Evaluation Framework for Korean Traditional Wooden Building (Hanok) through analyzing Historical Data

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Abstract

A comprehensive research has been initiated by Korean government in order to disseminate modernized traditional Korean building (Hanok). Major objectives of this project include reducing construction cost and enhancing performance by developing construction materials and method for modernizing traditional Korean architecture. For example, modern construction methods such as glulam, steel joint, and truss are modified in order to keep the representations of Korean traditional esthetics. As part of this project, seven test-bed projects have been actually built in order to validate the performance of the modernized Hanok, and each project has somewhat different applications depending on its own design requirements.

In order to systematically compare and analyze the different applications of newly developed construction methods, this study proposes an evaluation framework with influencing variables. Firstly, the influencing variables such as different types of floor plan, roof structure and long-span beam of Korean traditional buildings were explored and defined. Historical database of these seven test-bed projects were then organized with standard classifications and numbering system. Finally, the historical database was analyzed based on the influencing variables in order to find patterns and compositions in applying new materials and methods for modernized Hanok. The findings of this study would provide a guide to selecting effective alternatives for new building types in terms of cost and performance.

Keywords –

Traditional housing, Information, Historical data, Evaluation framework

1 Introduction

1.1 Background and Objectives

There are active efforts to develop timber construction technologies around the world, such as large-scale and high-rise wood buildings. With this trend, researches in Korea are also being carried out to develop the technology of wooden buildings. One of them is to inherit the context of Korean traditional wooden building technology and modernize it [1].

In Korea, wood had been actively used in construction over the several centuries. Traditional architecture style of 'Hanok' had been widely used, and it was a typical housing type of Korea. However, due to the rapid industrialization, overseas technology such as masonry and concrete spreads rapidly, and the domestic wooden technology had relatively underdeveloped in Korea. As a result, 'Hanok' which was the traditional wooden structure of Korea now only exists as a traditional style, but it is hard to recognize it as a general urban building style [2].

Therefore, from 2010, Korean Ministry of Land, Infrastructure and Transport has conducted research on "Hanok Technology Development", which aims to develop Korean wooden technology by carrying on the legacy of Hanok. It has developed 'modernized Hanok' technology accommodating modern architecture technology [3]. 'Modernized Hanok' has been designed from the traditional Hanok to fit modern people's life, using modern methods and materials. This has resulted in improved durability and reduced construction costs. Currently, efforts are continuously being made to diffuse these technologies [4].

Moreover, using wood for high-rise and large-scale buildings is a world-wide trend. In line with this trend, researcher and practitioners are trying to develop large space and high rise [5] wooden buildings for modernized Korean traditional buildings.

The diversity of technology is largely divided into the user diversity and the technical diversity. The user diversity includes the requirements of the user such as the purpose of the facility, the size, etc., and the technical diversity includes the conditions applicable to the designer and the constructor such as the construction method and materials. Therefore, in the early stage of the project, it is required to technical diversity such as construction methods, materials and materials that can be applied to user diversity such as the use of buildings, size and budget. Especially, it is necessary to provide evaluation methods to solve this problem in boosting the architectural style of 'Hanok'.

Therefore, the purpose of this study is to propose an evaluation structure for examining various applicability of Korean wooden structure inheriting the traditional context of Hanok. For the purpose of developing the evaluation method, this study analysed seven test-bed projects those are actually constructed as part of this research. The evolving patterns of these seven test-bed projects are also analyzed in order to find implications

1.2 Hanok

Figure 1 Hanok - Ojukheon House
(Source: 'Korea Tourism Organization' Website)

Hanok is Korea's representative architectural style with more than 2000 years history. It is an eco-friendly building using wood as its main material and using natural materials such as stone and soil [7].

Traditional Hanok methods have only been connected by mortise and tenon joints [7]. This required considerable skill and effort, and it was disadvantageous for mass production. Further, it was difficult to have a large space due to the problems such as scarcity of large size wood materials. The inside space was formed by the column spacing of 2.4 ~ 2.6m [8], based on the unit space (칸, 間) consisting of four columns.

Traditional Hanok is a wooden building which has the advantages of eco-friendly and aseismicity, but it is difficult to reflect it in the modern age due to the structural limitations on durability and space enlargement.

Nevertheless, due to its traditional beauty, Hanok is still regarded as a type of housing that Koreans want to live in (As of 2008, 42% of Korean people want to live in Hanok) [9]. Today, although the appearance of the building seems to be a traditional Hanok style, its interior of the building is being developed using modern construction methods such as concrete. However, the discussion on how to define 'Hanok' in architectural style is controversial.

The purpose of this study is to provide a basis for the evaluation criteria of the applicability of modern construction methods to propose the continuous development direction of the Hanok applying various construction methods.

1.3 Hanok Scope of development

Before proceeding with research, 'Hanok' should be defined first. The reason is to propose a standard to judge to what extent Hanok can be defined as 'Hanok' when the Hanok evolved into various technologies.

"Hanok" in "Act on Value Enhancement of Hanok and Other Architectural Assets" is legally defined as follows. "the main structure of which consists of wooden columns, beams and Korean style roof frames and which reflects the traditional style of Korea, and any building annexed thereto [6]." According to the Seoul Metropolitan Government Ordinance of the Republic of Korea, "Hanok" is defined as follows. "The main structure is made of wood, and it means the buildings or their attached facilities that have traditional beauty among the buildings using Korean style tiles [7]". Table 1 summarized the definitions about Hanok in the literatures and the laws in Korea.

Table 1 Requirements of Hanok

Original Hanok[8]	・Main structure and all visible elements : traditional techniques, ・Indoor space: Modernized kitchens and bathrooms, applying modern technology for heating and air-conditioning equipment, electrical equipment, insulation, sanitary facilities
Traditional Hanok[9]	Hanok with traditional technology and space
Modern Hanok[8]	・Main structure: Wood ・Roof, Stylobate, Wall : traditional
Traditional Urban Hanok[10]	・Korean style tile, wooden column, ・Buildings that maintain the traditional style of the wooden structure
Hanok style House[11]	・Main structure: Wooden structure or Traditional hanok style using other materials, ・Korean style tile

As a result of examining related laws, ordinances and research literature defining Hanok, it could be summarized as follows.

1. The exposed main structural part should be wooden. (External columns must be exposed)
2. Korean style Tiles should be used on the roof.
3. Do not expose the metal connector to joints.
4. It should be finished with natural material.

According to these requirements, the material other than wood (e.g. steel, concrete) can be used for main structure of Hanok if it is finishing with wood.

In this way, it is very important to analyse quantitatively the process of the various materials and the construction method according to various demands in the historical and industrial aspects of Korean architecture.

It is also very valuable to set standards for analysing the changes in materials and construction methods and accumulating information.

2 Case Study

In the modernization of traditional Hanok, it is important to predict the range of applicable technology for various needs and apply the optimal combination through it. Therefore, this study aimed to classify the applicable technologies to Hanok through Hanok test-bed projects as a step to derive the optimal technology combination.

2.1 Analysis of the Hanok cases

'Modernized Hanok', which was constructed in the research process of modernizing traditional Hanok, was attempted as far as possible in the application of various modern new building methods and materials, without hindering the traditional aesthetic appearance. During the period of about 6 years, there were efforts of the research team to establish a total of seven different test-bed buildings. In addition, various as-built databases of test-bed projects such as construction cost, construction period, and productivity from the construction process were standardized and accumulated. Especially, intensive efforts to lower the high cost of construction, which was one of the characteristics of traditional Hanok, and to improve the quality had been concentrated.

The entire study was carried out in two stages. The first stage was residential facilities, and the second stage was extended from residential to public facilities for various applications of technology. In addition, the third stage of research is started in 2018, and the technology is being developed for large-scale Hanok.

In order to propose the evaluation structure, seven case studies were carried out except for the case of a village test-bed project. Case 1 used traditional Hanok construction methods for comparison purpose, Case 2 and Case 3 were built by using modernized methods for residential housing. Finally, Case 4, Case 5, Case 6 and Case 7 are modernized Hanok for public buildings.

Table 2 summarized the general outlines of the seven cases. Carpentry construction accounted for about 30% of the total construction cost. But the fact that proportion of construction cost is decreasing didn't mean the decreased use of wood materials. It was caused by increased cost of concrete in the foundation.

Though the total costs including carpentry, finishing, equipment, mechanical, and electrical works were analysed, this paper focuses on carpentry works cost per unit area, a large amount of construction cost was used without any major change in the absolute amount of

Carpentry is the main structural part of the Hanok and occupied a large portion in terms of total costs and quantities.

Table 2 Table 2 General outlines of 7 actual modernized Hanok cases

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
							
Total construction cost ($)	240,000	260,000	275,000	2,406,000	1,002,000	708,000	541,000
Total floor area (㎡)	70	130	140	950	450	260	250
Building area (㎡)	70	80	70	570	340	275	110
Characteristics	Traditional	Wet+Dry	Glulam	Curved Beam	Truss	Arch Frame	Steel Frame, Concrete Slab
Construction period (day)	-	-	154	337	237	167	199
Roof form	3	3	5	5	5	5	3
Carpentry Cost ($) per area	1,144	439	676	702	468	684	252
Carpentry ratio (%)	33%	21%	34%	28%	21%	25%	12%

2.2 Needs for Standard Classification for Hanok Construction

As mentioned above, the aim of this study is to develop an evaluation methods for selecting appropriate methods for different type of Hanok projects. The evaluation structure should reflect user diversity and their technical diversity. In order to explain this, it is necessary to classify the technical standard of the Hanok wooden structure and the following suggestions was drawn to define it.

First, the structure of Hanok should be based on wood columns and beams.

From the past, Hanok has emphasized the characteristics of each element of the building. Various terms were used depending on the details of the design used, the shape of the member, the size, and so on. It was also possible to estimate the era of Hanok construction through these characteristics. Therefore, a very complicated terminology has been used, and the problem has arisen that the standard classifications are not clear when modern architects try to describe modernized Hanok elements. However, this is one of the most representative features of Hanok. So it is difficult to apply modern classifications, while completely ignoring it. Therefore, in order to know the applicable technology range of the modernized Hanok, it is necessary to define the terms of the absence of the classification according to the element, and to organize the applicable techniques such as the construction methods and materials.

Second, in order to utilize the best combination of technologies for each span and scale at the time of building a Hanok, including large size and high-rise buildings, it is necessary to review the structural safety evaluation standards.

Third, it should be able to support the analysis of economic efficiency in the construction method and material selection in the state where the original design of the Hanok is fully reflected.

Fourth, it should be able to support the industrialization of materials. Industrialization of each member is essential for the spread of Modernized Hanok. Through the standard classification of Hanok technology, it is possible to derive efficient member dimensions for each technology according to the span and scale of the building, and these dimensions should be standardized to support establishment of industrialization base.

3 Standard Classifications for Hanok

Standard classifications for Hanok technique are defined as element classification, method classification, and material classification reflecting the characteristics of Hanok discussed above.

3.1 Element Classification

Element classification should be the first since Hanok has different characteristics and methods. The element classification was divided into five categories: roof, roof structural system, beam, column, and floor through previous studies [16]. Complex and various traditional terms were re-defined with simple descriptions.

Roof included timber used for roof parts such as rafters [*Seo-ka-re*] and wood board. Roof Structural system was located between the columns and the roof, and represent the overall structure of the roof and the building. This is one of the distinct characteristics of Hanok, and includes purlin [*Dori]*, etc. Beam in the highest floor was categorized as one of the roof structural systems. However, it was classified in order to perform detailed analysis for each applied method. When comparing quantities by element in this paper, they were combined and analysed together. The columns included inner columns [*Go-ju]* and outer columns [*Pyeong-ju]*. The slabs include joists [*Jang-sun*], floor boards [*Ma-ru*] and the like.

3.2 Method Classification

The classification criteria of methods based on literature reviews as well as domestic and foreign wooden building case studies (including 7 modernized Hanok test-beds) are summarized as follows. It was classified into one column system, one slab, four roof structural systems, four beams, and two roof systems. Table 3 below summarizes the applicable methods for each elements. The column method is divided into one vertical column, which supports vertical load, and the slab is divided into one, horizontal slab method. The roof structural system is divided into four types: Korean Traditional, truss, arch, and tension cable. Among them, the beam part which is one of the members of roof structural system is divided into four parts: straight beam, curved beam, truss beam, and Tension Supported Bending structure. The roof is divided into two types, wet type and dry type.

Of course, it is difficult to see the all applicable method for each element, but it was based on the possibility in the category of Hanok which is now recognized, and it can be added later

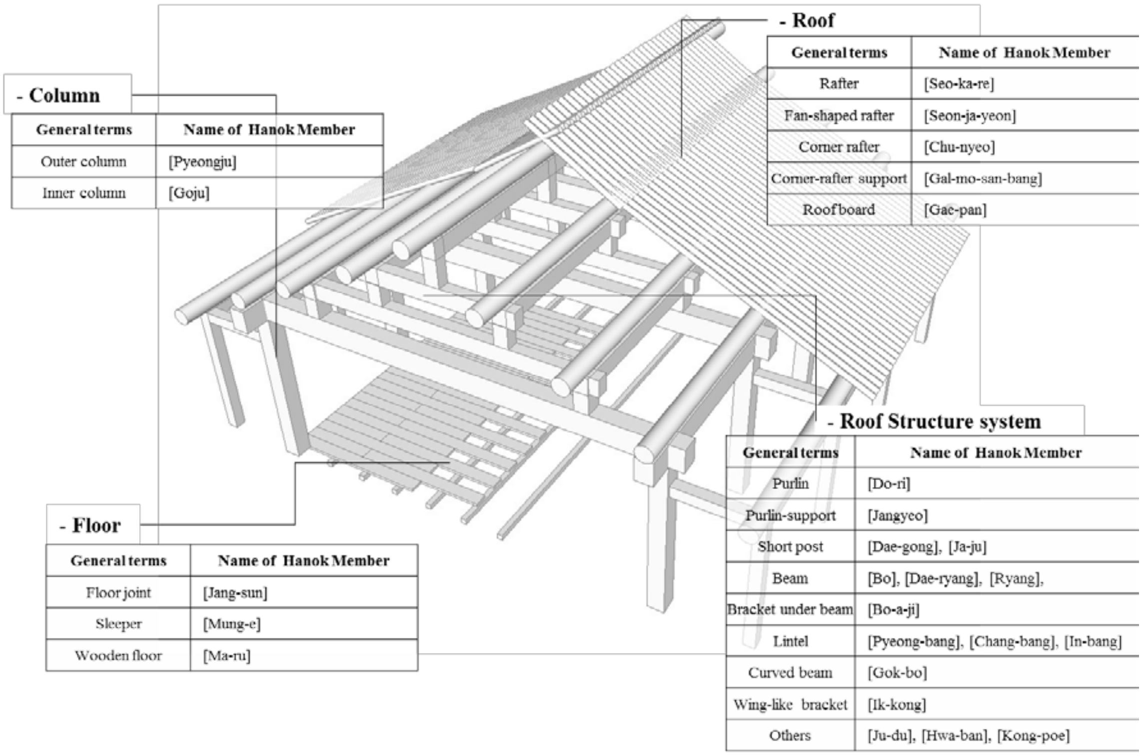

Figure 2 Element classification of Hanok (Preceding study) [16]

Table 3 Elements Classifications and Methods Classifications in each part

Elements		Methods	
C	Column	C01	Upright Column
S	Slab	S01	Floor Slab
F	Roof structure system	F01	Korean Traditional
		F02	Truss
		F03	Arch
		F04	Cable
B	Beam	B01	Straight Beam
		B02	Curved Beam
		B03	Truss Beam
		B04	Tension Supported Bending Structure
R	Roof	R01	Wet (Traditional Method)
		R02	Dry

3.3 Material Classification

Next, materials that can be used in each method should be selected. The classification of materials was summarized by using literature data and classified into five categories: wood, glulam, steel, reinforced concrete and composite. (Table 4)

Clearly Hanok architecture is a wooden building, so it is required to pay attention to use other materials other than the wood for the main structural parts. However, as the different requirements (size, use) of the main structural parts of the Hanok have been increased, other materials including steel and concrete have been applied to the standards so as able to be reflect the possibility of various applications.

Table 4 Classification of Materials

Materials	
W	Wood
G	Glulam
S	Steel
R	Reinforced Concrete
C	Composite

Among the standard classification of Hanok technology, the top three categories were summarized as elements, methods, and materials. When it has shown as matrix, the total range of its combinations was about 80,000 cases.

In future studies, the most unlikely combinations should be excluded through the quantitative evaluation to find a more optimal combination.

4 Utilization of SC Matrix

Hanok can be applied in various ways beyond the traditional style of the past by applying modern technology and it can be developed into a large scale and a high rise.

Therefore, in modernization of Hanok which has the potential of development, it is required to quantitatively analyze and systematize the variables.

4.1 Concept of Evaluation Framework

Hanok can be developed variously through application of modern technology.

Figure 3 shows the concept of the evaluation framework that draws the optimal combination of technologies according to the diversity of users by using the standard classification matrix of the Hanok technology. Variables according to user diversity, such as the size, use, and budget of the facility, are entered as input variables in the standard classification matrix of Hanok technology, and the matrix is used to evaluate the practical, productive, and economic combinations. In this way, optimized combinations of method and material are drew about each element, and optimal combinations of type1, type2, type3, etc. can be selected as output.

In conclusion, the purpose of the evaluation framework is to find out the optimal value required by the user more efficiently and to consider the correlation, quantity ratio, economical efficiency, productivity, etc. in the total number of possible cases of Hanok technology. In addition, it is to evaluate the combination of classification elements by analyzed quantitatively.

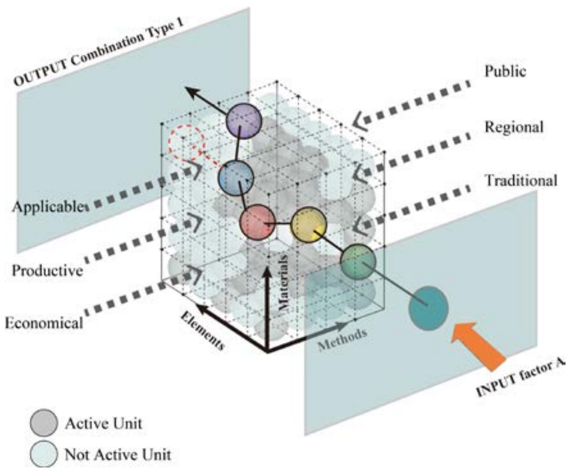

Figure 3 Evaluation Framework Structure using SC Matrix

The evaluation framework using the standard classification of Hanok technology can support to select the optimal technology combination, and it can be used in various ranges.

First, it can be used to estimate the appropriate construction cost. It is possible to analyze the correlation between each combination technique using the actual Hanok data and use it to predict each construction cost, and estimate it more accurately.

Second, it is possible to find the optimal combination according to various variables such as the size and the floor of the Hanok that users want to build. The combination of appropriate technologies based on span, number of floors, type of building, etc. is quantified and evaluate. And ultimately it makes it possible to select the optimum combination of high evaluation values.

Third, it is possible to consider the design which preserved the traditional Hanok. Proportion and harmony are important when designing considering the traditional Hanok. It can be evaluated in consideration of the dimensions and proportions of members, and it can be utilized in the design of traditional Hanok.

In the following chapters its utilization was explained with more specific examples.

4.2 Case-study using Evaluation Framework

In order to propose a combination of Hanok wood structure using the evaluation framework, it is necessary to draw elements through analysis of many accumulated actual cases.

Among the seven test-bed projects of the modernized Hanok introduced in the previous chapter, five cases were selected for this case-evaluation except case 1 and 3. Because case 1 and case 3 were too difficult for comparing with the others (Case 1 used traditional method and case 3 wasn't classified by the same classification).

Table 5 compared the main structures by case for technical classification of wooden structures. Case 1, Case 2, and Case 3 were residential buildings and had similar wooden structure characteristics. And these public buildings of cases 4, 5, 6 and 7 in which various requirements were changed from the residential were used for the analysis of the wooden structure.

As shown in Table 5, the evaluation framework could be effectively used to compare the wood structures by element, material and construction method. There were many cases where materials other than wood materials were used in the floor part when dividing the quantity of wood, so it was difficult to compare and it seems that it will become more serious in the modernization of Hanok.

Table 5 shows the share of wood per square meter. The wood quantity of the columns, the roof structural system part, and the roof part were examined by each case. When the wood quantities in the cases are compared (except for the quantities of wood flooring), the proportion of each part of total wood use is as follows. Case 2 showed 7% of columns, 44% of roof structural system, and 49% of roofs. Case 4 showed 12% of columns, 40% of roof structural system, and 48% of roofs. In Case 5, 11% of columns, 48% of roof structural system and 43% of roofs were used. In

Table 5 Comparison of materials and methods by elements, Qty Unit : ㎥ (Slab : ㎡)

	Case 2		Case 4		Case 5		Case 6		Case 7	
	Technique	Qty	Technique	Qty	Technique	Qty	Technique	Qty	Technique	Qty
Roof (㎥)	R01G	9.3			R02G	1.1			R02G	0.5
	R01W	6.1	R02W	122.6	R02W	33.7	R02W	37.3	R02W	48.0
R Total		**15**		**123**		**34.8**		**37.3**		**48.5**
Roof wooden structure (㎥)	F01G	0.2	F01G							
			F01W		F01W	13.39	F01W	12.0	F01W	37.6
					F02W	15.4				
							F03G	1.1		
F Total		**0.2**		**0**		**28.79**		**13.1**		**37.6**
Beam (㎥)			B01G	35.0						
	B01W	14	B01W	59.5	B01W	10.2	B01W	18.05	B01W	3.2
			B02G	8.1						
B Total		**14.2**		**102.6**		**10.2**		**18.05**		**3.2**
Column (㎥)	C01G	2.1	C01G	26						
			C01W	4	C01W	8.9	C01W	5.0	C01W	2.3
									C01C	
C Total		**2.1**		**30**		**8.9**		**5.0**		**2.3**
Slab (㎡)	S01G									
	S01W	290			S01W	1141.6	S01W	163.8		
			S01R	467			S01R		S01R	
S Total		**290**		**467**		**1141.6**		**163.8**		**0.0**
Total floor area (㎡)	130		950		450		260		250	
Wood Qty (㎥) per Total floor area – **R** ㎥/㎡	**0.12**		**0.13**		**0.08**		**0.14**		**0.20**	
F ㎥/㎡	**0.11**		**0.11**		**0.09**		**0.12**		**0.16**	
C ㎥/㎡	**0.02**		**0.03**		**0.02**		**0.02**		**0.01**	
S ㎡/㎡	**2.30**		**0.49**		**2.56**		**0.62**		**0.00**	

Case 6, 7% of columns, 42% of roof structural system, 51% of roofs, 3% of cases 7, 44% of roof structural system and 53% of roofs were used.

By comparing the cases, the similar distributions of the wood quantity were found except for Case 7, where the first floor was constructed with a steel frame and then finished with wood. In this way, it can be inferred that the cross section and the number of columns are maintained at a constant ratio with the amount of wood in the roof structural system part and the roof part. In addition, other materials can be used through the ceiling finish, which can reduce construction costs by replacing traditional methods of exposing wood to roofs without ceiling finishes.

It can be seen that most wood structures use raw woods. This can be considered in relation to the emotional part of Koreans, and it means that the use of natural wood, which has been used from the past, has been recognized as a representative material of Hanok until now. However, the use of glulam is expected to increase in modern Korean Hanok, and it is expected that the use of this will become even higher due to safety reasons in the modernized Hanok, which is growing in size.

Most of the beams and roofs are similar, but the change of the partial construction method can be confirmed because of the increase of the space area or the installation of the attic room.

Although it is only the result of analyzing with few cases, it was possible to analyze the change of the structure of Hanok wood structure through the Hanok technique classification more accurately. It will analyze these more in detail in the future and incorporate it into the main component of the evaluation framework. In particular, it will be finally necessary to elucidate factors such as economic analysis, design proportion, regional characteristics, and structural safety of the evaluation structure proposed.

5 Conclusion

The purpose of this study is to suggest a framework for evaluating the application of various methods available in Hanok construction and for deriving optimal technology combinations.

For this purpose, this study defined a standard classification of Hanok wooden structure, which accounts for the highest construction cost in Hanok construction. Based on a literature review and seven test-bed projects, the concept of evaluation framework was proposed to develop a classification matrix.

Furthermore, a detailed and systematic evaluation will be developed in near future by building more test-bed projects.

Future study will include the relationship of wood quantities between the column and the roof structural system, the relationship between the area (or span length) of the space and the wood quantity, and the relationship between the sectional area of the member and building (or roof) area, and so on.

It is expected that this evaluation structure will be used as a research that would systematically suggests the combination of modernized Hanok technology that encompasses future large-scale Hanok and future Hanok.

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