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Application Technology of New Hanok Style R&D in Demonstration Project Verification

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ABSTRACT

Purpose: Research on the development of the demonstrative construction and tangible models of new Hanok style social welfare facilities was conducted to create a foundation for modern succession and convergence technology of Korean traditional architecture with the aim of spreading new Hanok style buildings and securing research and development (R&D) practical technology. The new Hanok style R&D, applied to public buildings, is a new form that combines traditional wooden structures with modern construction methods and can be evaluated as a technology development field with a significant impact on the wooden architecture market. Furthermore, the ripple effect of the new Hanok style public building type model development and demonstration construction project at the national research and development project level is expected to be the driving force for the dominant market. **Method:** This study discusses the possibility of developing applied technology by analyzing the scope of the empirical reflection of applied technology and specific examples of three public facilities built based on R&D research on the new Hanok style and Hongseong Children's Forest Experience Center to be completed in 2021. **Results:** From this study, we hope that it will be used as basic data to determine the constructability, economy, aesthetics, and utilization of the new Hanok style technology applied to public buildings and discuss the scalability to embrace future regions and uses.

KEYWORD

New Hanok Style Social Welfare Facility
Demonstration Construction
Development Model

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1. Introduction

1.1. Background and purpose

Research on the empirical construction of new Hanok style social welfare facilities and the development of tangible models[1)] was carried out to lay the foundation for the modern succession of traditional Korean architecture and convergence technology with the aim of disseminating new Hanok style buildings and securing practical research and development (R&D) technologies. After completing the second phase of the new Hanok style demonstration project (2014~2016), the third-stage demonstration project (2017~2021) is currently in progress. The new Hanok style demonstration is the phase in which the effectiveness of the building is verified through policy proposals and improvement measures for the dissemination of new Hanok style public buildings; it is a process in which the possibility of dissemination is evaluated through legal matters such as the ordinance and administrative procedures supporting Hanok, with great implications for the field of technical research. Particularly, the new Hanok R&D applied to public buildings is a new architectural style that combines traditional wooden structures and modern construction methods, which can be evaluated as a technology development field with a significant ripple effect on the wooden construction market as well as the social and cultural meaning of traditional heritage. Furthermore, considering that 72% of Hanok buildings (traditional and other Hanok buildings including cultural assets and historic buildings) constructed in South Korea are ordered by the public sector, the ripple effect of the New Hanok style public building model development and demonstration project at the national R&D level is expected to become the driving force to lead the market.

This study aims to analyze the scope of the empirical application of technology and specific cases in three public buildings constructed based on the new applied technology of the new Hanok R&D research as well as the Children's Forest Experience Center in Hongseong, a social welfare facility to be completed in 2021; it also aims to discuss the potential for the development of application technology considering the review of the prototype technology application and the efficiency of on-site construction. This study intends to provide the basic data for evaluating utilities such as the constructability, economic feasibility, aesthetics, and usability of the new Hanok style technology applied to public buildings, and for discussing the scalability in terms of region and purpose of application.

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1.2. Method and Scope

For this study, the results of the second phase demonstration projects [1] of the Public Daycare Center in Sunchang (2015), the Agricultural Fair Venue in Naju (2016), and the Community Center in Eunpyeong (2016), where the concept of the new Hanok style public building was first applied, and the third phase demonstration project [2], the Children's Forest Experience Center in Hongseong (2021), were reviewed, and the main contents were as follows.

First, the application range and reflection rate of the existing R&D technology in each case were compared. Among the R&D technologies, the unapplied technologies were identified and their problems were analyzed.

Second, the proposed design and construction technology and on-site application technology were analyzed [3] at the time of the demonstration for each phase. The degree and characteristics of the R&D technologies, such as the development of wood processing technique and the use of new materials, newly introduced and applied in the third phase demonstration project (Children's Forest Experience Center in Hongseong) were analyzed.

For this study, the existing research reports [4] and papers related to the second phase demonstration projects were reviewed. To examine the application and characteristics of the R&D technologies in the third stage demonstration project, the above reference data and design drawings for the demonstration were analyzed. Table 1. lists the site of the demonstration projects.

2. Hanok technology development R&D for demonstration construction

2.1. Overview and Status of R&D for Hanok technology[2)]

Hanok technology development R&D was a government-led technology development project organized by KAIA (2009 to 2016) which was followed by a tangible model study considering the expansion of application aand dissemination of the R&D technology that had already been developed through the 10m-class Large Space Hanok Design and Construction Technology Development project in 2017.

Table 1. Demonstration Construction Site of New Hanok Style Public Buildings by Research Phase

Demonstration Project	New Hanok Style Public Buildings	Current Status
Step 2 Test Bed	**Sunchang** Public Daycare Center (2015)	Completion
	Naju Agricultural Fair (2016)	
	Eunpyeong Community Center (2016)	
Step 3 Test Bed	**Hongseong** Children's Forest Experience Center (2021)	Construction in progress (2021.09 scheduled)

The construction of the new Hanok style building is economical with 1/3 [3)] of the cost of the traditional wooden Hanok. The construction performance has been reported to be comparable to the general construction cost of modern buildings. The new Hanok technology R&D is carried out to ensure structural safety and durability for maintenance. Through the demonstration projects from residential buildings to public and social welfare facilities, the technological prowess was exhibited with increased reliability [6].

In 2009, the first phase of the new Hanok technology R&D project focused on residential buildings, showing an inherent limitation in that the scope of technology application in non-residential public facilities was limited. From the second phase of the new Hanok technology R&D project, the scope of demonstration was expanded to a child care facility, a fair venue, and a community center, to verify the applicability of the R&D technology.

In particular, the third phase demonstration project, the Children's Forest Experience Center in Hongseong, which is under construction as part of the research on the development of a type model for a new Hanok style social welfare facility, is an example of the new Hanok style public facility emphasizing the hybrid convergence of tradition and modernity unlike the previous demonstration projects. In addition to the significance of forming a new architecture market, it has implications in terms of policy as it can lead to the effects of human resource development and job creation. This is considered to have laid the foundation for the establishment of a support system for the design and construction of new Hanok style welfare facilities as well as the establishment of a promotion system for the projects. It is meaningful as a site where the limitations of R&D technology manifested in the previous two phases of the new Hanok style public building demonstration project are identified to prepare supplementary measures.

2.2. Classification and application status of New Hanok R&D technology

New Hanok R&D technology has been applied to improve the current construction method, which relies on skilled workers who require long training and practical experience, and to improve the performance of the main materials. Furthermore, R&D has been conducted for the dissemination and generalization of the Hanok by reducing the cost of distribution and establishing a modular distribution structure based on mass production.

The technical requirements for design and construction according to each process are classified into essential (11),

optional (16), and additional (58) items; essential technologies act as a key factor from the planning stage to the actual construction of the new Hanok style public facility. Among the 11 essential technology processes, there are five construction items[5] excluding the design software, and the additional group containing technology development for the detailed construction process accounts for approximately 69% of the total (Table 3.).

Each technology shows a difference in the application rate according to the characteristics of each use. For the technologies

Table 2. List of Required R&D Techniques

Application level	Application Technology of essential list			Sun Chang	Naju	Eun Pyeong	Hong Seong
	High-class		Sub-class				
Business planning stage	N.H.S* standard classification system	1.1	CBS[4]	O.P.*	O.P.*	O.P.*	O.P.*
		1.2	WBS	O.P.*	O.P.*	O.P.*	O.P.*
		1.3	GBS	O.P.*	O.P.*	O.P.*	O.P.*
		1.4	MBS	O.P.*	O.P.*	O.P.*	O.P.*
Design and build stage	N.H.S* design method	2.1	N.H.S* structure, Sections conditions table	O.P.*	O.P.*	O.P.*	O.P.*
		2.2	N.H.S* Building structure design Automatic S/W manual	O.P.*	O.P.*	O.P.*	O.P.*
	Model village Application Technology	3.1	Foundation blocks of the fence blocks And using this fence blocks	-	-	-	-
		3.2	N.H.S* Fence for using a panel of a fence	-	-	-	-
		3.3	Korean-style house tile roof structure	A.P.*	A.P.*	A.P.*	-
		3.4	Wood structure Construction Insulation Materials and Structures	A.P.*	A.P.*	-	-
		3.5	Foam plastic module for dangolmakyee and dangolmakyee using the same	-	-	A.P.*	-

N. H. S = New Hanok Style / O.P. = Original Plan, A.P.* = Application Plan

Table 3. List and Application Rate of R&D Technologies by New Hanok Style

Corresponding process (Total technology)	No.	Range of application technology by process (Total technology)	Sun Chang		Naju		Eun Pyeong		Hong Seong	
			O.P.	A.P.	O.P.	A.P.	O.P.	A.P.	O.P.	A.P.
1. Planning **(4)** - standard	**1**	TestBed CBS	1		1		1		1	
		TestBed WBS	1		1		1		1	
		TestBed GBS	1		1		1		1	
		TestBed MBS	1		1		1		1	
2. Program **(2)** - Section Conditions	**2**	New Hanok Style Structural Member Sectional Condition Table	1		1		1			1
		New Hanok Style Use structural redesign automation S/W	1		1		1			
3. Foundation **(4)**	**3**	Foundation (2)	-		1		-			1
	4	Stylobate (2)	1		1		1		1	
4. Carpentry **(16)**	**5**	Stylobate (4)	-		-			3		4
	6	Metal joint (11)	2		1	1		1		5
	7	Construction Technology (1)	-			1	-			1
5. Roofing **(16)**	**8**	Rafter (2)	-		-		-			
	9	Roof frame Composition (2)		2			1			
	10	Danggolmakyee (4)		1		1		4		
	11	Roof tile (5)	1					1		
	12	Construction (dry method) s(3)	2	1	1	2		2		
6. Wall **(11)**	**13**	Dry method-1 (butt join) (6)	1	3		3	1	3		
	14	Dry method-1 (rip off) (5)	1	2	-			3		1
7. Flooring **(7)**	**15**	Floor Work-1 (5)		3		2	2	3		1
	16	Floorwork-2 (2)	-		-			1		
8. Ceiling **(4)**	**17**	Ceiling Work-1(2)		2	1		2			
	18	Ceiling Work-2(2)		2	-		1			
9. Joinery **(10)**	**19**	Wood window (6)		1	-		1			4
	20	Wood Systems Window (4)	-		-		3			2
10. Landscaping **(6)**	**21**	Fence work (6)	Not Applicable							
11. Other **(3)**	**22**	Other Works (3)	Not Applicable							
12. Monitoring **(2)**	**23**	Monitoring (2)	2		2		-		-	
Applied Technology Total **(85)**	Total for the entire range of technology.		16	17	14	10	17	21	5	20
	Applied Ratio (%)*		38.8%		28.2%		44.7%		29.4%	
Design and construction proposal R&D technology			15		14		16		8	

* Formula for calculating application rates – Percentage of the total number of technologies related to building construction and the sum of the original and applied technologies for each site

associated with roofing among the essential technologies, the dry construction method for the "Korean-style house tile roof structure" was applied to all sites, and the dry construction method for "wood structure construction insulation materials and structures" was applied to the demonstration projects for wall construction. The essential technology group shows a prototype application rate of approximately 72% in each project, whereas in the selective technology group, only the Eunpyeong Community Center has been applied with prototype technologies, showing a low prototype application rate.

Observing the application of the additional items, the application rate of technology is higher in the roof and wall construction. Including the technologies that can be applied in the construction process, the R&D technologies are applied the most in the roof construction process. Particularly, among the roof and wall processes, the dry construction method has a high application rate, which is regarded as a factor directly contributing to shortening the construction period as well as improving the construction performance and economic feasibility.

In each case, the scope of application has been set for R&D technology items to as many as an average of 31 processes. Except for the Naju Agricultural Fair project, the prototype technology seems to have been applied and reflected according to the field conditions. If this is evaluated only in the construction field among all processes, it can be observed that the application technology group is reflected at a value close to 1.5 times the prototype application rate.

The Children's Forest Experience Center in Hongseong is the demonstration site with the lowest prototype application rate, exhibiting a trend of the construction processes distinguished from the application technologies. Compared to the previous sites in Sunchang, Naju, and Eunpyeong, the Children's Forest Experience Center project in Hongseong is applied with more than four times the number of application technologies than the prototype technologies. It is evaluated as a construction site suggesting the possibility of expanding new Hanok style R&D technologies with remarkable adoption of carpentry and joinery technologies, which have been applied in a relatively passive manner in previous projects.

The application rate of the new Hanok R&D technology can be divided depending on the calculation method into the rate for the detailed technology in each process or the rate for the application range. The former is significant as a basis for data for discussing the evaluation and application method of technology that is directly related to the construction of the building; the latter is characterized by a relatively high application rate as it accommodates a wide range of technology applications focusing on the overall process range.

Table 4. List of R&D Techniques

No.	Process	Classification			Total
		Required	Selection	Addition	
1	Planning	4	-	-	4
2	Program	2	-	-	2
3	Foundation	-	-	4	4
4	Carpentry	-	5	12	17
5	Roofing	2	5	11	18
6	Wall	1	1	9	11
7	Flooring	-	1	6	7
8	Ceiling	-	-	5	5
9	Joinery	-	2	7	9
10	Landscaping	2	-	4	6
11	Other	-	-	3	3
12	Monitoring	-	2	-	2
Total		11	16	61	88

These can be considered as evaluations of the technology- and process scope-driven application rates. The technology-driven application rate is calculated by adding up the prototype and application technologies, focusing on 68 construction-related technologies excluding programs, landscaping, and other monitoring processes that correspond to the software in the planning stage among a total of 85 R&D technologies. The process scope-driven application rate is calculated by evaluating the application status in all 23 processes based on the range of technologies for each part and adding up the number of processes. Where, if the application of a prototype technology (a) is counted as 1, the application of an application technology (b) is counted as $\times 0.7$[6] (Eq. 1).

$$y = \frac{(a \times 1) + (b \times 0.7)}{23} \times 100 \quad \text{(Eq. 1)}$$

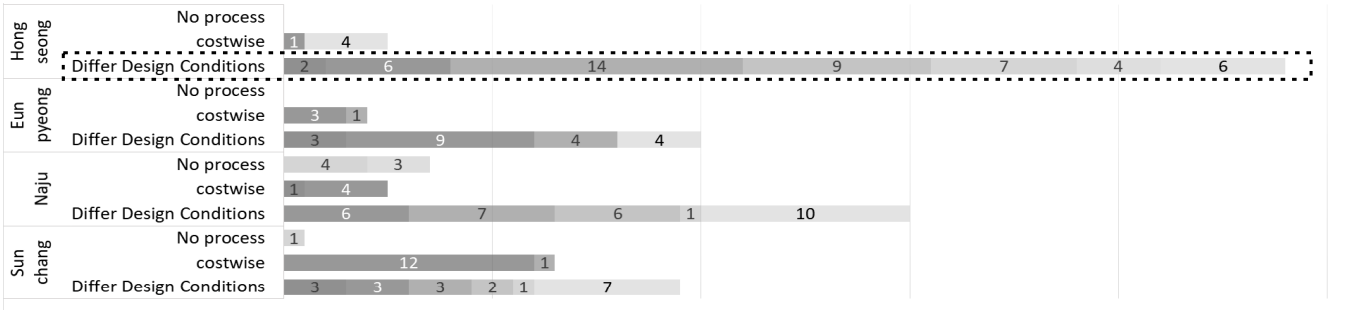
The process scope-driven application rate was as high as 50% or more in all cases, which can be interpreted as a more favorable policy standard as an evaluation index for promoting the new Hanok style buildings.

However, the construction method can be analyzed more accurately and precisely through the quantitative evaluation of detailed technology using the technology-driven application rate. Therefore, complementary use of the two standards is required for evaluation.

2.3. Unapplied R&D technologies

In most cases, unapplied R&D technologies are mainly associated with unreasonable processes and increased construction costs. The R&D technologies devised for residential and living spaces were excluded owing to a different set of requirements for public facilities (Fig. 1.).

For example, for the wall construction, the steel reinforcement R&D technology, which had been discussed for application depending on actual necessities, was not applied as it did not seem



	Sun chang			Naju			Eun pyeong			Hong seong		
	Differ Design Conditions	costwise	No process	Differ Design Conditions	costwise	No process	Differ Design Conditions	costwise	No process	Differ Design Conditions	costwise	No process
foundation	3				1		3			2		
carpentry	3	12		6	4		9	3		6	1	
roofing	3	1		7			4	1		14		
wall	2			6						9		
flooring	1		1	1		4				7		
ceiling						3				4		
joinery	7			10			4			6	4	

Fig. 1. Unapplied Technology Classification and Proportion

Table 5. Technology Application Rate - Process Scope-Driven / Technology-Driven

Criteria		Total of application technology by process			
Total		Sun Chang	Naju	Eun Pyeong	Hong Seong
R&D Technology 68		27	18	32	20
Applied Ratio (%)		36.8%	23.5%	47%	29.4%
Applied Coverage 23	O.P.	9	10	10	0
	A.P.	8×0.7= 5.6	7×0.7= 4.9	9×0.7= 6.3	20×0.7= 14
Applied Ratio* (%)		63.5%	64.8%	70.9%	60.9%

* Ratio total of original and application to coverage

necessary in the actual construction; the flooring technology, which had been excluded owing to different design conditions was applied by reflecting some construction methods. Nevertheless, many of them were not applied as they did not meet the on-site and design conditions.

As a result of classifying the unapplied technologies, excluding items in which the prototype technology was applied partially or reflected as an applied technology among the technologies in a total of 85 processes for each site, into the cases associated with different design conditions, an inevitable increase in the construction cost, or non-relevance with the construction was observed; the cases with the technology group differing from the design conditions accounted for the most. The proportion of unapplied technologies owing to the increase in the construction cost decreased with the progression of the demonstration projects, reported to have reached an insignificant level in the most recent project at the Hongseong site. When an increase in construction cost was expected, flexible adjustments and applications were made on site by modifying the planned prototype technology to change the material or reduce the scope of construction based on the technology accumulated through field experience. When looking at the unapplication rate by process, that of the carpentry technology group was the highest. The unapplication rate for joinery technologies was high in Naju, whereas that of the roofing technologies was high in Hongseong, indicating a large deviation depending on the design plan of each site.

3. New Hanok style R&D technologies by type applied to the demonstration projects

3.1. Application of second phase Hanok R&D technologies

1) Application of R&D technologies for foundation and stylobate

The application of R&D technologies for the foundation is limited to two types of technologies: mat footing+independent footing and combined footing+strip footing. Depending on the formation of the basement or structure, the technologies were not applied in Sunchang, Naju, and Hongseong as mat footing was selected. In Eunpyeong, the R&D technologies were not applied because they did not meet the design conditions owing to the basement and steel structures of the first floor.

However, the technology used in the Eunpyeong Pilot Hanok (2013) with rectangular stone and granite flagstone applied to the base was used at all sites. Particularly, considering the increase in construction cost, the technology was applied to adjust the construction cost by replacing the rectangular stone with artificial granite.

The stylobate could be omitted as a foundation constructed by introducing the mat footing + strip footing construction incorporating the developed R&D technology also acting as a cornerstone. This lays the foundation for the proposed technologies to supplement the construction, durability, and safety of the reinforced concrete mat structure by enhancing the performance of the floor structure and facilitating the use of the hypocaust (Fig. 2.).

2) Application of R&D technologies for carpentry

The traditional assembly of wooden structures presented as a selective technology for carpentry maintained the joint structure between members in the traditional way with a wooden fitting method designed to reproduce the traditional joint type even by a general carpenter while improving the joining method, and was expected to contribute significantly to the dissemination of Hanok construction (Fig. 3.).

It is an effective alternative for providing an application type allowing selective acceptance according to the condition and location of the column while improving the airtightness between members to suppress distortion, cracking, and deformation, which is also effective in terms of energy saving by overcoming irregular structural performance. However, further research on the development of members and processing methods to supplement the tensile strength and bending moment resistance of the joint will be required.

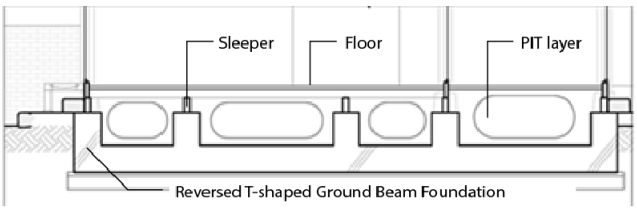
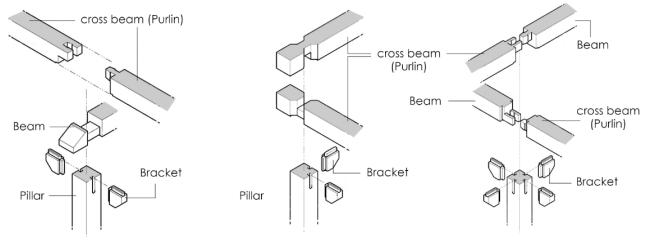
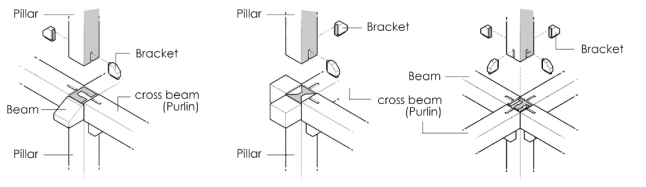


Fig. 2. Mat Base + Strip Foundation Details of Foundation Stone



pillar with bracket 1. corner pillar with bracket 1. curve pillar with bracket 1.



pillar with bracket 2. corner pillar with bracket 2. curve pillar with bracket 2.

Fig. 3. Wooden Structure - Assembly Truss and Arch-Beam

Additionally, the metal joint technology was applied in all sites. Especially at the Naju Agricultural site, structure of the joining members of traditional wooden technology of pillars (Pyeongju), the corner studs (Wooju) and valley part (Hoecheom) are applied in combination with the metal joint technology of the cornerstone + lower column, indicating that the scope of application for the metal joint had been expanded through the experience of the previous demonstration projects.

The assembly of members using metal joints is used to connect pillars and cornerstones or pillars and pillars in wooden constructions. It has the advantage of securing airtightness by minimizing the external exposure of the plate-type connecting device as well as preventing the pillar from being pushed out or lifted from the cornerstone or the top of the pillar. This technology was improved by assembling the cornerstone with the pillar using the Binyeo technique on the site with concerns for the increase in construction cost owing to the cost of the backside metal joint structure. This method prevented the cracking of the pillar after construction owing to perforation, and compensated for the shaking of the column by fixing it using the Binyeo technique.

3) Application of R&D technologies for roofing

Among all the processes, roofing is the process with the most technological elements developed, and at the same time, there have been numerous studies dedicated to improving the rationality of roof construction in new Hanok style buildings. Particularly, among the Hanok roof structures, the use of rafters and lightweight tiles for weight reduction, and the technology related to Danggolmakyee for improving insulation and airtightness, are regarded as representative applications of R&D technologies to enhance durability while considering traditional aesthetics.

For the core technologies applied to the Public Daycare Center in Sunchang, wood structure construction insulation materials and structures, the rafter type Hanok roofing technique, and the foam plastic module for Danggolmakyee were used. The developed Danggolmakyee increased airtightness and heat insulation by flexibly responding to the separation between members caused by shrinkage of the rafters

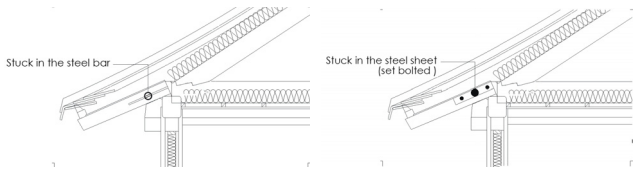


Fig. 4. (L)Stuck in the steel bar (R)Stuck in the steel sheet (set bolted)

and contributed to reducing construction costs with consistent quality and shortening of the construction period based on the dry construction method. In the site with the endorsement rafters, the detailed method of manufacturing the endorsement rafters was improved to the method of inserting the rafter member to the steel sheet (mounted with bolts) instead of the steel bar to prevent sagging in their short and long-term use (Fig. 4.).

In the Eunpyeong site, the Korean-style tiled roof structure was applied by replacing the "fiberglass insulation" in the prototype to "Low-E insulation" inside the roof to improve the insulating performance. The traditional Korean roof tiles were used considering the curve of the roof.

4) Application of R&D technologies for the wall

For wall construction, the "wood structure construction insulation materials and structures" and the exterior wall construction method introduced in the experimental Hanok project of Myongji University were applied in all sites except for the Hongseong site with different design conditions.

At this time, an application technology with partial change or improvement to the prototype was used for the construction; some walls were in the form of finishing with traditional Korean wallpaper on gypsum or CRC boards. In addition to the OSB plywood installation with Starco finish + handy code + urethane foam, waterproof sheets (Tyvek, CRC board) were installed depending on the actual use. The wall was constructed by the on-site construction of factory-made finished products, which was developed as an applied technology supplementing the prototype. Thus, the convex (凸) joint of the devised column and wall panel improved the insulation performance by increasing the airtightness through the application of the prefabrication method by inserting the pre-assembled panel into the column groove while shortening the construction period (Fig. 5.).

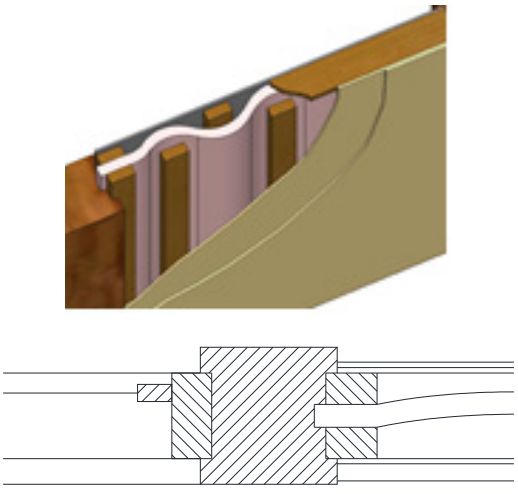


Fig. 5. Column to Wall Panel Type 凸 Connection

5) Application of R&D technologies for flooring

For the flooring, the process differs depending on the installation of underfloor heating; nevertheless, the technique introduced in the experimental Hanok project of Myongji University (2013) was applied in most sites.

However, in some construction methods, changes were made in terms of material, such as applying a combination of interlayer noise prevention material and plywood instead of using general plywood, or using laminate flooring and power-saving hot water heating instead of a red clay hypocaust. The linkage with modern heating facilities was enhanced through combination with modern floor construction technology while increasing the traditional beauty of the Hanok by constructing a Wumul-maru type Ondol floor or applying the "PVC Wumul-maru pattern tiles" depending on the site.

6) Application of R&D technologies for ceiling and joinery

In all the demonstration sites, a ceiling was constructed and a lightweight steel roof frame composition was applied in each room, for which the Yeondeung ceiling was not planned, such as the kitchen, office, and room. However, joinery is a field with prominent R&D for technological elements. Intensive research has been conducted to solve the problems associated with insulation, soundproofing, and protection of the Hanok. Consequently, the configuration of the Korean-style system windows to enhance a sense of openness as well as the technologies to improve insulation, airtightness, and heat shielding performance of traditional Korean-style windows were developed.

The developed and improved Korean style joinery technologies are applied to windows and doors regardless of the opening and clothing method. Window types are selected according to the actual use of the room. The type of windows were suitable for living spaces, where insulation, windbreak was applied; the decorative and aesthetic effects were also considered in the selection of the type of windows. The "Korean-style house system window door," a representative application technology, has been applied in various ways as it was advantageous for natural lighting, easy to maintain, and highly aesthetic.

Fig. 6. New Hanok Style House System Window Door

3.2. R&D technologies applied based on proposal in design and construction

The scope of the applied technology is largely divided into the construction for each part and the follow-up management program. Generally, the technologies proposed by the architect or contractor are reflected in the construction stage after the actual design. The technologies were proposed based on the rationality and suitability for the situation on site. To achieve a structural system advantageous in reducing the construction costs and construction period, the technologies were applied through consultation with the research team and construction company. R&D technologies applied based on the proposal of the design and construction were as follows.

1) Proposed design and construction technologies applied in structural part

In the new Hanok style public facility demonstration projects, the proposed design and construction technologies applied in the structural part mainly included the adoption and combination of the Hongyebo (arched beam), truss, and steel composite structures.

The Hongyebo (arched beam) structure was applied by accepting the proposal of the contractor for the mass-arched superstructure, which was planned in the initial design of the Naju Agricultural Fair site. The Hongyebo (arched beam) became a direct factor for solving the structural problem in securing the upper space of the roof, and it was the first case of construction in a new Hanok public facility applying the construction method proposed by the contractor. Hongyebo was applied to increase the usability of the space on the second floor (attic) by securing the openness of the mezzanine structure, contributing to creating an interior space differentiated from the existing Hanok architecture by functioning not only as a structure, but also as a design element maximizing visual openness.

Next, the truss structure was partially applied to the Sunchang Public Daycare Center. The initial design of the public daycare center was a traditional five-purlin wooden structure, but trusses were applied to the section consisting of a ceiling to facilitate the use and maintenance of the configured indoor space. The upper part of Daecheong (the main hall), which was configured as a Yeondeung ceiling, was constructed according to the original design, and as a result, a combination of girder and truss structures was used. It was possible to obtain the economic effect of reducing the construction cost and shortening the construction period by maintaining the form of the girder structure while incorporating the truss structure. Because the use of the truss is more advantageous for constructing a large space with the same amount of wood, it is regarded as a suitable technology for public facilities requiring a relatively long span. Additionally, it is regarded as an advantageous structure for the application of endorsement rafters, effective for combined use with the new Hanok style R&D technologies. However, because the critical view based on the aesthetic heterogeneity also plays a significant role, a multifaceted attempt is required for universality.

The steel-frame composite structure was partially applied on sites including the Eunpyeong Community Center. The two-story Eunpyeong Community Center is a complex structure, in which the first floor is applied with a steel frame and a wood junctional structure to ensure safety, and the entire second floor is constructed using the traditional wooden structure. The first-floor steel column was constructed to mirror the image of a Hanok by joining wood. Simultaneously, it was planned to be used as lighting by exposing the lighting inserted on the first or second side of some H beams. It is evaluated as a case where technology to expand the scope of expression in Hanok is applied by accepting and reflecting free space design.

2) Proposed design and construction technologies applied in roof such as roof tiles

The "Korean-style house tile roof structure" applied at Sunchang Public Daycare Center reduced the roof load by replacing the roof soil by assembling the roof neck member, facilitating the construction, while reducing costs by 20 to 50% compared to the traditional roof. It was applied to reduce the weight of the roof while having an appearance similar to the traditional Hanok tile roof using Hanok style assembly tiles (Fig. 8.).

The lightweight roof tiles are made of PVC or resin concrete material and include joints for binding. It is not in the form of the Japanese-style tile, but is configured in a way that the female and male roof tiles are assembled by connecting the joints allowing the easy placement and replacement (maintenance) of damaged tiles, not requiring an experienced tile worker for the construction. Although the lightweight roof tiles improved the

Fig. 7. H-shaped Steel + Wood Junctional Structure - Eunpyeong Community Center

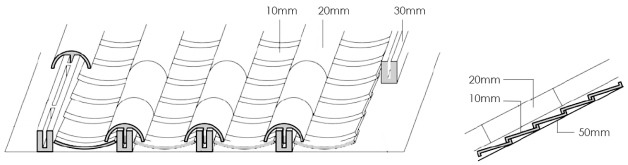


Fig. 8. New Hanok Style Assemble Roof Tile Application

Fig. 9. Skylight Window - Eunpyeong Community Center

sense of heterogeneity with modern materials by reproducing the exterior of the traditional Hanok roof tile with improved constructability and economic feasibility, cracks occurring in the process of joining the metal parts could reduce durability, and there is a limit to their application in various types of roofs as they are distributed as ready-made products rather than custom-made products. Various attempts on the shape and material will be required in this field to address these problems.

At the Eunpyeong Community Center, a vertical "skylight" was formed on the slope of the roof, which was attempted based on the proposed technology to increase the comfort of the indoor space and ventilate the stagnant upper air.

Despite the intensification of the copper plate and insulation reinforcement process for the roof insulation and leakage prevention, it was a significant attempt proving that a technical response to the modern demand, which had not been accommodated in the traditional Korean-style roof was possible (Fig. 9.).

3) Proposed design and construction technologies applied for use of heterogeneous materials

A curtain wall was applied to the stair hall of the Naju Agricultural Fair site, which was designed to ensure safety with an increased sense of openness and comfort upon installing a lift for wheelchairs.

For the curtain wall, double-layer THK22 glass as well as modern building materials were used, but the decorative elements were excluded to minimize heterogeneity. The natural flow plan from the hallway to the stair hall created a space that enhanced natural lighting in the building and promoted user convenience. It was a case effectively demonstrating the convergence and complex linkage with concrete and wooden structures.

4. Analysis of R&D Technologies Applied to Phase Three Demonstration Project - Children's Forest Experience Center in Hongseong

4.1 Previous R&D technologies

The Children's Forest Experience Center in Hongseong, which was a project leading to the final results of the third phase of the Hanok technology R&D, was carried out with a focus on the realization of the New Hanok style public building in a more economical and modern form by relaxing the criteria for the application of selected essential items, unlike the previous demonstration projects. Consequently, the prototype application rate[7] of R&D technology was only 5% with one case, and 95% (19 cases) of the technologies were used as application technologies. The technology with rectangular stone and granite flagstone applied to the stylobate was applied to all demonstration sites, at the beginning of the interior finishing work after installing the foundation stone on the matte concrete and completing the carpentry and roofing work.

The traditional assembly of wooden structures was used for the woodwork joints, and the galvanized steel + bolted hardware joining method was applied to the cross-joining part. In the construction of the cornerstone and lower part of the column, the lateral force was reinforced by installing a "J-shaped anchor" that connected the mat foundation + the cornerstone + the lower part of the column. When connecting at a right angle to a column, a column hardware set was used; when connecting at a cross or oblique angle, a "T-shaped hardware" was installed. The lateral force was secured by connecting the lintel between the lower part of the column as well as the epoxy filling of the hardware joint.

While the previous demonstration construction sites generally reflected R&D technologies focusing on the roof and wall processes, in the Children's Forest Experience Center in Hongseong, various joinery technologies were applied as most of the exterior walls were composed of windows and doors along the curved wall forming a spiral plane. Among them, the Korean-style wooden system windows and doors were designed to cope with the problems of sagging and warping associated with the traditional Korean-style windows by reinforcing

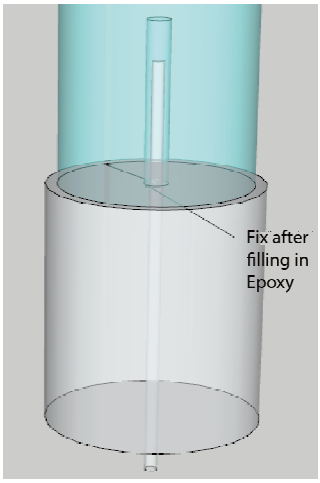


Fig. 10. Mat Foundation+Cornerstone+Column Bottom Combination

insulation and airtightness based on the aggregation technology for solid wood and aluminum.

4.2 R&D technologies applied based on proposal of design and construction

1) Haang truss structure

The Haang truss structure has a similar appearance to the Western scissors truss, but the design is in an applied form of the Haang member, one of the bracket styles, which is evaluated to be a more advanced technique based on the technology accumulated through previous demonstration projects and verified cases. The Haang truss applied in the Children's Forest Experience Center in Hongseong formed a free plane and a corresponding organic structure, and the wood and hardware joining technology was incorporated in a positive way for constructability and expressiveness [5]

The detailed drawing of the Haang truss joint shows the Haang + clasp joint structure and the hardware joint structure applied to the Haang + middle purlin. additionally, each connection of the pillar + Haang, pillar + purlin, and pillar + endorsement was also made using a metal joint, excluding the "traditional assembly of the wooden structure," which had been applied to all previous sites, from the plan (Fig. 11, 12.).

Particularly, the technology related to the metal joint was fully utilized at the Children's Forest Experience Center in Hongseong as a joining method verified through previous demonstration projects. As a joining technology to reinforce the lateral force, including the upper and lower joints of columns, the development and application of the metal joint types according to the form of joint with the column were planned to be followed by stability verification through structural analysis. This could be regarded as a pilot case for expanding the scope of application of R&D technology based on the technology proposed by the contractor.

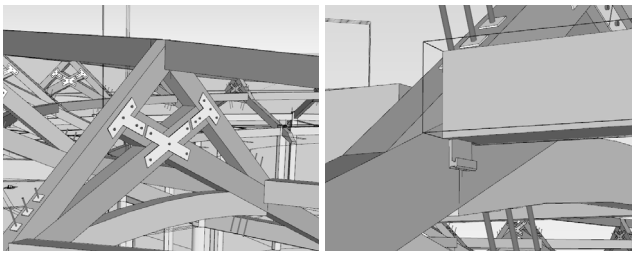


Fig. 11. Haang Truss Connecting Part Details

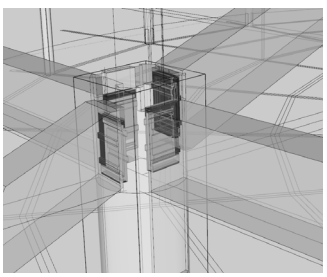


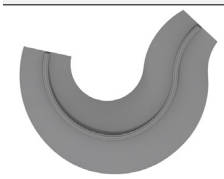
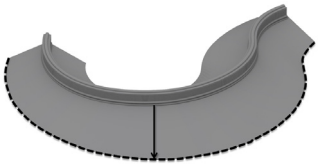
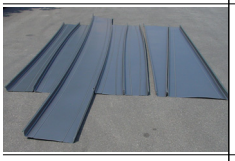
Fig. 12. Column Upper Metal Joint Structure Details

2) Pre-coated metal roofing sheet

The pre-coated metal roofing sheet applied with the Haang truss structure was designed and manufactured for application according to the curved shape of the roof through shaping and processing. It was the first case of applying the pre-coated metal roofing sheet in a new Hanok style public building.

The roof of the Children's Forest Experience Center in Hongseong has a steep slope and a curved surface with an almost twofold difference in length between the inner and outer diameters compared to the Korean-style tiled roof. The difference in the length of the roof end and central part of the roof was configured differently for each section. As there was a limit to realizing the designed form with the existing Korean-style roof tiles, an alternative method of reproducing the design of tiles that fit the traditional and modern senses using steel plate materials was proposed (Table 6.).

Table 6. Roof Finishing Plan

Design Features for Buildings	
Roof Plan	**Eaves Diameter**
	
Roof Area : 280㎡	External Diameter : 57m
	
Standing Seam Panel	Internal Diameter : 29m

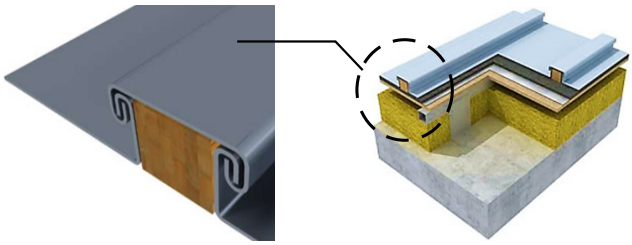


Fig. 13. Detail of Batten Seam Panel

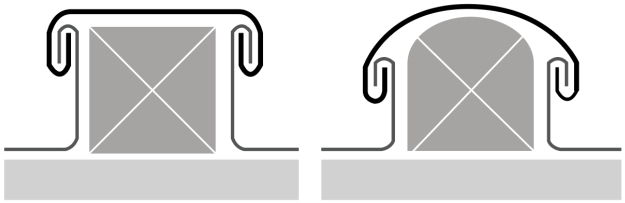


Fig. 14. Batten Seam Panel Basic(L) / Application(R)

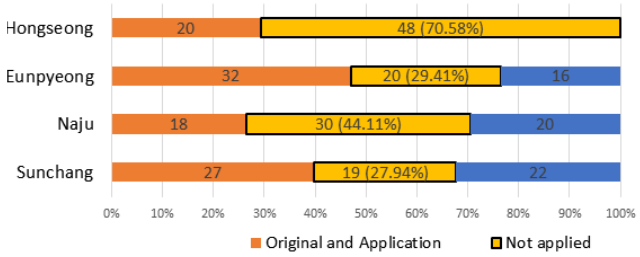


Fig. 15. Unapplied Technology Classification and Proportion

Additionally, it was designed and proposed to reflect the most effective colors and patterns to express curved roofs and to ensure aesthetics while preventing discoloration and corrosion caused by atmospheric exposure through the introduction of printing t echniques. The pre-coated metal roofing sheet was cheaper than copper and blue roof tiles, as well as traditional roof tiles, providing complete waterproofing functions with excellent economic feasibility as an alternative material that could effectively protect the building from water leakage.

The roof surface was composed of a trapezoid-shaped tapered panel with different widths on the upper and lower sides; the batten seam panel[8] construction method was adopted to express the protruding elevation of the traditional male roof tile along the joint of each member.

Originally, the batten seam was a method of fixing a lumber on the lower part of the steel plate, covering the angular ㄷ-shaped metal caps and connecting the two sides by lock seaming. It was intended to give the three-dimensional effect of traditional roof tiles by adjusting the height and shape of the folded materials creating clear shadows and outlines between the members. Particularly, the shape of the metal cap was proposed and applied to be processed in a round shape by processing the upper surface of the lumber.

4.3. Analysis of unapplied R&D technologies

The biggest cause of unapplied R&D technologies analyzed through the previous demonstration projects included the case in which the technology was excluded owing to differences in the design conditions, and the case in which an increase in construction cost was expected.

For the cases of R&D technologies applied to the Children's Forest Experience Center in Hongseong, 25 cases (29.4%) of existing technologies were reflected, of which the prototype application rate was below 20%, demonstrating a different trend from the previous demonstration projects. All unapplied technologies identified in the Children's Forest Experience Center in Hongseong were the cases of exclusion owing to differences from the design conditions, accounting for 70% of the total R&D technologies. This was a high number compared to the ratio of unapplied technologies of existing sites, which was counted as an average of 42%. Despite that the process of roof and wall construction was most frequently applied in the existing demonstration sites, 10 carpentry (40%) and joinery (24%) application technologies were applied, and technologies related to roof and wall construction were excluded in the Children's Forest Experience Center in Hongseong.

These results suggested that the scope of R&D technology application was limited in the first attempt of the curved planar structure. It was difficult to freely apply the technologies in design owing to the limits in terms of the use and shape of the building.

5. Conclusion

This study aimed to review the application and characteristics of R&D technologies applied to each phase of the new Hanok style public facility demonstration projects. Particularly, with a focus on the third phase demonstration project of the Children's Forest Experience Center in Hongseong, the degree of application of the existing R&D technologies as well as the characteristics of the applied technologies proposed by design or construction were reviewed. The results of this study are summarized as follows:

First, essential technologies in the planning stage of demonstration were applied to all sites by strictly following the prototype application criteria. The application rate in the construction process was an average of 65%, indicating that the application rate of the application technology was gradually increasing. The list of new Hanok style R&D can be divided into technology-and process scope-driven evaluation, which can be used as complementary standards in evaluation indices for new Hanok style public buildings in the future.

Second, the R&D technology applied in the scope of construction in seven fields reflected the items that meet the design standards and characteristics of each site. Nevertheless, the application technologies were actively used excluding the case with an expected difference in the design conditions and the case with an increase in construction cost. Based on verification through construction, the technologies were used and applied in the follow-up sites, resulting in the trend of focused technology application in roof and wall construction.

Third, the proposed design and construction technologies as well as improvement plans are evaluated as representative achievements of the new Hanok style R&D projects. While the set of application technologies were used in compromising the construction cost and design, the proposed technologies were presented considering structural stability and aesthetics. For the Children's Forest Experience Center in Hongseong, the compliance with the guidelines for reflecting the essential and

selective application technology applied to the previous demonstration buildings was relaxed. Accordingly, it was possible to adopt a new type of floor plan and construction method by combining the traditional Hanok elements with modern construction methods and materials, which may have been because of the increased constructability[9] in terms of material supply and processing. The proposed technologies were reflected without being limited to a certain scope of application and there has been a need for evaluation as a qualitative research according to the scope of applications, rather than the number of applications.

This study aimed to analyze the scope and specific examples of R&D technologies applied to new Hanok style public buildings in each stage of demonstration for reviewing the prototype application and analyzing the possibility of development for application technologies. Based on the results of this study, the applicability of new Hanok style public buildings should be reviewed based on the analysis of the characteristics of the New Hanok style R&D technologies as well as the application method of associated technologies from the prototype to technologies proposed on site such as design or application. If necessary, a Hanok technology R&D database that can be widely applied to New Hanok style public buildings in the future should be established by supplementing previously developed technologies.

Acknowledgement

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1) The New Hanok Style Social Welfare Facility Demonstration Construction Development Model project is a detailed task of the 10m-class Large Space Hanok Design and Construction Technology Development project, which was established through a total of 56 months of research from April 25, 2017 to December 31, 2021 conducted by the Korea Agency for Infrastructure Technology Advancement (KAIA).

2) The technology developed through Hanok technology R&D is called "New Hanok technology".

3) While the average construction cost of a traditional Hanok is approximately KRW 12 million/3.3㎡, the construction of a new Hanok style building costs approximately KRW 3.6 million/3.3㎡, saving more than 60% of the cost, with economic efficiency comparable to that of modern architecture (KRW 4.5 million/3.3㎡).

4) CBS/WBS/GBS/MBS are the "standard items applied for test bed construction project"

5) More than half (seven items, 64%) of essential technologies are software related to design programs, and there are five construction related technologies. The five construction related technologies include foundation blocks of the fence blocks, NHS fence for using a panel of a fence, Korean-style house tile roof structure, wood structure construction insulation materials and structures, and foam plastic module for Danggolmakyee.

6) In the application of new Hanok style R&D technology developed through the first and second phases of new Hanok style demonstration projects, if the application rate of a prototype technology is scored as 100%, the application rate of an application technology is scored as 70% of the prototype technology. This intends to differentiate the application technology from the prototype technology devised through verification, and it is a conversion index for calculating the application rate.

7) The programs corresponding to software in the planning stage, landscaping, monitoring, and other processes are excluded.

8) The method of forming an appearance similar to male and female tiles by folding each edge of the metal plate differently, and inserting and fixing them is referred to as lock seaming. Depending on the shape of the seam, it is classified into the flat-lock, standing, step lock, interlocking, and batten seams.

9) The joint processing and additional use of manufactured machines were carried out with a focus on improving the precision of construction such as plate cutting and finger joint members.