Framework for Long-Term Public Housing Supply Plan Focusing on Small-Scale Offsite Construction in Seoul

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Abstract: The public housing demand in Seoul has been continuously increasing, but the available land for housing is insufficient. To meet the demand, the Seoul government is planning to develop small-scale housing in urban areas through various methods. Construction activities for increasing housing capacity cause negative environmental impacts, and this inevitably leads to an increase in the number of civil complaints. The complaints can be mitigated by using offsite construction (OSC) for fabricating components. However, OSC remains underdeveloped in Korea owing to concerns over high project costs. To promote OSC, the government must develop a long-term plan to secure demand for OSC. For such a plan, the number and feasibility of applicable sites in Seoul must be estimated. This study suggests a two-stage research framework: (1) estimate the number of applicable sites in Seoul using GIS and (2) conduct feasibility analyses of these sites through architectural planning. The estimated number of sites was equal to the expected supply of small-scale housing units in Seoul for 8 years, and the selected case sites were identified to be feasible. Therefore, the use of OSC for developing small-scale housing units in Seoul is reasonable. This research differs from previous studies in that the previous use of qualitative studies to promote modular construction was replaced with a quantitative analysis that included the entire Seoul area. Using the research framework, the Seoul government can develop a specific long-term plan based on the quantitative research analysis. Furthermore, manufacturers can develop plans based on the government plan and deliver returns on the higher initial costs. The contractors can reduce the higher project cost and doing so is expected to mitigate the negative perception and to promote modular construction in Korea.

Keywords: small-scale housing supply; offsite construction (OSC), modular construction; feasibility analysis; long-term supply plan; geographical information system (GIS)

1. Introduction

Urban construction projects impact the environment negatively, such as through demolition waste, construction waste, noise, dust, and vibration, which result in civil complaints and, in turn, schedule and cost overruns [1–4]. To mitigate these problems while improving the project performance, the construction industry has adopted offsite construction (OSC) methods [2,3]. In OSC projects, construction work is performed in a factory environment instead of onsite [5]. OSC is, therefore, considered promising compared with conventional construction methods [6,7].

Modular construction is a promising OSC method [8]. In this method, a significant proportion of construction work is conducted in a factory rather than onsite, resulting in reduced civil complaints, construction duration, waste, and cost while providing higher quality. Therefore, this method is considered an effective and sustainable solution for dealing with the growing housing demand in urban areas [2,9,10]. In particular, modular construction is being used in cities such as Hong Kong, Singapore, and Melbourne to rapidly and efficiently construct buildings in both the private and the public sectors [10,11]. Seoul is a densely populated urban area and has seen increasing public housing demand, especially in the central urban area. The public housing supplier of Seoul (PHSS)
is supplying housing to meet this demand; nonetheless, its average inventory rate remains lower than that of other OECD countries [10]. To increase supply, the PHSS is planning to adopt a development scheme that uses a small-scale site acquired from either the public or the private sectors in a central urban area. It is also planning to use modular construction methods for supply. By use of unit production in a factory, it is expected that development can be effectively conducted without negative environmental impacts [12,13]. To validate the applicability of this approach in urban areas, exemplar modular projects have been conducted, and these were shown to result in reduced civil complaints and disruptions to nearby public services [10].

In spite of the adoption plan of the government and its applicability, the Korean construction industry remains hesitant to adopt modular construction methods, and these conservative attitudes are affecting the sustainability of modular housing supply. The main reason for this hesitation is negative perceptions related to high costs [11,14,15]. To overcome these perceptions and promote modular construction, the UK, Australia, Hong Kong, and Singapore governments, all of which have effectively implemented modular construction, have publicized the long-term direction of their housing supply plans [11,15]. Contractors can accordingly develop a plan that delivers a return on the high initial cost and that mitigates the higher project cost by achieving economies of scale [15].

Therefore, the PHSS must develop a long-term plan and demonstrate the feasibility of small-scale public modular housing (SSPM). Previous studies evaluated single or multiple modular projects to determine the feasibility or identify drivers and barriers of modular construction. These studies emphasized the importance of the government’s role in promoting modular construction to realize economies of scale [14,16–18]. However, the realization of a promotion plan or policies for modular construction was not included in the scope of the studies. To develop a plan, the PHSS must estimate the total number of applicable sites across Seoul for securing sustainable demand. Based on the developed plan, the practitioners can be conceived to invest the initial cost. Furthermore, it must be proven that a given project can be carried out feasibly and can overcome negative perceptions at an applicable site.

In this light, the present study has the following objectives: (1) to estimate the number of applicable sites in Seoul and (2) to evaluate the feasibility of these applicable sites. First, a preliminary study is conducted to identify the demand for SSPM, barriers to the uptake of modular construction, and efforts in other countries. Second, a framework is suggested for achieving these objectives. Then, the application of the framework is explained through case studies. The research scope is limited to government-owned sites, and the housing demand is limited to one- or two-person households for which a standardized modular unit is suitable. Finally, the number of applicable sites and the size of potential projects are estimated. This study makes the following contributions: (1) develop a basis for a long-term housing supply plan using modular construction by estimating the number of applicable sites from an urban perspective, (2) mitigate negative perceptions related to higher costs, and (3) improve public housing welfare by securing profitability based on feasibility analyses.

2. Literature Review

2.1. Public Housing Demand and Supply Methods in Korean Urban Areas

The public housing demand in Korea has shown a continuously increasing trend. In 2027, the demand for public housing is expected to be 25.47 million households, and that for public pre-sale housing is expected to be 613,000 households. A significant proportion of this demand, 66%, will be concentrated in Korean cities. Thus, the urban housing supply needs to be increased. To meet this demand, the PHSS is supplying housing to central areas. Nonetheless, this supply needs to be increased because the average public housing inventory rate of 7% is lower than that of other OECD countries [19,20].

In the past, public housing in Seoul was provided through large-scale housing sites that were developed on the outskirts of the city. However, the available land for housing
sites in central or outer urban areas is now insufficient, and there are limitations to applying this land development method. Moreover, the demand for urban public housing and urban infrastructure such as public transportation, universities, hospitals, and workplaces is high and is increasing continuously [12]. To compensate for the limitations of the current land development method, the PHSS is planning to supply housing through the development of small-scale housing in dense urban areas [21]. It will aim to construct and supply public housing alongside existing public facilities by purchasing sites from the private sector or using government-owned sites. This development method is considered promising to (1) increase the utilization rate of central urban areas, (2) refurbish decrepit houses or areas, and (3) meet the housing demand in central urban areas [12].

2.2. Public Housing Supply in Urban Areas and Modular Construction Method

Urban construction projects inevitably have negative environmental impacts that result in civil complaints and, in turn, schedule and cost overruns that reduce the project efficiency [4,22,23]. These impacts must be mitigated to sustainably supply public housing. To deal with these impacts, the PHSS plans to use modular construction methods to reduce on-site construction activities compared with those in conventional construction methods [12,24]. To validate the reduced impacts, the PHSS conducted exemplar projects in urban areas and demonstrated that these resulted in reduced civil complaints and disruptions to nearby public facilities such as public parking lots and community centers [10]. In the previous study, to validate the benefit of modular construction, cases chosen according to the housing size were evaluated, and the evaluation results showed a 50% time reduction and a 70% waste reduction [24].

Despite the reduced environmental impact, there are barriers to the adoption of modular construction as the principal method for supplying public housing. One barrier is cost-related factors. Some Korean modular construction projects had higher project costs compared to those of conventional construction projects; further, these projects failed to meet the expectations of the Korean construction industry and resulted in negative perceptions [11,14]. These modular construction projects still benefitted from the mass production of units, but the higher costs stemmed from the high initial investment and the immature modular construction industry in Korea. Modular construction requires a high initial investment for establishing a unit production environment (e.g., factories), securing yards, and hiring a specialized workforce; this initial cost also results in the high bidding price of contractors and project cost [15].

The higher cost can be justifiable considering the value-added benefits such as reduced environmental impacts and construction waste causing non-value-added cost, both of which are hard to objectively quantify and are rarely included in cost–benefit analyses of modular construction projects [1,15,25]. However, government financing for supplying public housing is limited. A suitable public housing supply policy must be adopted for providing a sustainable supply while enabling the public housing supplier to generate returns [26]. To overcome the negative perceptions and the limited public finance, the value of modular construction projects must be estimated, and higher project costs must be mitigated.

2.3. Efforts to Promote Modular Construction Projects

The construction industry has been conservative in adopting new technologies; in fact, it does not adopt them until their additional value has been demonstrated [27]. Therefore, the proportion of modular construction projects cannot increase until the negative perceptions about them disappear. To overcome these perceptions, the creation of a policy to promote modular construction is required, in which the government must play a critical role. In previous studies, the lack of government policies to promote or support modular construction was considered a major barrier [28]. The governments of countries in which modular construction has been effectively implemented are therefore carrying out exemplar
projects to show the effectiveness of and promote modular construction with implementing the promotion policies [15].

Modular construction methods provide economies of scale through the repeated production of multiple units [24]. To achieve economies of scale, the government plays an important role as the biggest client. For example, the Singapore, Hong Kong, and UK governments have developed long-term modular housing supply plans to secure the demand for modular construction [11,15]. These plans convinced practitioners of benefits such as economies of scale and returns on initial investment.

The Seoul government recognizes the importance of its role as a client in promoting modular construction methods, and it plans to use this method for supplying small-scale public housing in central urban areas [12]. However, it is hard to achieve economies of scale through the fragmented construction of small-scale housing [11]. Therefore, to develop a long-term plan that affords economies of scale, the number of potential projects suitable for small-scale modular housing must be estimated and feasibility analyses must be conducted to demonstrate modular construction as a sustainable supply method in urban areas.

2.4. Standardization of Modular Construction

The benefits of modular construction are derived from economies of scale; however, standardization is required to appreciate this benefit [12,29]. Through standardization, the waste during unit production and construction can be reduced, and the reduced waste alleviates non-value-added costs such as landfill tax levy [1]. In terms of cost-effectiveness, the unit cost decreases as the number of standardized components produced increases [30]. To reduce the cost caused by design errors, the Hong Kong and Singapore governments have introduced design guidelines to standardize modular construction [11]. A lack of design standards or codes is a barrier to modular construction [15]. Moreover, lack of skilled workers has been considered another barrier. These barriers are related to reworks because of errors in the engineering and construction phases. The cost caused by the errors is higher for modular construction than it is for conventional methods because the changes in the design and construction phases are more difficult than conventional construction methods [25]. The limited expertise, complex rectification process for changes, and management complexity of modular construction are major risk factors, which are related to the increase in the project cost. To overcome these barriers, standardization is required to enable practitioners to reduce risks and improve efficiency [15,31,32].

Modular buildings are built using modular units that are transported from a factory to a construction site. Generally, the size of such units is determined by road traffic regulations [29]. In keeping with Korean regulations, the floor area of a unit is 19.8–39.6 m². A residential unit is formed through a combination of one or more units. Although the area of a residential unit can be varied by combining different units, it is recommended to build a residential unit by minimizing the unit type variation because the production efficiency decreases with increasing variation. Therefore, the floor area of modular residential units and unit variations must be considered carefully.

2.5. Development of a Long-Term Plan to Supply Public Modular Housing

To sum up, PHSS is required to supply public housing to urban dense areas, and the construction projects are expected to affect the environment negatively. Modular construction can be used as a promising housing supply method by reducing a significant portion of on-site work. However, to adopt the method, a favorable industrial environment should be prepared. PHSS recognizes the importance of its role as a big client and is planning to develop a long-term plan to supply housing using modular construction. For the development of this plan, a quantitative analysis is required, and the target demand class should be identified for the economies of scale and standardization.
### 3. Methodology

The Seoul government requires a long-term plan to develop small-scale public housing facilities using modular construction in central urban areas. To develop this plan, the number and feasibility of applicable sites must be estimated. Then, the class of residents that can live in this modular housing must be selected. For this purpose, this study proposed a framework to estimate the number and feasibility of applicable sites. The framework consists of two stages: (1) selection of applicable sites based on geographic information system (GIS) data of Seoul and (2) feasibility analysis of the selected sites. The Seoul government can use this framework to estimate the potential demand and the feasibility of the selected sites. Figure 1 shows the proposed framework.

![Framework to estimate the number of applicable sites and profitability.](image)

#### 3.1. Estimation of Number of Applicable Sites for SSPM

#### 3.1.1. Business Model Classification

In the first phase of the framework, the number of applicable sites for SSPM in Seoul is estimated. The PHSS used various types of public housing programs to supply customized housing depending on the characteristics of the residents. In the first step, public housing programs suitable for modular housing are selected. The economies of scale can be achieved by repetitive production of similar units. If the target consumer is varied, various types of residential units are required, which results in an increase in the types of modular units.
needed. Therefore, the housing program should be selected to limit the types of modular units. The residential unit is composed of modular units and the larger the residential unit, the more the types of modular units needed; therefore, the residential unit area should be limited. For example, the Happy Housing Program is aimed at providing housing to one- or two-person households consisting of students, young professionals, newlyweds, and the elderly; it is considered suitable for modular construction in terms of the residential unit area and repetitiveness of units [12,21].

To supply housing for residents, the supplier has operated business models such as development through housing construction, purchase of private houses, and long-term lease of houses from the private sector. The features of the business model include the housing unit specification (floor area, rooms, and bath), residential environment (proximity to a specific facility such as public transportation, hospital, and university), and target resident information (age; class, such as students, young professionals, and newlyweds; and number of household members). The business models for the Happy Housing Program were customized to meet the housing demand in central urban areas. Table 1 presents the features of the business models and the housing for the happy housing program that was supplied through the development method [21].

| Type | Development Method | Features | Relevant Class | Residential Area |
|------|--------------------|----------|----------------|------------------|
| Type 1 | Rebuilt on a decrepit house | Located near station (0.5 km) and university (1.0 km) | Students, newlyweds, young professionals, vulnerable groups | More than 18 m² for one person and 36 m² for two people |
| Type 2 | Constructed on undeveloped government-owned site | Decrepit and underdeveloped public facility | | |
| Type 3 | Complex development on a public facility | Elderly households | | |

3.1.2. Selection of Applicable Sites Using GIS

In this step, the sites are identified based on the features listed in Table 1. The Seoul government operates a GIS containing information about government-owned sites, public facilities, and public housing purchased from private sectors. The research objective is to estimate the applicable sites for the development of the long-term plan of the Seoul government and thus, the scope of the search was limited to government-owned buildings or sites. To determine applicable sites for each business model, the features listed in Table 1 and additional conditions relevant to each model were used as search conditions. Table 2 lists the search conditions for each model. To search the sites considering the conditions, QGIS, which is an open-source program, was used, and the GIS information was downloaded from the government-operated GIS portal, the National Spatial Data Infrastructure Portal of Korea.

| Type | 1st Condition | 2nd Condition | 3rd Condition | Order of Development Priority |
|------|---------------|---------------|---------------|-------------------------------|
| Type 1 | Government-owned house | Decrepit houses built before 2000 and located near station (0.5 km) and university (1.0 km) | Located near station (0.5 km) and university (1.0 km) | The more the necessary facilities within the set distance, the higher the priority for development |
| Type 2 | Government-owned site that is undeveloped where houses can be constructed | Site area 100–3000 m² | Located near station (0.5 km) and university (1.0 km) | |
| Type 3 | Decrepit public facilities (more than 15 years) with a legal floor space ratio of 60% or less | Located in residential area | More than 150 m² site area and able to develop more than 300 m² | Located near station |
3.1.3. Characteristics of Selected Sites

The applicable sites for constructing SSPM were selected using the GIS, based on the features of each business model. Figure 2 shows the GIS map of each type. As a result, 74 sites were selected and of these, 37 had development priority. The selected sites for each model show different characteristics. Type 1 sites had been acquired by purchasing private houses. These sites were concentrated in areas that met the price requirements set by the Seoul government. Most of the selected sites were suitable for small-scale projects and had areas of 100–400 m². Type 2 sites were uniformly distributed across Seoul. However, many were irregularly shaped, and therefore, remained undeveloped. Most of the selected public facilities of Type 3 were concentrated in northern Seoul. In other words, Type 1 and 3 sites were clustered together.

| Type                  | Searching Condition                                      |
|-----------------------|---------------------------------------------------------|
| Type 1                | Government-owned houses built before 2000                |
|                       | Inputting public facilities information to GIS          |
|                       | Selected Houses                                         |
|                       | Location of university                                  |
|                       | Location of stations                                    |
| Type 2                | Government-owned and undeveloped sites; site area 100–3000 m² |
|                       | Inputting public facilities information                 |
|                       | Blue dot: under 100 m²                                   |
|                       | Red dot: more than 100 m²                                |
|                       | Location of university                                  |
|                       | Location of stations                                    |
| Type 3                | Decrepit public facilities                              |
|                       | Inputting GIS searching condition                       |
|                       | Underdeveloped public facilities in developable area    |
|                       | Residential area information                            |
|                       | 1. More than 150 m² site                                |
|                       | 2. Able to develop more than 300 m²                     |

Figure 2. Site selection using GIS.

3.2. Feasibility Analysis of Selected Sites

The number of applicable sites for SSPM in Seoul was estimated in the first phase of this framework. To sustainably provide modular housing, feasibility analyses of projects must be conducted. Although some value-added benefits of modular construction cannot be objectively quantified [15,25], the project cost is a widely used performance evaluation criterion. In this feasibility analysis, only visible cost factors are considered to evaluate the project conservatively. Therefore, if a small-scale project is evaluated as being profitable, it is considered feasible because the other value-added benefits, such as reduced environmental impact and disruption of public facilities, would be achieved.
Various methods can be used to evaluate the cost performance of a project. Modular construction is considered a cost-effective method; however, its effectiveness remains debatable [10,14]. In some cases, the cost of a modular construction project was higher than that of a conventional one [14]. For public housing, the scope of the cost–benefit evaluation must be extended from direct cost evaluation to long-term profitability analysis, including the lifecycle cost [33]. If a public housing supplier can make a profit in the long term, housing can be supplied sustainably [26]. To evaluate the long-term profitability, discounted cash flow methods such as net present value (NPV) and equivalent annual cost (EAC) are widely used. NPV and EAC are used when the life span of a building is fixed and flexible, respectively [33]. In the feasibility analysis in this study, NPV was used. Equation (1) represents the net present value of income at time $t$. $R_t$ means net cash flow at time $t$, and $i$ is discount rate. Equation (2) is used to estimate feasibility considering the sum of the net present value of regular income such as monthly rent and initial investment such as construction cost. If NPV is more than 0, the project can be considered feasible.

\begin{align*}
NPV &= \frac{R_t}{(1+i)^t} \\
NPV &= \sum_{t=1}^{T} \frac{R_t}{(1+i)^t} - \text{initial investment}
\end{align*}

To develop a long-term modular housing supply plan, the feasibility of all selected sites must be evaluated. In addition to the business models considered in this study, the Seoul government is planning to adopt new site acquisition methods, such as renting from the private sector and buying numerous small-scale plots of land for the improvement of old residential areas. Therefore, in this study, the application of this framework is explained through feasibility analysis of one site of each type of business model as case studies. This framework can be used to monitor the applicable sites among the acquired ones.

To conduct the feasibility analysis, one site of each type of business model that has development priority was selected. Such sites have a higher developable floor space ratio than others, and therefore, the potential effectiveness of development is higher. Table 3 describes the properties of such sites and Figure 3 shows the location of the sites and infrastructures.

| Properties                  | Type 1  | Type 2       | Type 3        |
|-----------------------------|---------|--------------|---------------|
| Location                    | Mapo-gu | Mapo-gu      | Gwangjin-gu   |
| Site area                   | 239.3 m²| 330.0 m²     | 1000.0 m²     |
| Building area               | 139.9 m²| 264.4 m²     |               |
| Floor area                  | 259.8 m²|              | 661.0 m²      |
| Building-to-land ratio (legal) | 58.4% (60%) | (50%)          | 26.4% (60%) |
| Floor area ratio (legal)    | 108.5% (200%) | (250%)         | 66.1% (200%)  |
| Additional developable area | 218.8 m²| 825.0 m²     | 1339.0 m²     |
To develop a long-term modular housing supply plan, the feasibility of all selected sites must be evaluated. In addition to the business models considered in this study, the analysis may include other potential models that can be tailored to the specific needs of the development area. This framework can be used to monitor the applicable sites among the acquired ones. The framework can also be expanded to include other factors that influence the feasibility of modular housing development, such as site conditions, community needs, and market demand.

4. Case Studies

4.1. Feasibility Analysis of Selected Sites

To explain the feasibility analysis of SSPM, three sites were selected for each business model. As shown in Table 2, these sites have higher development priority and potential than other sites because of their greater developable area. To conduct feasibility analyses, the number of residential units and long-term cash flows including rental fees, construction costs, government subsidies, and maintenance costs must be known. Therefore, the architectural planning for each site was developed in consideration of the site conditions. Table 4 lists details of the planning, and Figure 4 shows the building before development and the developed architectural planning (e.g., floor plan and bird’s-eye view).

| Location of sites |
|-------------------|
| Type 1            | Type 2            | Type 3            |
| ![Type 1 Location](image1.png) | ![Type 2 Location](image2.png) | ![Type 3 Location](image3.png) |

Table 4. Properties of architectural plans for selected sites.

| Properties                      | Type 1 | Type 2 | Type 3 |
|---------------------------------|--------|--------|--------|
| Building area                   | 134.68 m² | 161.08 m² | 597.88 m² |
| Floor area                      | 315.72 m² | 638.76 m² | 1844.34 m² |
| Building-o-land ratio (legal)    | 56.28% (60%) | 48.81% (50%) | 59.79% (60%) |
| Floor area ratio (legal)         | 131.93% (200%) | 193.56% (250%) | 184.43% (200%) |
| Number of floors                | Three stories | Five stories | Seven stories |
| Number of residential units      | 8 units (17.92 m²) | 20 units (17.92 m²) | 29 units (17.92 m²), 23 units; 35.84 m², 6 units |
| Additional facilities           | Common space for residents | Commercial space | Village office |

In the architectural planning, a few development constraints were identified. The architectural planning of Type 1 is for a three-story building with a more developable floor area. It was underdeveloped because the building design guidelines were affected by the regulation applied to the road-adjacent sites; thus, half of the fourth floor could not be constructed. In modular construction, irregular building shapes decrease the effectiveness, and thus, the final plan was developed for a three-story building. For a site area of 300–1000 m², it is expected that construction can be performed without being affected by design guidelines because it is possible to keep a certain distance from the road. During site selection, a few sites were excluded because the condition of the roads to these sites was unsuitable for transporting units. Therefore, when planning the construction of small-scale modular housing, constraints need to be considered in the early phase.
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The NPV method was used for the feasibility analyses of the plan. A plan is considered feasible if its NPV is more than zero. Table 5 lists the variables used in these analyses. The modular public housing was set to operate for 30 years, and the buildings were constructed on a government-owned site. No land rent fee was assumed, and the land would be returned to the government after the operating period. The government subsidy amounted to 27,703,220 KRW per residential unit, and the subsidy was equally applied to all residential units regardless of the type of business model. The deposit, rent, and increase rate refer to the regulations of public housing supply providers. Table 6 shows the NPV analysis for each business model type.

Table 5. Variables used in feasibility analysis.

| Variables | Criteria for Feasibility Analysis |
|-----------|----------------------------------|
| Construction | Land rent | No rent (government owned) |
|            | Construction cost | Estimated cost of each plan |
| Operation | Rent | Refer to public housing rent program (68% of students, 72% of newcomers, 80% of newlyweds based on rent of housing near the developed site) |
|            | Deposit increase rate | 3% every 2 years |
|            | Rent increase rate | 5% every 2 years |
|            | Maintenance cost | Repair and maintenance ratio according to building year |
| Financial | Discount rate | 5.5% (Seoul government regulation) |
|            | Deposit ratio | No standard but minimize deposit ratio |
|            | Subsidy | 27,703,220 KRW/unit |
|            | Interest rate | 3.5% |
|            | Operation period | 30 years |
Table 6. NPV analysis results of each type of business model.

| Cash Flow | Type 1 | | | | Type 2 | | | | | Type 3 | | | |
|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|           | NPV    | Sum    | Y0  | Y1  | . . . | Y29   | Y30   | NPV    | Sum    | Y0  | Y1  | . . . | Y29   | Y30   |
| Inflows   | 1224   | 2307   | 458 | 103 | 83    | 82    | 2716   | 4942   | 1154   | 227   | 169  | 166 | 5628  | 9019  | 3383  |
| Subsidy   | 199    | 222    | 222 | 0   | 0     | 0     | 498    | 554    | 554    | 0     | 0    | 0    | 672   | 748   | 748   |
| Loan      | 224    | 236    | 236 | 0   | 0     | 0     | 569    | 600    | 600    | 0     | 0    | 0    | 2497  | 2635  | 2635  |
| Deposit   | 70     | 95     | 63  | 0   | 3     | 0     | 163    | 221    | 0      | 146   | 6    | 0    | 252   | 342   | 0     |
| Rent      | 731    | 1754   | 0   | 40  | 80    | 82    | 1487   | 3567   | 0      | 81    | 162  | 166 | 2207  | 5295  | 0     |
| Outflows  | 703    | 1203   | 521 | 4   | 47    | 142   | 1752   | 3056   | 1300   | 9     | 116  | 337 | 5635  | 9538  | 3609  |
| Land rent | 0      | 0      | 0   | 0   | 0     | 0     | 0      | 0      | 0      | 0     | 0    | 0    | 0     | 0     | 0     |
| Construction cost | 493 | 521 | 521 | 0 | 0 | 0 | 1233 | 1300 | 0 | 0 | 0 | 3421 | 3609 | 3609 | 0 |
| Payment of loan | 110 | 370 | 0 | 3 | 31 | 31 | 274 | 924 | 0 | 7 | 78 | 78 | 1585 | 3895 | 0 | 98 |
| Return of deposit | 18 | 95 | 0 | 0 | 0 | 95 | 42 | 221 | 0 | 0 | 0 | 221 | 65 | 342 | 0 |
| Maintenance | 81 | 244 | 0 | 1 | 15 | 15 | 203 | 610 | 0 | 2 | 39 | 39 | 565 | 1693 | 0 | 5 |
| Inflow-Outflow (NPV) | 533 | 1077 | −63 | 99 | 36 | −60 | 991 | 1886 | −146 | 218 | 52 | −171 | 29 | −519 | −226 | 243 | −50 |

Unit: million KRW; Year Y0: 1: construction completion; Y1: move into houses and start residence.
4.2. Results of Feasibility Analyses

For Type 1, new houses were constructed after demolishing the existing ones. To estimate the NPV, it was assumed that construction would be completed in 6 months. The estimated project cost was 520 million KRW (approximately 460,625 USD), and 240 million KRW were borrowed. The total subsidy was 220 million KRW, and the expected rent of public housing for all residential units in the housing was set as 40 million KRW for the first year. The cash flow, including the conditions listed in Table 5, showed an outflow after construction was completed; this was changed to an inflow for the operation period. Then, a cash outflow occurred owing to the return of the rental deposit in the 30th year of operation. As shown in Table 6, the NPV of Type 1 is higher than 0; this means that the planned development is profitable in the long term. The cash flow of Type 2 was similar to that of Type 1. The NPV was 990 million, and this project was expected to be more profitable than the Type 1 project. The housing of Type 3 was constructed through the redevelopment of decrepit public facilities. The construction duration was assumed to be 1 year. The NPV of Type 3 was 30 million. This value was lower than that of the other types and showed minimum profitability.

The feasibility analyses showed that the cases with government-owned sites secured minimum profitability. The NPV of Type 2 was higher than that of the others; this suggests that the features of Type 2, such as the unused site and area exceeding 1000 m², are favorable for small-scale housing development. However, the plan for each type showed minimum profitability, indicating that SSPH in urban areas is feasible.

4.3. Potential Project Size Estimation in Seoul for Long-Term Supply Planning

To develop a long-term plan for a small-scale modular public housing supply, the potential project size must be estimated in consideration of the cost, site area, and number of houses in Seoul. The number of sites of Types 1, 2, and 3 satisfying the features of each business model in Table 2 was 74. Table 7 shows the estimation results of each type. The PHSS provided 12,000 houses in 2018; of these, only 156 were small urban houses that considered specific needs such as the business models in this study. Using the research framework, 1250 modular houses were estimated, which is equal to the expected supply over 8 years. Moreover, the modular housing supply is expected to become larger through the use of unsold sites in the housing site development district of Seoul.

Table 7. Potential project size estimation results.

| Results                      | Type 1 | Type 2 | Type 3 |
|------------------------------|--------|--------|--------|
| Applicable sites             | 32     | 23     | 19     |
| Total site area              | 6620 m²| 5050 m²| 21,100 m²|
| Estimated number of modular residential units | 400    | 300    | 550    |
| Required project cost        | 20.6 billion won | 20 billion won | 75 billion won |

1 Required project cost for development on applicable sites of each business model type.

5. Discussion

5.1. Project Productivity Improvement for SSPM

To overcome the negative perception of modular construction and to supply SSPM in the urban area of Seoul, a long-term plan of the Seoul government should be developed. To develop the plan, the number and feasibility of applicable sites in Seoul should be estimated. The framework of this research was used to estimate the number of potential sites for SSPM and to develop the long-term plan from an urban perspective. Although the selected cases were profitable, the project efficiency could be improved by exploiting the features of the selected sites. Sites of Types 1 and 3 were clustered in a specific area, and the sites of each type were similar in terms of features such as the site area, type of residents, and specification of units. Therefore, if the projects at these sites are carried
out simultaneously, economies of scale can be achieved, and the project efficiency can be improved. This is one of the differences between other studies focusing on a single project feasibility estimation.

The Korean government develops a comprehensive project plan every year by combining all local governments’ construction project plans, which are announced and bid for through the central government system. The local governments have to submit their yearly project plans to the central government by 15 January. Therefore, local governments can highlight projects that are suitable for SSPM and can select a project progress method that is suitable for modular construction. In this phase, if a comprehensive plan that includes clustered sites is developed, the efficiency of each project can be improved because the components can be standardized, and project management costs can be reduced. Therefore, the research framework can also be used for developing comprehensive plans.

5.2. Using Research Framework to Promote SSPM

The countries that intended to promote modular construction announced policies related to using modular construction, and the policies contributed toward increasing the use of the method. The construction industry has been considered conservative in adopting new technologies, and technologies have been used only when the effectiveness was validated. Considering this conservatism, it is expected that the market share of modular construction can be rapidly increased with the quantitative demand announced by the government because economies of scale can be achieved and a plan for return on initial investment can be developed. Therefore, the framework of this research can be a starting point to develop promotion policies. This framework has an advantage over the work done in other studies in that the quantitative results include the entire Seoul area.

Through the estimated number of potential sites for SSPM, a roughly 8-year small-scale housing supply plan can be developed. Developing such a long-term plan allows for a chance to deliver returns on the higher initial investment cost. However, the estimated number is not enough for realizing the widespread use of modular construction methods instead of conventional construction methods. To increase the market share of modular construction, the business model of the government must be diversified. The Seoul government, in addition to using government-owned sites, is planning to acquire suitable sites for SSPM by purchasing land from the private sector. Moreover, the government can announce the preferred purchase of SSPM, and the development can be carried out by the private sector. Diversifying the business model of the government can reduce project costs and thereby increase the demand for modular construction. This explains how some pioneering countries have achieved success with modular construction. The research framework suggested in this study can be used for realizing diversification by transforming the business model or by estimating the number of sites for the transformed model.

5.3. Combination of OSC Methods for Public Housing Supply Strategy

In this study, the modular construction method was adopted to supply SSPM. Even with this method, conventional construction methods inevitably need to be used sometimes for building the foundation or a staircase. To improve the project efficiency, the complexation of various OSC methods in a project can be considered. For example, the foundation and the basement of a modular building can be constructed using the precast concrete (PC) method. Complexation could reduce the cost and duration while improving the quality of a project. As described in the case studies, Type 1 housing was not fully developed because of the regulations of the design guidelines. The use of the PC method, a panel-type OSC method, instead of the volumetric modular architecture could enable more floor area to be developed. Therefore, to improve the efficiency of modular construction projects, complexation with other OSC methods must be considered during the planning phase.
6. Conclusions

The modular construction method affords benefits such as reduced civil complaints, reduced disruption of public facilities, high productivity, and shorter construction duration by conducting a significant proportion of construction work in an environment-controlled factory. This method has been considered an effective approach to meet the housing demand in urban areas. The PHSS is planning to adopt the modular construction method to supply SSPM to satisfy the housing demand in urban areas. However, a long-term plan from the PHSS is required for the Korean construction industry to overcome the negative perceptions of modular construction and actively participate in SSPM development projects. To develop such a long-term plan, the number of sites suitable for SSPM in the urban area of Seoul should be estimated.

The research framework suggested in this study can be used to estimate the number of sites suitable for SSPM and the feasibility of these sites. The estimation results showed that SSPM can be supplied for 8 years, and the cases selected for feasibility analysis based on the architectural planning for SSPM were profitable. Therefore, SSPM is justified for supplying housing in urban areas, and modular construction can be promoted by diversifying the land acquisition method for different business models. The project efficiency of SSPMs can be improved by integrating and simultaneously conducting SSPMs.

This study differs from previous ones in that the feasibility of modular construction was evaluated from an urban perspective, and the suggested framework can be used to develop a long-term plan for the PHSS. This means that the policy for small-scale housing supply can be developed based on the quantitative analysis, and the positive estimation results can be related to improved housing welfare policies. Moreover, the feasibility estimation results and public housing supply of modular construction can be a basis to overcome the negative perception related to high project cost and initial investment. One limitation of this study is that although SSPM can be constructed at various sites in Seoul, the research scope was limited to government-owned sites. The other limitation is that a detailed long-term plan for the PHSS was not developed. However, the suggested research framework can be used to enable local governments to estimate the number of suitable sites for different business models and to enable the central government to use these data to develop a detailed long-term plan.

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