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Analysis on Prefabricated Space Structure Based on Overseas Patent Case Study

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Abstract This study analyzes the method for easily constructing a simple space in various environments. It also analyzes cases of modular prefab construction structures and explores various solutions and development directions that can form temporary residential spaces. This research intends to propose the diverse methods and solutions for constructing residential space for users' stable living environment in various unpredictable situations. This study amis to collect and analyze cases of various foreign patents related to the subject. With the analysis on the patents case, the prefab structures are mainly grouped into 4 types of 1) Assembly method using small parts, 2) Prefab module stacking method, 3) Space expansion method, and 4) Production methods of detailed elements. Based on the results, future research will inquire the lower cost and more efficient way of constructing prefab structure.

Key Words : Temporary Housing, Prefab, Simple Home, Prefabricate House, Modular Structure

요 약 본 연구는 다양한 환경에서 임시 주거를 위한 공간을 쉽게 구성하는 방법을 분석한다. 이를 위해 모듈라 조립식 건축 구조의 사례를 분석하고 임시 주거 공간을 형성할 수 있는 다양한 해결 방안을 탐색한다. 본 연구를 통해 예측이 불가능한 다양한 상황에서 사용자의 안정적 생활 환경을 위한 주거 공간을 구축하기 위해 다양한 방법을 제안하고자 한다. 이와 관련된 다양한 해외의 특허 사례를 수집하고 분석하여 다음과 같이 총 4가지의 그룹으로 그 결과를 도출하였다. 이는 1) 소규모 부품을 활용한 조립 방식, 2) 프리패브 모듈의 적층 방식, 3) 공간 확장 방식, 그리고 4) 세부 요소의 제작 방식으로 구분될 수 있으며, 이를 기반으로 향후 보다 더 저비용 및 효율적으로 구축이 가능한 프리패브 임시 주거 공간의 구조를 연구하고자 한다.

주제어 : 임시 주거, 프리패브, 간이 주택, 조립식 주택, 모듈라 구조

1. Introduction

1.1 Background and Purpose of the Research

This study analyzes the method of easily constructing a simple space for unexpected situation. It analyzes cases of modular prefab construction structures and explores diverse solutions and development directions that can form temporary residential spaces. In order to respond to sudden emergencies, it is very important to establish a space that can guarantee the lives of victims for emergency situations[1].

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This research intends to propose the diverse methods and solutions for constructing residential space for users' stable living environment in various unpredictable moments.

1.2 Boundary and Method of the Research

In order to analyze the structure of the prefab modular space, various patent data were collected and analyzed. In the previous study, a number of patent cases registered in Korea were analyzed. This study amis to collect and analyze cases of foreign patents related to the subject. "Google Patents(Patents.google.com)" was used for overseas patent collection, and research was conducted based on a total of 10,628 patent cases derived by searching through a combination of keywords of "Prefabricated", "Temporary", and "Modular". Among them, a detailed analysis process was conducted for the final 16 patents(registered in public from year 2000 to 2020) that are considered to be most closely related to the subject of this study. Also, in this research "Prefab" is indicated to be "Prefabricated" structure.

2. Prefabricated Space Structure

2.1 Prefab Residential Space Structure

A temporary housing facility can provide temporary housing for displaced people, and includes facilities that are easy to accommodate and safe, such as public buildings, schools, churches and town halls[2]. In addition, the prefabricated space means to build a space or architecture through a simple assembly procedure by transporting the structure manufactured in the factory to the site, and refers to a techniques of transforming the assembled structure or parts to the area to assemble[3]. The prefab structure is a type of temporary housing which can be divided into six types of "Emergency shelter", "Temporary shelter", "Temporary housing", "Transitional shelter", "Progressive shelter", and "Core shelter". Also, "Transitional shelter", "Progressive shelter", and "Core shelter" are temporary housing types that can be used for many years semi-permanently[4].

As the temporary housing should be easily moved and conveniently assembled or constructed, most of the temporary housings are constructed with light-weight structure. And the core element of the light-weight structure or architecture is to maintain the similar structural efficiency and strength or rigidness while substituting the heavy materials to the lightweight materials. Consequently, the lightweight construction should maximize the intrinsic and rational properties of each material while using fewer materials, and it also involves research and interpretation of the structure[5].

2.2 Features of Prefabricated Space Structure

However, there also is weakness of the prefab structure, and the defects needs to be reinforced for providing the safe and stable residential space to users. Prefabrication was not a new concept for the architects, but it was a necessary element for constructing precise modern structure which was created in factories and transported to the actual site. However, the prefabricated buildings or structures sometimes poorly designed and constructed. But in the 21st century, prefabrication constructing methods become more active and popular[6].

There are many restrictions for the construction of the prefab module, but since each module must be transported by vehicle to the site, it must be manufactured according to the limiting standards. The width of each module should be 3.0~3.3m and the length should be within 6~12m. Prefab construction can be classified in various ways according to the

manufacturing method and materials, and it is divided into a total of 6 stages[7].

Table 1. Types of Prefab Structure (Steinhardt.et.al., 2013)

Prefab Level	Type	Definition
High	Complete	Moved and installed in a box-type structure, completely assembled on a building site
	Modular	Structured form. Assembled and installed on site as it moves as a partial element to the construction site.
	Pods	Pre-assembled structure. Devices fastened to the structural frame in the field, such as bathrooms or kitchen pods
	Panels	Structural and non-volume frame elements used to create space, such as structural insulated panels (SIP) and precast concrete panels
	Component sub-assembly	Pre-assembled parts such as doors and trusses produced directly on site
Low	Materials	Standard building materials used in field construction

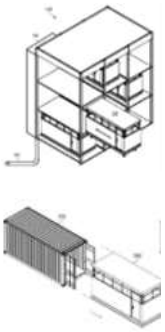
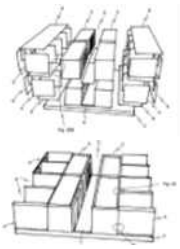
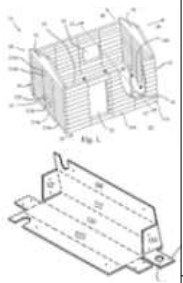
3. Prefabricated Space Case Analysis through Overseas Patents

3.1 Prefab Space Case Study

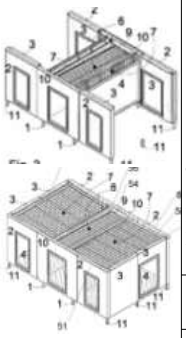
Investigation and analysis were conducted for each case of Prefab. A total of 10 cases searched through "Google Patents" were analyzed as shown in <Table 2>.

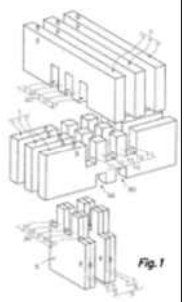
In order to analyze each case, the items of "Material(MT)", "Cost(CO)", and "Assembly(AS)" were divided into six yields. In addition, "Material(MT)" for each case is indicated as "Concrete(C)", "Metal(M)", "Wood(W)", "Glass(G)", "Plastic(P)" and etc. "Cost(CO)" is divided into a total of 6 units, where 1 is the lowest production cost and 6 is the highest production cost. "Assembly(AS)" is divided into a total of 6 units, where 1 is the lowest assembly difficulty, 6 is the highest assembly difficulty. The difficulty of assembly is limited to the case where the parts for moving installation are small and can be easily moved without using cranes or other facilities. The more difficult the number of parts is and the more time it takes to assemble in order to form a specific space, the more difficult the assembly is marked as "difficult".

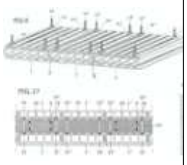
Table 2. Types of Prefab Structure

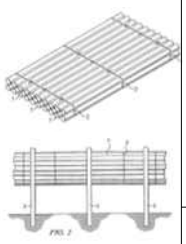
Type	Image/Title/Patent#	Details/Analysis
A	 Modular Housing Units, Reusable Support Structure, and Utility Connector[8] US20160312485A1	• Modular housing unit • Reusable using multiple prefab modular housing units • It can be moved in a transport container. The roof is lowered to lower the height and change to a size suitable for the container. • It moves quickly in response to a disaster, but in the construction of the building, it is not suitable for use as a temporary residence for the displaced by entering the large frame located in each region. • It would better to be configured without requiring a frame.
		MT: C ● / M ● / W / G ● / P / etc. ● CO: 1 / 2 / 3 / 4 / 5 / 6 ● AS: 1 / 2 / 3 ● / 4 / 5 / 6
B	 Method and System for Construction of a Building[9] US9556632B2	• Modular and panel-based construction using walls • Utilizing the advantages of modules and panels, making the most of automation technology • Suitable for multi-room buildings with single rooms such as hotels and hospitals • Additional space can be created by utilizing 4 wall surfaces that are joined between the floor and the column. • Creating spaces that are connected to each other by utilizing various aspects. Somewhat inconvenient when you need privacy and separate space
		MT: C ● / M / W / G / P / etc. CO: 1 / 2 / 3 / 4 / 5 ● / 6 AS: 1 / 2 ● / 3 / 4 / 5 / 6
C	 Prefabricated Building and Kit[10] US9428926B2	• Modular way of folding sheets Polypropylene • The building is constructed by cutting and folding a sheet made of polypropylene to make a block and stacking it. • Easy to transport and easy assembly • Strength can be increased by inserting reinforcement in the block. • Easy to mass production, various types of space can be configured • It is possible to save time and labor by applying a method of making a relatively large block rather than a block that is too small.
		MT: C / M / W / G / P ● / etc. CO: 1 / 2 ● / 3 / 4 / 5 / 6

		AS	1	2	3	4	5	6
						●		

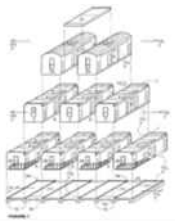
D	 Prefabricated Foldable Building Module[11] US9611637B2	• Foldable modules Iron, concrete, aluminum • A folding structure is formed by unfolding the folded wall. Unfolding the centrally located panel to form a roof • Easiest for transportation and reuse • Small to large number of people can be accommodated as needed If the structure is reinforced and stacked like a layer, the structure become more effective.							
		MT	C	M	W	G	P	etc.
			●	●				
		CO	1	2	3	4	5	6
							●	
		AS	1	2	3	4	5	6
						●		

E	 Prefabricated Construction System and Method with Three-dimensional Structural Nodes[12] US20170370090A1	• 3D structure applicable to prefab construction Wood, iron, etc. • The three intersecting plates have a vertical structure. • Two plates are filled in the middle space to prevent distortion. • Structurally connecting the vertical columns and the horizontal and vertical layers. • Applicable to various materials • Needs simplification in configuration, assembly time and process with a large number of parts							
		MT	C	M	W	G	P	etc.
				●	●			
		CO	1	2	3	4	5	6
					●			
		AS	1	2	3	4	5	6
						●		

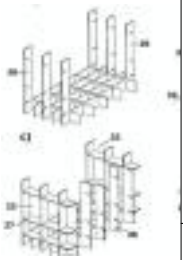
F	 Element of Brick Material for Realizing Prefab Panels for the Building Industry[13] US20080022621A1	• The square-shaped panel element pushes the pin through the C-shaped opening on the top. • Concrete and cement can be reinforced • Wires can be passed through the space between the panels, and it is light enough for transportation. • 25 prefabricated structures are applied with double inner walls, outer walls, single floors, and reinforced ceilings. • Each panel is easy for mass production with adjustable distance with mushroom-shaped rods, and to control the distance between the wall made of panels.							
		MT	C	M	W	G	P	etc.
			●				●	
		CO	1	2	3	4	5	6
						●		
		AS	1	2	3	4	5	6
					●			

G		• Modular type for a light structure w/natural reed(bamboo, kingrass) • Structurally lightweight and easy to handle w/significant savings in cost and configuration • Can be harvested twice a year and recycled 100%. • Bundled with plastic belt to form the required shape							
		MT	C	M	W	G	P	etc.	

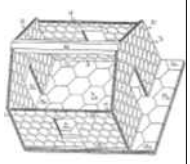
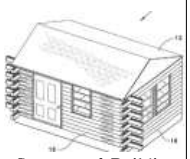
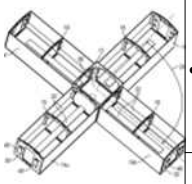
	Light Prefabricated Module Made from Natural Reed and Used as a Construction Element[14] US20060062959A1				●		●		
		CO	1	2	3	4	5	6	
			●						
		AS	1	2	3	4	5	6	
					●				

H	 Light Weight Modular Units for Staggered Stacked Building System[15] US20150121775A1	• They are stacked alternately to form a "bonus space". • Stacked alternately using wooden and metal frames to build a path over the space. • With a lightweight modular structure, it can be easily transported through a crane. • Provides residential space for a large number of people in a small space and in a short time.							
		MT	C	M	W	G	P	etc.	
			●	●	●				
		CO	1	2	3	4	5	6	
							●		
		AS	1	2	3	4	5	6	
								●	

I	 Prefabricated Container House[16] US20120255240A1	• The prefab container house can be expanded to three times its original size • The ceiling support beam and the floor support beam are formed on the pre-made "U" shaped assembly wall between the ceiling and the board, which is configured to be withdrawn from the main body. • It can be stacked upstairs to high floors and is easy to transport. • Wide space formation through unfolding wall							
		MT	C	M	W	G	P	etc.	
				●					
		CO	1	2	3	4	5	6	
							●		
		AS	1	2	3	4	5	6	
				●					

J	 Modular Building Construction[17] US8458980B2	• Stable structure by forming a grid and can be supported in all six directions by connecting the ceiling, walls, and floor. • Shortening the assembly time by supplementing the connection of parts using cement in the field and the use of many parts in the production process. • Cutting flat plates is efficient in mass production. • Better stability and distortion							
		MT	C	M	W	G	P	etc.	
				●					
		CO	1	2	3	4	5	6	
					●				
		AS	1	2	3	4	5	6	
								●	

K	 Method and System for Prefabricated Construction[18] US20040237439A1	• A system that creates various structures with a combination of stackable modules • Block module using concrete Consists of an arch-shaped corner block, key block, and center block • All blocks have the advantage of being stackable • Quick assembly and disassembly are easy and various types of buildings can be produced. • Quick assembly is possible but not suitable for temporary residential facilities due to its weight.							

		MT	C	M	W	G	P	etc.
			●					
		CO	1	2	3	4	5	6
						●		
		AS	1	2	3	4	5	6
							●	
L	 A Hexagon Building Structure Offset Layering System[19] US20040221529A1	• Utilizing the panelizing method that composes the surface of the building using hexagonal wood panels • Wood panel, panel fixing bolt • Hexagonal wood panels are used for the walls of the building. • Hexagonal panels can be fitted together to create various wall shapes. • Recyclable for remodeling or rebuilding of buildings.						
		MT	C	M	W	G	P	etc.
				●	●			
		CO	1	2	3	4	5	6
				●				
		AS	1	2	3	4	5	6
				●				
M	 Prefabricated Building System[20] US8365483B2	• Modular construction with a grooved plastic module followed by a round roo • Plastic module, frame • Plastic modules can be joined by sliding them from the front in the vertical direction. • Even inexperienced users can disassemble and assemble quickly, and all parts can be used semi-permanently						
		MT	C	M	W	G	P	etc.
							●	
		CO	1	2	3	4	5	6
					●			
		AS	1	2	3	4	5	6
					●			
N	 System of Building Modular Log Homes[21] US20050126084A1	• A structure building the outer walls by stacking logs at intersections • Modular log • The wooden modules are fixed to each other using a regular groove. • As the log modules pile up, the outer walls of the four sides are fixed to a stable structure. • Materials can be cut quickly to a certain size using a saw.						
		MT	C	M	W	G	P	etc.
					●			
		CO	1	2	3	4	5	6
					●			
		AS	1	2	3	4	5	6
					●			
O	 Modular Building Components, Systems, and Methods Thereof[22] US20180340326A1	• Structure supporting all loads through columns and vertically fitting walls and roofs • Steel columns, wall/roof panels • It can be easily assembled with a small number of people by using the structure stacked from top to bottom.						
		MT	C	M	W	G	P	etc.
				●				●
		CO	1	2	3	4	5	6
					●			
		AS	1	2	3	4	5	6
						●		
P	 Modular Shelter[23] US20170328054A1	• Structure that expands space from the central module in all directions Steel columns, wall/roof panels • The room extended in all directions prevents the shelter from being overturned by strong winds • Various horizontal expansion is possible but vertical expansion is not possible. • A large land area is required for installation.						
		MT	C	M	W	G	P	etc.
				●				●
		CO	1	2	3	4	5	6
							●	
		AS	1	2	3	4	5	6
							●	

3.2 Analysis of Prefab Case Study

3.2.1 Analysis on Used Material

The types and characteristics (advantages/disadvantages) of each material used directly in the prefab space for each case are summarized as follows. Considering the characteristics of each material, a prefab modular structure that efficiently responds to various situations will be built.

Table 3. Material and Features for Prefab

Type	Features
Metal (Aluminum)	Light, durable, and has good moldability It can be manufactured in various shapes and shapes. It has little strain due to the external environment.
Concrete	A mixture and hardened material formed by bonding aggregate to a pool, which is an inorganic(cement, lime, gypsum, etc.) or organic(asphalt, resin, plastic, etc.) binder. It has high compressive strength and excellent durability. Construction is relatively simple and easy to maintain. Cracks may occur due to shrinkage[24].
Plastic (Polypropylene)	It is polymerized from propylene obtained from petroleum. It is free from environmental hormones and can be recycled. Lightweight, resistant to friction, and has high flexural strength[25].
Etc.	In an environment where continuous maintenance is difficult in the future, it is also very important to construct it using various materials that can be easily obtained in a specific area. Materials such as wood, bamboo, and kingrass can be sufficiently utilized to build a space for temporary housing.

3.2.2 Analysis of Construction Cost and Installation Difficulty

It is important to easily move and assemble, but the cost required to build a specific space is

also important. In the case of a module of a container prefab that can be extended, there is an advantage that it is more easily transported and installed than when installed in the field. However, because it is relatively bulky and heavy, it costs more to use a vehicle for the movement, and a crane for installation. On the other hand, it is easy to move the prefab module composed of small parts, and it does not require heavy equipment such as a crane when installed in the field. However, because of the large number of parts, it takes a relatively long time to assemble and install the structure, which are directly related to labor costs. Although there is no way to clearly define that there exists an absolutely low cost method, it is important to choose a prefab module that is appropriate for the certain time and situation.

The larger the number of parts, the more complicated the assembly and the more time it takes. The structure of moving and unfolding in the assembled and completed state in the prefab is relatively low in difficulty of assembly. On the other hand, the method of stacking, assembling, and expanding using various detailed modules requires various numbers of parts, and is relatively more complicated and requires more time to assemble and install the structure.

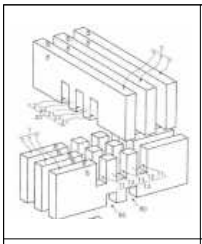
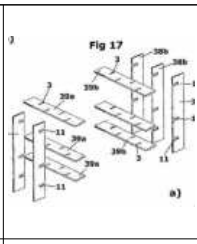
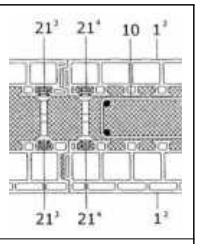
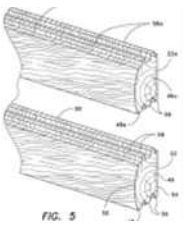
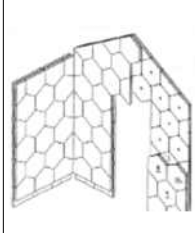
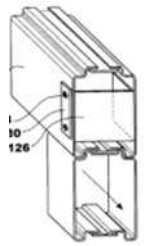
3.2.3 Comprehensive Analysis

The characteristics of each case were synthesized and analyzed as follows.

1) Assembly method using small parts

Rather than assembling and moving the whole in advance, such as a prefab container, it is a method of constructing a space by using a small component module. Small component modules are produced in prefab form and assembled in various ways in the field. While there are advantages in terms of cost for the move, the assembly process takes some time, which can be directly related to the labor costs.

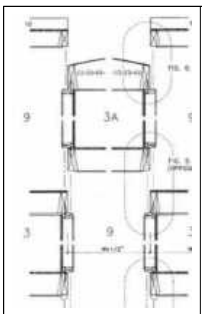
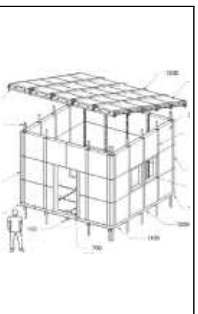
Table 4. Assembly Methods Using Small Parts

		
Three-dimensional Structural Nodes	Modular Building Construction	Element of Brick Material
		
Log Module	Hexagon Wood Panelizing	Plastic Module

2) Prefab module stacking method

It is a method of constructing a space by using a larger prefab part rather than each detailed part. It is easy to assemble and install in the field by using container type prefab module or panel type prefab module. However, because there are restrictions on size and volume, it may take some time to move or install the structure.

Table 5. Prefab Module Stacking Method

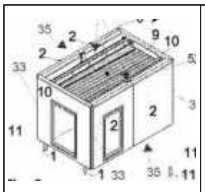
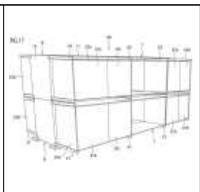
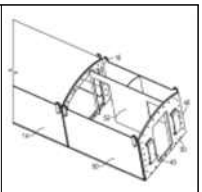
		
Staggered Lamination	Block Stacking Using Concrete	Wall and Roof Module Stacking

3) Space expansion method

This is a method of manufacturing and completing a prefab module for each space at the factory to expand the space in the field after moving. Depending on how the space is

expanded, it can be classified into vertical expansion, horizontal expansion, and radial expansion, and the expansion scheme can be applied according to the nature of the available land.

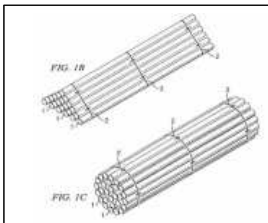
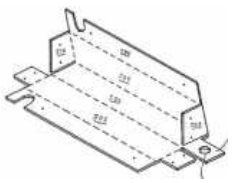
Table 6. Space Expansion Structure

		
Vertical Expansion	Horizontal Expansion	Radial Expansion

4) Production method of detailed elements

This is a method of constructing a space by utilizing the minimum unit of the elements constituting each space. It is similar to the concept of making bricks for constructing a building, and it is easy to manufacture the minimum components of the space by using cheap plastics that are easy to produce and easy-to-use plastics or natural materials (wood, lead, etc.) that are readily available in the field. This has the advantage that the space itself can be easily maintained.

Table 7. Production Method of Detailed Elements

	
Use of Natural Material	Block Module Using Plastic(

4. Conclusion

The method of constructing a space structure using prefab for temporary housing in various environments was analyzed. The research investigated foreign patent cases to analyze cases of modular prefab building structures and explore various solutions to form temporary residential spaces. Through this study, various methods are proposed to build a residential space for a stable living environment for users under various unpredictable situations. Foreign patent cases related to this have been collected and analyzed, which can be divided into 1) assembly method using small parts, 2) prefab module stacking method, 3) space expansion method, and 4) production method of detailed elements. In the previous study, the characteristics of the prefab module were analyzed for domestic(South Korean) patents, and the characteristics of the prefab for overseas patents were classified through this research. Based on this study, the future research will be proceeded with a prefab structure development that can be more efficient and cost effective for construction and installation.

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