Experimental Housing Project  
- Pilot project of Kodan Skeleton Infill Housing -  

Satoshi Ikeda, Masami Amino  
Urban Development Corporation  
1-14-6 Kudan-kita, Chiyoda-ku, Tokyo, 102-8201, JAPAN

Abstract  
Urban Development Corporation (UDC) plans to supply of skeleton (support) and infill housing, and UDC has promoted technological development for SI housing. At first UDC constructed KSI experimental housing in UDC technology center, and studies on both skeleton and infill technologies. So this paper deals with this KSI experimental housing. Concretely speaking, as for the skeleton rigid frame structure is employed considering its durability. On the other hand, 4 housing infill units were constructed in KSI experimental housing. One infill unit was designed by UDC and the other 3 were designed by private companies. Each infill unit has respective features depending on its adaptability.

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1. Introduction / Concept of KSI housing  

1.1 Purpose of KSI housing  
UDC has launched a comprehensive experimental project named "KSI". SI represents Skeleton (or Support) and Infill. K is the initial of KODAN which means public corporation in Japanese language and also it is familiar to many people as KODAN housing. The reason why UDC promotes KSI project is that SI system has many possibilities to solve lots of problems which urban collective housing is facing at present. UDC studied KSI's possibilities based on the following 4 view points.

(1) Social concern  
Saving energy and natural resources, keeping durability and adaptability  
(2) Urban design  
Adaptability of collective housing to many kinds of changes of urban function in the future  
(3) Customers' needs  
Flexibility and adaptability of interiors design  
(4) New industries  
Promotion of "infill industries" through implementation of SI system

1.2 Goal of KSI housing project  
KSI housing project is positioned to be a leading development project in UDC. Its goal is as follows;

(1) To develop new SI housing technology which could be associated with UDC activities.  
(2) To disseminate SI housing system in Japan.

1.3 The Program of KSI housing project  
KSI housing project is composed of 4 stages shown as follows. (fig. 2)  

1st stage  
* Design for KSI housing  
2nd stage  
* Construction of KSI experimental housing  
* Development of supply system
3rd stage
* Trial construction and supply in model projects
* Standardization by degrees based on SI specification
4th stage (not concreted yet at present)
* Development concerning the renewal of collective housing
* Development to solve another problems which should be clear in the course of the project

At present, the construction of the 2nd stage has been completed. Therefore this paper deals with the 1st and 2nd stage in details.

1.4 Technological features of KSI housing
UDC attaches importance to the following 3 points, as a technological features of KSI housing.
(1) open use
Since the UDC is a public institution, development of the KSI housing is not focused on special technologies and systems available only under limited circumstances, but on openly used technologies and systems applicable to UDC housing and collective housing in Japan.
(2) economy
Economy and open use are closely connected to the prevalence, therefore, is specifically emphasized. For example, KSI housing is designed to be 3,000mm story height because of economy.
(3) practicality
In terms of practicality, UDC as a housing supplier will employ existing technologies and new technologies with potential for implementation at an earlier date to reflect the outcome of research and development on actual projects as early as possible. The essential technologies and systems used in KSI housing are evaluated from an economical viewpoint, as well as durability, easy maintenance and rearrangement.

1.5 Design criteria for KSI housing
Among the essential technologies complying with the concept of KSI housing, UDC has specified the following most important design criteria as essential requirements.
(1) Structure life of 100 years.
(2) One large floor slab without unevenness and sub-beams.
(3) Vertical drain pipes installed in the common area.
(4) Electrical wiring should be separated from the structure.
Compliance with all of the above KSI essential requirements in the design of each project would mean a building complying with the concept of KSI housing.

2. KSI Experimental Housing

2.1 Outline of KSI experimental housing
UDC built KSI experimental housing at UDC Technology Center which is located in Hachioji city based on the concept of the KSI housing mainly to review essential technologies. The purpose of
Experimental housing can be summarized into the following 3 points.

1. Review of SI technologies by experiments and verification.
2. Research and development in collaboration with private companies with related technologies.
3. Dissemination of SI housing by disclosing the results of these efforts to the public.

2.2 Design policies for KSI experimental housing

UDC considers that the essential character of KSI is as follows;

1. Durability of the structure over 100 years.
2. Flexibility and adaptability for infill layout, unit size and use.
   - slab without sub-beam, vertical drain piping outside of the unit and wiring outside of the frame.
3. Economically examined story height on condition of barrier-free.
   - pursuit of using regular slab instead of usually used reversed girder.

As for the separation, UDC has classified non-bearing wall (like outer wall and partition wall) and windows into "common use infill" apart from "private infill". When the condition of design was set, UDC has decided that the building should be applicable to a standard size of building and unit, that is, an open corridor-access system, 11 stories and 75 m²/unit.

Table 1 Outline of KSI Experimental housing

<table>
<thead>
<tr>
<th>Building Data</th>
<th>History of the experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Frame; Rigid frame structure with non-bearing wall</td>
<td>1997.12 Start of design</td>
</tr>
<tr>
<td>· Height; Two stories (designed as a part of 11 stories)</td>
<td>1998.06 Start of construction</td>
</tr>
<tr>
<td>· Floor area; About 500 m²</td>
<td>1998.09 Application of technological proposals from private enterprises</td>
</tr>
<tr>
<td>· Outline of the rooms</td>
<td>1998.11 Completion of skeleton and a part of infill.</td>
</tr>
<tr>
<td>103,102 Exhibition room</td>
<td>Exhibition of those completed part</td>
</tr>
<tr>
<td>203 Experimental infill by UDC</td>
<td>1999.06 Completion of remaining experimental infill.</td>
</tr>
<tr>
<td>101,201,202 Experimental infill in collaboration with private enterprises</td>
<td>Exhibition of whole parts</td>
</tr>
<tr>
<td></td>
<td>1999.12 Renewal of the part of experimental infill</td>
</tr>
</tbody>
</table>

Fig. 3 First floor plan

Fig. 4 Second floor plan

Fig. 5 Section

Fig. 6 KSI Experimental housing
3. Skeleton of KSI experimental housing

One of the most attractive points of KSI Housing is its highly durable Skeleton, which can be maintained for as long as 100 years. KSI experimental housing has 3.6m story height in first floor (considering house could be changed into shops, offices, etc.) and has 3.0m story height in second floor which is higher than average height. Skeleton technologies employed for the experimental housing are introduced here.

3.1 Highly durable structure
In order to achieve a long life of 100 years, high design criteria for reinforced concrete forming a core structural component have been employed. To avoid occurrence of explosion due to rainwater invading through cracks, a major cause of defects in reinforced concrete, two methods are available increasing covering depth by 10mm and having water-cement ratio of 55% or less. Both methods have been employed for the experimental housing.

3.2 Solid rigid frame/pre-stressed concrete beams
The structure of experimental housing employs a solid rigid frame with non-bearing walls. This is because experimental housing requires non-bearing walls for party walls allow changes of unit-size. For normal projects where changing unit-size is not necessarily required, a rigid frame with bearing walls may be more economically advantageous. Since a 10m span has been required to be designed in the span direction for economic reasons in experimental housing, pre-stressed concrete beams for reinforced concrete have been employed in the span direction. (Fig.7)

3.3 One large floor slab
KSI housing requires a flat floor free from sub-beams and unevenness of slabs to minimize constraints in floor planing for layout changes. For this reason, one large floor span with void has been employed. This slab is enlarged by burying styrene foam or metal pipes (frame for void) in the void area of concrete. In comparison to other slabs of the same weight (per square meter), this slab has more stiffness to allow large slab installation at the long span, and is expected to attain high soundproofing qualities.

3.4 Supply piping and wiring in centralized vertical shaft system / supply piping and wiring
For supply of utilities such as water, gas, electricity and communication the experimental housing uses a centralized vertical shaft located in the common outside corridor. (Fig.8)
Conventionally, utilities are supplied vertically and individually in a meter box of each housing unit. When allotment of housing unit will be changed in the future, however, the installed supply piping will become constraints on layout changes. Therefore, the experimental housing has employed a centralized vertical shaft to bring utilities and parallel piping / wiring from the shaft in the space above the suspended ceiling of the corridor to connect to the meter box of each unit. As the centralized vertical shaft is closely connected with changing unit-size, the system needs further review and research together with bearing walls system.

3.5 Installation of vertical common drain piping outside of the housing unit / drain header
Conventionally, two to three common vertical drain pipes are installed inside housing units, therefore, they put constraints on layout changes. In KSI housing, the drain header in combination with a low gradient drain system is concentrated at one common drain pipe at the meter box outside the unit.
(Fig. 9) This system has the following merits.
(a) High flexibility for the original layout
(b) Reducing constraints for layout change
(c) Excellent maintenance compared with the limited access to the insides of housing units for cleaning
(d) Reduced drainage sound because of installation outside housing units

3.6 Modular coordination
Modular coordination means a design using certain dimensions (module) for efficiency of housing production from design stage to construction. For KSI housing, a module of 300mm has been used according to the dimensional rules set by UDC. In reality, clear dimensions of secondary walls have been established as 300N(300mm × N) with a supplemental dimension of 150mm added where necessary. Housing components such as unit bathrooms are excluded from the modular coordination.

![Diagram of Housing on the roof top and Structure](image)

Fig. 10 Skeleton of KSI Experimental housing

4. Infill of KSI experimental housing

UDC also developed technologies for Infill system and made work-experiment at 203 room of KSI experimental housing. (Fig. 11) It was completed at November 1998 and opened to public at the same time with Skeleton and a small exhibition room in which the history and technologies of open building were shown.

On the other hand, UDC looked for technological proposals for KSI project to private enterprises at September 1998. From 40 companies, 48 proposals were presented. As the results, using 3 empty rooms of KSI housing, UDC began to make work-experiment in collaboration with 11 companies. Those were completed at May 1999 and opened to the public. After that, 2 units have already been renewed.

Each infill has respective characteristic as follows;
Fig. 11 203 room
Note
1) This infill unit named "Infill Studio" uses technologies developed by UDC.
2) This unit plan was symbolically designed to express the flexibility of water service area.

Fig. 12 101 room / 3-D (3-Dimension) Si housing
Note
1) The basic idea of 3-D is to keep story height higher (approximately 1.5 times of ordinary house) and realize a comfortable living space.
2) Although the story height is 1.2 times at this time, the principal concept is succeeded.
3) Water service area is concentrated at one side of plan to gain maximum volume of 3-D free space.
4) The space under the floor is used for heating pipes, electrical and multimedia wiring, storage units, etc.
Fig. 13  201 room / integrated infill system  already made renewal
Note
1) The proposer is developing their own infill system.
2) Dressing wall units are faced party wall and exterior wall.
3) The space behind dressing wall units are used for electrical wiring and drainpipes.
4) The space upper the ceiling and under the floor are used for equipment.
5) The workers with capability of making all infill parts, practice working.

Fig. 14  202 room / infill components system by 8 companies  already made renewal
Note
1) The 8 companies make the work-experiment of each part, floor, partition, etc. assembled by UDC.
2) Infill space is made up by floor units and partitions.
3) The space under elevated floor is used for electrical wiring, drainpipe and supply piping. Air-conditioning and ventilation is supposed to be put in ceiling ducts.
5. Conclusion

As reported above, the development of KSI housing has steadily progressed through housing research, design of essential technologies, and construction of experimental housing. On the other hand, the progress of technological development has revealed new problems and issues, requiring a wider range of KSI housing research and development. General issues related to KSI housing are listed below:

1. Model projects
2. Standardization by degrees
3. Cost analysis and cost reduction
4. Application to renovation technologies

Supply systems (software) of KSI housing also need further review, which is another big issue.

Model projects
Model project means a leading and trial project to be actually constructed and supplied to the market. At present UDC has started to construct 5 KSI model projects. The list of model projects is as follows.

Table 2: Model projects

<table>
<thead>
<tr>
<th>Project name</th>
<th>Meguro-higashi project</th>
<th>Shiodome project</th>
<th>Sangenjaya project</th>
<th>Shiga-koen project</th>
<th>Takami project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Meguro, Tokyo</td>
<td>Minato, Tokyo</td>
<td>Setagaya, Tokyo</td>
<td>Kita, Nagoya</td>
<td>Konohana, Osaka</td>
</tr>
<tr>
<td>Number of stories</td>
<td>6-13 stories</td>
<td>56 stories</td>
<td>6 stories</td>
<td>7 stories</td>
<td>14 stories</td>
</tr>
<tr>
<td>Number of housing</td>
<td>484</td>
<td>About 900</td>
<td>47</td>
<td>62</td>
<td>240</td>
</tr>
</tbody>
</table>

Standardization by degrees
Standardization means that all UDC housing will be gradually upgraded to meet the requirements of the KSI housing concept. In order to realize the standardization, design criteria should be prioritized based on the cost analysis and useful details should be developed. These are also important issues in terms of disseminating KSI housing.

cost analysis and cost reduction
Cost analysis and cost reduction are important for UDC as a housing supplier in particular and are essential for disseminating KSI housing. This is more appropriately rephrased: "How the cost increase incurred to build SI housing can be reduced" and requires review of both the Skeleton and Infill. On the other hand, SI housing improves maintenance and renewal opportunities, and may well pay off from LCC (Life-Cycle Cost) viewpoints. This is another issue to be verified.

Application to renovation technologies
Lots of the housing stocks face to the problems of the renovation. These stocks are not necessarily built separated I from S, but SI system is expected to be applied for the renovation technologies.

6. Reference
2) Masami AMINO, Satoshi IKEDA, and others, A series of summaries of technical papers on "KSI housing project", Summaries of annual meeting AJU (Architectural Institute of Japan) 2000