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# Investigating the Impact of the Prefabrication Concept on the Design and Selection of Building Components, Case Study: Peripheral Walls in Mass Housing Projects


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Today, Prefabrication is considered as one of the concepts of industrialization in response to the growing needs of human societies for development. It is particularly important to address this concept in mass housing projects. The most important goals in adopting the prefabrication approach are to increase construction speed and quality and reduce costs. A review of the literature on prefabrication illustrates the importance of Design for Manufacturability and Design for Assembly concepts about components of prefabricated systems. In this regard, this research has been carried out to identify the criteria and indicators for selection of prefabricated peripheral walls and to design a system based on updatable databases to select proper options according to the importance of criteria and indicators in various mass housing projects. The research method is descriptive-analytical. The results indicate the necessity of involving building material suppliers in designing the mentioned system. Therefore, it is envisaged to continuously import new material specifications in the form of suggested options by the material suppliers in the system's database. The criteria and indicators of peripheral wall selection extracted from the literature review of prefabrication and an Analytic Hierarchy Process structure is proposed to obtain the appropriate options considering the importance of criteria and indicators. To determine the scoring criteria for options, on the one hand, the standards set for the technical specifications of materials were discussed and on the other hand, samples including materials and Peripheral wall systems were investigated based on the prefabrication criteria.

**Keywords:** Prefabrication, Industrialization, Design for Manufacturability, Design for Assembly, Analytic Hierarchy Process.



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## Introduction

The widespread and increasing need for human societies to develop construction suggests the necessity of employing new building systems and materials and modern construction methods based on these main goals; increasing construction speed as well as reduction of building weights, costs, and environmental effects. In this regard, the concept of Industrialization to meet these goals is important. Industrialization is considered as a transition from the traditional stages to optimally exploit human resources and raw materials along with maintaining the quality and value of the produced product to meet the needs of the market and economic efficiency so that using modern technologies in a systematic structure leads used resources operate at the best level of efficiency. Increasing the speed and quality of construction along with reducing the time and price of the work are the benefits of industrialization (Eghbali & Hessari, 2013).

Industrialization, which has to be employed as an effective strategy in the restructuring of the construction system, seeks its objectives with a systematic approach by applying a chain of actions and processes as follows:

- \_ Detailed planning and implementation of systematic monitoring of the design and construction process with the help of integrated management.
- \_ Application of modern materials and technologies and mass production of building components.
- \_ The stimulation of demand for integration and concentration of consumption market especially in new towns and worn-out urban fabrics.
- \_ The preparation of the building site from urban design and infrastructure power of view.
- \_ Promoting industrialization and training skilled workers and experts.
- \_ Developing prefabrication systems.

Investigating the challenges faced with prefabrication methods is particularly important especially in mass housing projects. Prefabrication refers to the process of producing components of a system outside the location of its establishment and carrying them to be assembled in the designated place. The earliest examples of prefabricated buildings in the 17th century have been built in the UK as buildings made of wooden panels that were portable and had the capability of disassembly (Eghbali & Hessari, 2013). Today the concept of prefabrication in the construction industry is associated with industrial manufacture and assembly. In this regard, using similar building components is of particular importance to enable mass production in the factories. Despite the advantages of prefabrication methods, using them in mass housing projects especially in less developed regions can bring some challenges in architectural design and construction and maintenance of projects (Azman, Ahamad, Majid, & Hanafi, 2010; Manley, Mckell, & Rose, 2009). Therefore, there are many types of research in different aspects of prefabrication that can be mentioned.

Goulding et al. (2015) have examined the economic challenges facing prefabricated methods. Mao et al. (2013) have examined the technical obstacles and restrictions of prefabricated methods. Blismas et al. (2006), as well as Arif and Rahimian (2012), investigated the benefits of prefabricated methods in their research. Taghdiri and Ghanbarzade (2015) investigated the benefits of prefabricated compared to conventional construction methods and concluded that various prefabricated benefits have different values, in this regard, better management on improving the quality of precast products has the most value. Most of the studies have achieved the conclusion that overcoming challenges facing prefabricated methods is based on the continuous cooperation among all stockholders in the design, assembly, and installation stages of building components (KPMG, 2016).

Concerning the prefabrication policies in different countries, in china after the emergence of the environmental crisis in the 70s, the central government considered the prefabrication approach as the main strategy to diminish the bad effects of the construction industry on the environment (Li et al., 2014; Dou et al., 2019). In this regard, the prefabrication building's codes were published and financial incentives for prefabrication buildings were specified by the government. In the US, the prefabrication

approach dates back to the 30s. On that decade the production of affordable mobile houses had been industrialized. In the 70s, due to the emergence of the sustainable development theory, prefabrication was considered as one of the main strategies to diminish the bad effects of the building industry on the environment, so in 1976, the US Department of Housing and Urban Development established industry standards for prefabrication buildings (Wilson, 2012). Prefabrication construction in the UK dates back to the years between two world wars, on those years, this approach was developed due to the lack of expert workers and building materials (Howes, 2002). After the Second World War prefabrication construction was more prevailed due to the needs of fast reconstruction therefore in 1950 about 34% of London's residential buildings were constructed using prefabrication methods (Ibid). In 1965 the UK government developed a five years program to build half a million houses per year, so the prefabricated approach was more prevailed (Millins et al., 2006).

Peripheral walls are the basis of building facades and contain large amounts of finishing works. These components have great impacts on energy waste, so they are important in prefabrication construction. This applied research reviewed the principles and concepts related to industrialization and prefabrication and extracted the goals, criteria, and indicators of achieving them, to determine a structure for the selection of peripheral walls system in the mass housing projects in Iran. In this regard, according to the climatic, economic, cultural, and social conditions and level of available facilities and technologies in each region, the importance of derived indicators in determining the type of peripheral walls may be different. Therefore, this research provides the necessary basis to design an application that contains the technical specifications of peripheral walls systems with continuous updating capability and providing the possibility of determining the importance of criteria and indicators to introduce suitable alternatives according to project conditions.

The research questions are as follows:

- \_ What are the goals and criteria of prefabrication in mass housing projects?
- \_ What are the indicators of peripheral wall selection based on prefabrication goals in mass housing projects?

Today, it is largely accepted that the industrialization in the construction has uncontested and substantial advantages in comparison with traditional construction. Traditional methods of construction may cause the following problems that can be solved by using industrialized construction.

- \_ Waste of resources such as; energy, manpower, capital, time, and materials during the design, construction, operation, and demolition cycles of the buildings.
- \_ The lack of comprehensive and effective control of constructions.
- \_ lack of integrity in planning and activities

This shows the importance of the prefabrication concept as one of the necessities of industrialized construction. The review of literature on prefabrication and its related concepts shows the importance of standardization in the process of design and production of a prefabricated system's components. In this regard Wuni & Shen (2019) believe that standardization leads to diminishing the complexity of the design and the costs of construction, also the design of prefabricated buildings can be diversified by the customization of the component's production line. Standardization in the prefabrication approach brings the possibility of mass production and accelerates the construction (Gao et al, 2019).). Concerning the advantages of the prefabrication approach in residential projects, Kibert (2012) and Li et al. (2014) have mentioned some items like (1) Fast return on investment for developers (2) costs reduction for residents (3) safe working conditions for construction workers and (4) waste minimization due to the high precision and repeatable production. Rod (2015) and Steinhart & Manley (2016) believe that It is easier to standardize the components of residential buildings.

Design for Manufacturability (DFM) and Design for Assembly (DFA) are two bases of the prefabrication concept. DFM is the process of designing parts, components, or products for ease of

## The Importance of Prefabrication and Its Related Concepts

manufacturing with an end goal of making a better product at a lower cost. This would be possible by simplifying, optimizing, and refining the product design. The following are the requirements and benefits of DFM that should be considered in the design phase of the product:

- \_ Reducing the variation in system's components
- \_ Reducing the time and cost of the production
- \_ Simplifying the production methods
- \_ Simplifying and standardization where ever possible

DFA seeks to simplify the product, so the cost of the assembly process is reduced. DFA also includes a set of measures for combining parts to form the final product. Economical and technical justifications of using prefabricated methods in the field of the construction industry depend on technical measures in the architectural design phase (Stoll, 1986). Therefore, the assembly of the manufactured components in the building site can be done by the minimum construction operations, which causes accurate implementation, higher speed, and lower costs, so the desired goals will be more accessible (RIBA, 2013). DFM and DFA concepts should always be considered simultaneously in the prefabricated projects so the concept of Design for Manufacturability and Assembly (DFMA) has emerged in the literature of prefabrication (Bogue, 2012).

The primary studies on DFA date back to the research of Boothroyd and Dewhurst (1987) which resulted in the extraction of actions during the design stages to achieve the optimal results in the assembly of the components. The main point in the design stage is to reduce the number of components types to reduce the probability of errors in the assembly stage. Every part of a prefabricated system must be in coordination with other parts during the normal operation of the system and also should be separable from other components (Emmatty & Sarmah 2012). DFM related studies are also concerned with finding materials and methods of producing prefabricated system's components with a reduction in production costs, and ease of assembly (Ibid). Both issues are highly important in prefabricated projects and this indicates the necessity of addressing the concept of Design for Manufacturability and Assembly (DFMA).

DFMA consists of stages shown in Fig 1. The benefits and guidelines of DFMA are presented in Table 1.

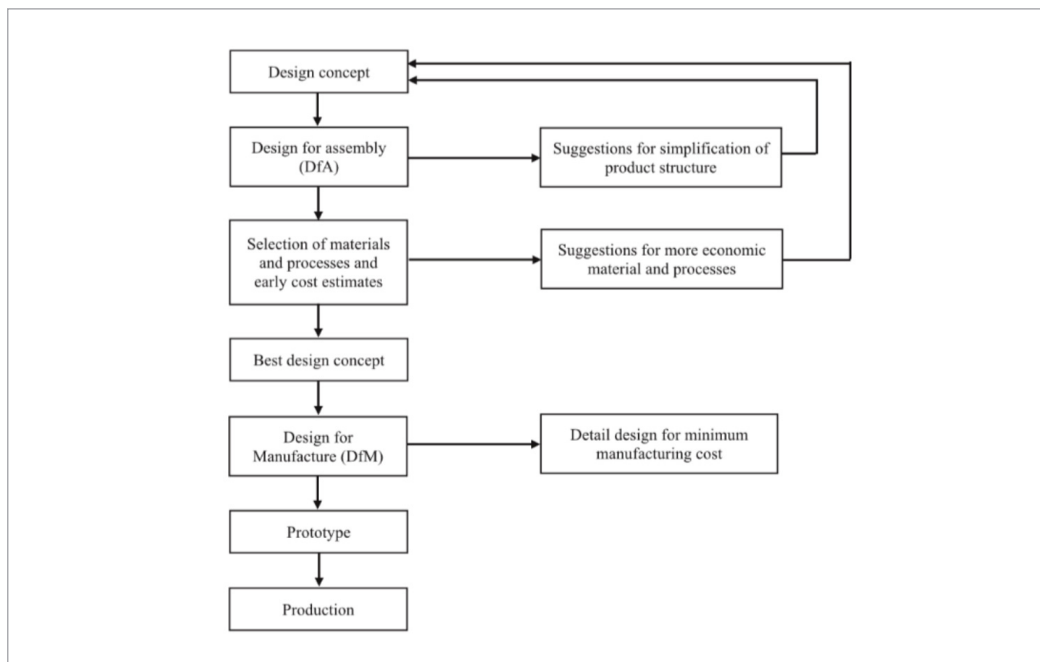


Fig. 1

Typical stages in a DFMA procedure

Table 1

General DFMA  
guidelines and their  
benefits

Benefits	Guidelines
Improved reliability, reduced purchasing and inventory costs, simplified assembly	Minimize the part count
Reduced costs, lower purchasing lead times, potentially greater reliability	Use standard, off-the-shelf parts rather than custom components
Reduced costs, simplified assembly, improved reliability, simplified repair and maintenance	Minimize and standardize the use of fasteners/ design for efficient joining and fastening
Simplified jointing, fewer manufacturing processes	Use as few dissimilar materials as possible
Cost reductions due to fewer part failures, easier handling and assembly	Minimize the use of fragile parts
Easier manufacture and reduced fabrication costs	Do not over-specify tolerances or surface finish
Cost reductions from the elimination of complex fixtures and tooling	Design for ease of fabrication
Reduced costs due to simplified assembly and test	Consider modular designs
Cost reductions by eliminating need to re-work incorrectly assembled parts	Aim for mistake-proof designs
Cost reductions due to non-valueadded manual effort or dedicated fixturing	Design for simple part orientation and handling
Cost reductions from use of proven/ known techniques	Design with predetermined assembly technique in mind
Potential cost reduction over manual methods	Consider design for automated/ robotic assembly

Source: (Bogue, 2012).

## Prefabrication Approach in Peripheral Walls

Today, buildings use about 40% of the total global energy consumption (Attmann, 2010). The external envelope system of the building which Non-load-bearing peripheral walls are of its main components is a significant contributor to the corresponding energy demand and indoor comfort conditions. Non-load-bearing walls generally can be classified from the aspects of function, position in the structure, and the type of materials.

These components have significant impacts on the building energy performance and its related costs and also the thermal and acoustic comfort of the occupants. Earthquake data in different parts of the world show the importance of the seismic performance of these walls and the necessity of their coordination with the whole structure (Noorifard.et.al, 2016). According to the concepts of DFM and DFA, in the case of the possibility of defining a factory production line for the components of a wall, and predicting the necessary preparations to assemble the components at the construction site, the prefabricated concept can be allocated to the system (Gao.et.al, 2019). However, the use of any material with these conditions can not necessarily lead to the achievement of the intended goals for prefabrication. Most studies have stated that the main objectives of using prefabricated systems are to increase the quality and speed and reduce the cost of construction (Eghbali & Hessari, 2013; Gao.et.al, 2019; Bogue, 2012; Emmatty & Sarmah, 2012; Kibert, 2012; Li et. al, 2014).

Quality includes a wide range of aspects from aesthetical to functional, which according to the purpose of this study, it is important to measure the quality in the proposed ranking system, so

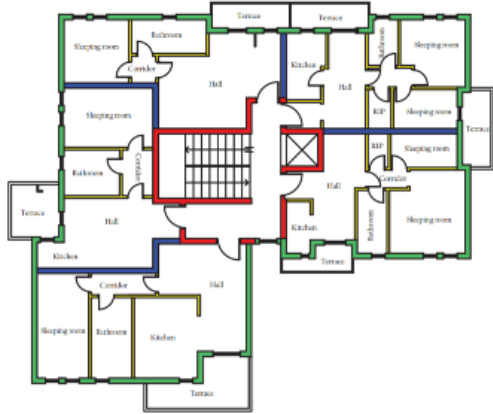
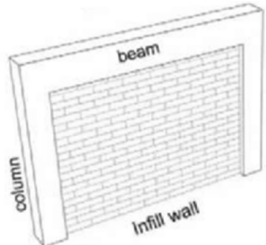
Non-load-bearing (Nonstructural) walls	Function	Peripheral Walls		 <p>Fig. 2. Walls Classification base on function</p>	
		Shared Walls	With neighbors		With interior shared spaces
			Partition Walls		
	Position in the structure	Infill walls	 <p>Fig. 3. Infill wall</p>		
		Partition wall			
	Type of materials	Discrete	Walls made of Blocks		
Continues		Walls made of Panels			

Table 2

Non-load-bearing walls Classification

Source: Authors.

the criterion for evaluation of measurable qualities are national or international standards and codes. In this framework the following factors and their evaluation criteria are important in the selection of peripheral walls in a prefabricated system:

- \_ Fire resistance (INBC: part 3; ISIRI:12055-1)
- \_ Energy performance (INBC: part 19)
- \_ Acoustic performance (INBC: part 18; ISO717-1)
- \_ The possibility of industrial production (INBC: part 11)
- \_ Seismic performance (INBC: part 6)
- \_ Other indicators: Durability, Maintenance and transportation costs, Environmental impacts the ability to recycle materials, and so on. (Expert questionnaire)

The criteria and indicators in Fig. 4 are considered as the decision-making basis in the selection of the peripheral walls in a prefabricated system. The method of content analysis based on the literature review was deployed to extract the indicators of the three main criteria of prefabrication. In this regard, an analytic hierarchy process (AHP) method can be used to compare the proposed options and choose the preferred option based on the importance of criteria and indicators under the structure in Fig. 5.

Fig. 4

Criteria and indicators of the selection of the peripheral walls in the framework of prefabrication

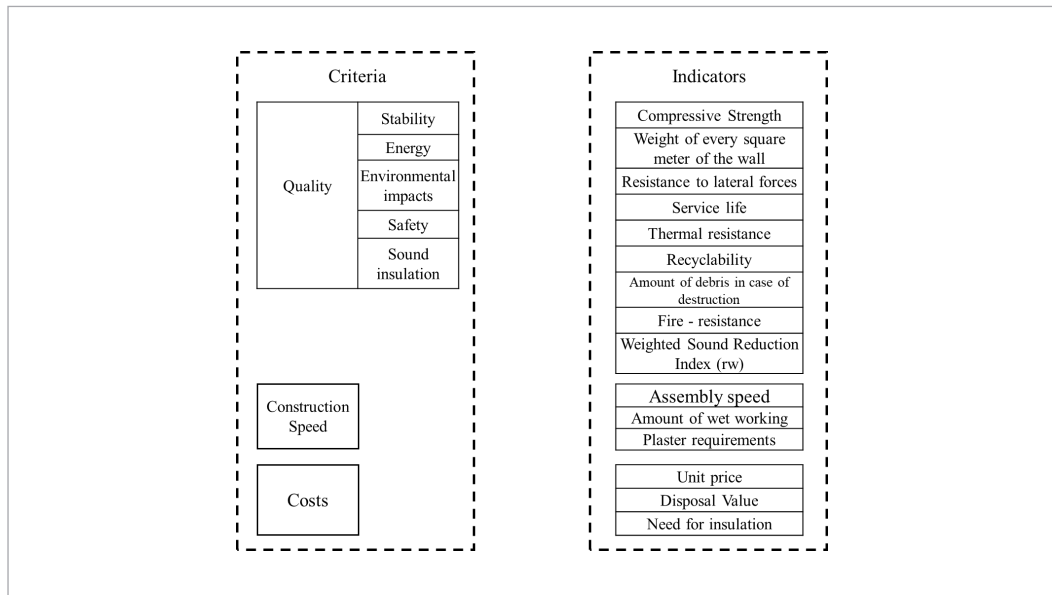
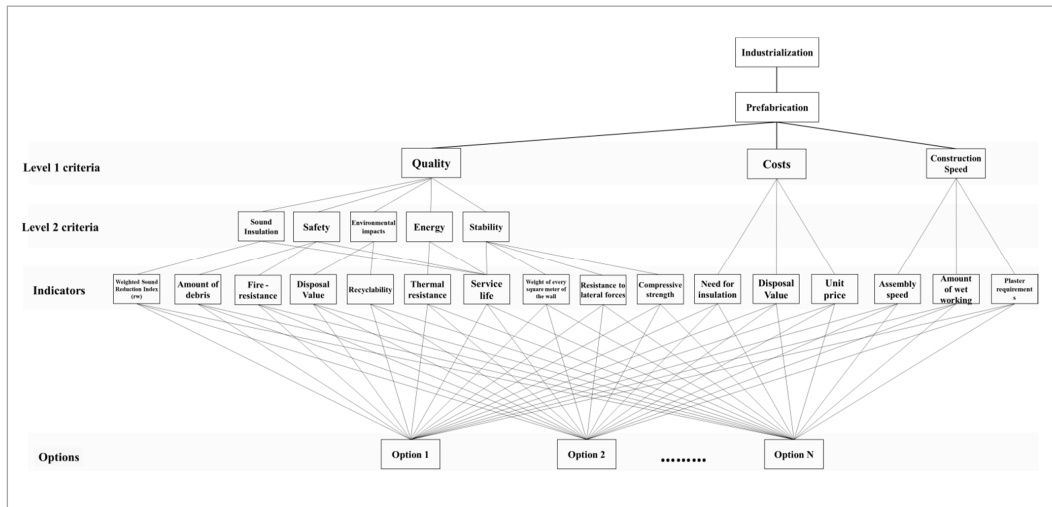


Fig. 5

The hierarchical structure of comparing the proposed options in determining the type of peripheral walls



## The Requirements of the Proposed Ranking System

Based on the criteria of the prefabricated approach, the proposed ranking system should include the following requirements for selecting superior choices about the peripheral walls.

- The possibility of determining the importance of different levels of criteria and applying changes in their values based on situations and desired goals.
- The possibility of loading different proposed options and introduce their technical specifications to enrich the data bank of the system.
- Determining the maximum and minimum scores on quantities and qualities of the technical specifications of each option based on available standards.

Therefore, the following workflow is being proposed for the ranking system.

The proposed system should be available for all stockholders to select the proper option about the peripheral walls by determining the value of criteria and indicators of prefabrication based on the features of their projects.

The procedure is as follows: the manufacturer of the product, after obtaining the necessary quality approvals, submit a request for registration of materials in the proposed ranking system data-

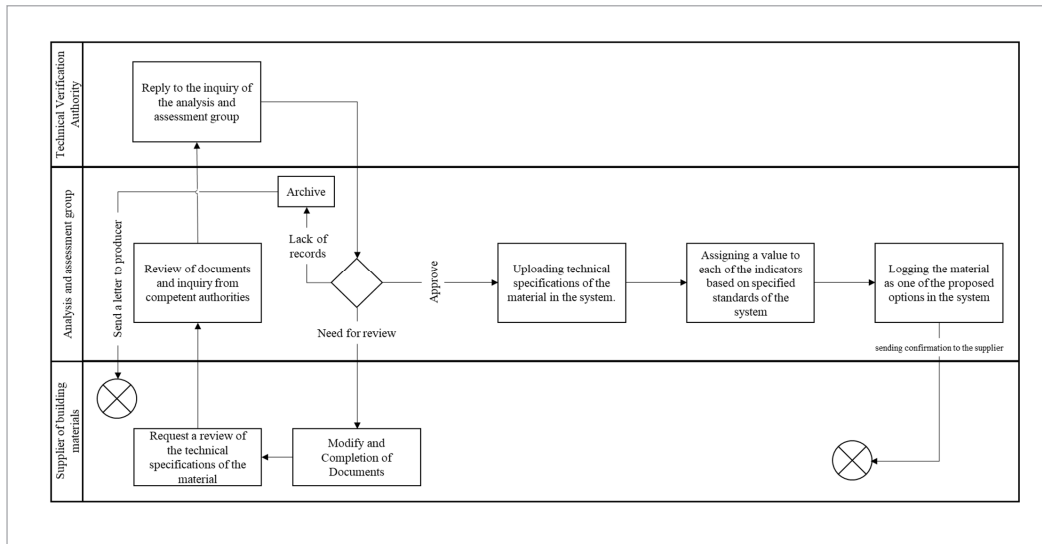


Fig. 6

The workflow of the proposed system of ranking

Source: Authors.

base. After confirming the technical specifications based on the inquiry from the certification authorities (Road, Housing and Urban Development Research Center of Iran), regarding the indicators for which there is a quantitative national or international standards, the system offers a point to each index by comparing technical specifications with other materials in the database. To determine the score of indicators which require experimental vision, technical specifications of materials with a questionnaire based on comparison with some of the basic materials that are addressed in the Samples, are being referred to the group of system's partner specialist. Therefore, all the materials in the system database are ranked in terms of quality and technical specifications, and it will be possible to introduce samples that are compatible with the value set for the selection criteria, based on the AHP selection process.

This part of the study deals with the Samples which include the common materials of the prefabricated peripheral walls. The requirements for entering any new option in the proposed ranking system are to pass quality tests and obtain approvals related to the Road, Housing, and Urban Development Research Center of Iran. Therefore, the qualitative evaluation of materials is done according to the approved technical specifications and comparison with the relevant standards. Regarding indicators for which there are no specific standards, the sources of evaluation are interviews with experts, including civil engineers and architects involved in construction projects.

The purpose of the Investigation of the Samples is to achieve a scale to determine the score of different qualitative aspects of the proposed materials. It is more important about indicators for which no specific standards have been set. Therefore, it has been tried that Samples include a wide range of common materials in the Iranian construction market in terms of qualitative characteristics, technical specifications, methods of assembly, unit size, and price.

The investigation of Samples aimed to achieve a suitable scale to determine the weights of the indicators in the AHP process for the selection of the peripheral walls system. The literature review shows the importance of three criteria of construction speed, costs, and quality in the prefabrication approach which include the mentioned indicators in Table 4. To adapt the different conditions existed for building projects, the importance of criteria and resulting indicators may be different and this affects the selection of systems for the building components. In the following table, the proposed domain of scores is given to indicators that can be the main source of the decision-making regarding the selection of the peripheral walls. These scores are determined based on the necessities of national building codes and standards and expert questionnaire.


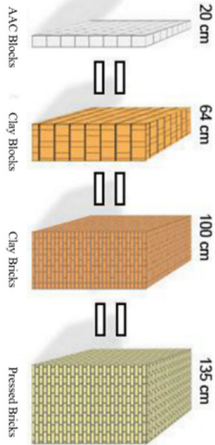
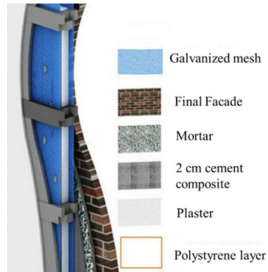
## Investigation of the Common Samples

## Findings



**Table 3**

Descriptive and analytic features of samples

Sample Title	Description	Advantages	Disadvantages	Related Images
Lightweight perlite blocks	<p>These blocks are produced using mineral or artificial material as coarse material and cement base materials as a sticky one. The important advantages of these blocks can be attributed to their thermal insulation properties, which in some regions of Iran provide the requirements of the national codes without the need for additional layers. The most important disadvantages of this option can be pointed out to the multiplicity of the later stages (finishing work), high water uptake and ultimately slow execution rates.</p>	<ul style="list-style-type: none"> <li>- Thermal and Acoustic insulation</li> <li>- Low Weight</li> <li>- Fire resistant</li> </ul>	<ul style="list-style-type: none"> <li>- Needs to later stages</li> <li>- Assembly Speed</li> <li>- High Amount of Mortar and plaster</li> <li>- Recyclability</li> <li>- High Disposal Value</li> </ul>	<p><b>Fig. 7.</b> Lightweight perlite blocks</p>  <p>Source: Authors.</p>
Autoclaved aerated concrete (AAC) blocks	<p>These blocks are made of a specific type of porous light concrete, which is mainly made of silica, cement, and lime. This product consists of two main processes; forming porosity in grout (a mixture of cement, lime, and silica powder) and curing. Sticky materials (mainly cement and lime) react in an autoclave with silica materials and give hydrated calcium silicate. These blocks are fire resistant with low thermal conductivity. The use of these materials leads to a no-diffusion of the flame (Bastani &amp; Ilani, 2011). AAC blocks are insulated against sound and heat due to their low special weight, so it is not necessary to use additional insulation layers and this can reduce the cost of construction and prevent waste of capital.</p>	<ul style="list-style-type: none"> <li>- High compressive strength</li> <li>- Thermal and Acoustic insulation</li> <li>- Low Weight</li> <li>- Fire resistant</li> </ul>	<ul style="list-style-type: none"> <li>- Needs to later stages</li> <li>- Assembly Speed</li> <li>- High Amount of Mortar and plaster</li> <li>- Recyclability</li> <li>- High Disposal Value</li> </ul>	<p><b>Fig. 8.</b> The thermal resistant comparison between AAC blocks wall and other walls</p>  <p>Source: (Bastani &amp; Ilani, 2011).</p>
HAYAT wall Panels	<p>The middle layer of these panels is made of polystyrene foam which is a product of the petrochemical industry and is composed of small crystals that expand under pressure and vapor. The side layers of these panels are attached to the center using special lace, which increases the strength and adhesion between the layers. The outer layers of these panels are made of lightweight concrete with special properties such as thermal and sound insulation, frostbite resistance, and a reduction of damage caused by the earthquake.</p>	<ul style="list-style-type: none"> <li>- Low weight</li> <li>- Thermal and Acoustic insulation</li> <li>- Low Amount of debris</li> <li>- Fire resistant</li> <li>- Assembly Speed</li> </ul>	<ul style="list-style-type: none"> <li>- Recyclability</li> <li>- High Disposal Value</li> </ul>	<p><b>Fig. 9.</b> Details of HAYAT wall panels</p> 

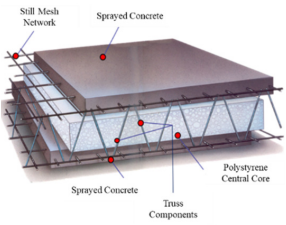
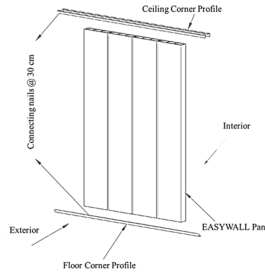
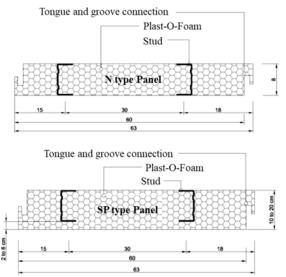
Sample Title	Description	Advantages	Disadvantages	Related Images
3D Panels with concrete cover	<p>These panels have an intermediate core of polystyrene or polyurethane, and two layers of steel mesh are placed on either side. After the installation, the sides of these panels would be sprayed by concrete.</p>	<ul style="list-style-type: none"> <li>- Assembly Speed</li> <li>- Low Amount of debris</li> <li>- Thermal and Acoustic insulation</li> </ul>	<ul style="list-style-type: none"> <li>- Needs to later stages</li> <li>- Recyclability</li> <li>- High Disposal Value</li> <li>- High Weight</li> <li>- Fire resistant</li> <li>- High Amount of Mortar and plaster</li> </ul>	<p>Fig. 10. Details of a 3D panel</p> 
EASYWALL Light Weight Panels	<p>These panels are made of fiber cement board for the panel facings with an interior composite core material of lightweight concrete mix made from ordinary Portland cement, additives, aggregates, admixtures and Expanded Polystyrene</p>	<ul style="list-style-type: none"> <li>- Assembly Speed</li> <li>- No plaster needs</li> <li>- Thermal and Acoustic insulation</li> <li>- Fire resistant</li> <li>- Low Amount of debris</li> </ul>	<ul style="list-style-type: none"> <li>- Resistance to lateral forces</li> <li>- Recyclability</li> </ul>	<p>Fig. 11. EASYWALL Detail</p>  <p>Source: Authors.</p>
EUROPANEL System	<p>These panels consist of two galvanized steel that the space between them is filled with high-density polystyrene (20 kg/m<sup>3</sup>) inside a special device and form an integrated panel. These panels are produced in two forms (Normal and Special) based on the position of the studs.</p>	<ul style="list-style-type: none"> <li>- Assembly Speed</li> <li>- Resistance to lateral forces</li> <li>- Thermal and Acoustic insulation</li> <li>- Low Amount of debris</li> <li>- Low Weight</li> </ul>	<ul style="list-style-type: none"> <li>- Fire resistant</li> <li>- High Amount of Mortar and plaster</li> <li>- Recyclability</li> </ul>	<p>Fig. 12. Section of the Europanel</p>  <p>Source: Authors.</p>

Table 4

Determining the scores of the indicators of prefabrication for peripheral walls in residential use.

Criteria	Indicators	Assigned Scores for AHP Process			Score reference
		0,1	2,3	4,5	
Construction Speed	Need for later stages	High (Finishing and hard Works)	Moderate (Finishing works)	Low	Expert Questionnaire
	Amount of wet working	High	Moderate	Low	
	Assembly speed (M2/Day)	10-29	30-59	60 and upper	
Costs	Unit price (M <sup>2</sup> )	The scores are determined based on the minimum and maximum price of materials in the data bank			List Price of the current year
	Disposal Value (%)	10 and upper	5-9	1-4	Expert Questionnaire
	Need for insulation	Sound and Thermal insulation	Sound or Thermal insulation	No need	INBC (part 18 & 19); ISIRI: 8568-3, 11058, 8621
Quality	Compressive strength (Kg/cm <sup>2</sup> )	10-19	20-39	40 and upper	INBC (part 6)
	Weight of every square meter of the wall (Kg/ m <sup>2</sup> )	120 and upper	50-119	Less than 50	
	Resistance to lateral forces (Kg/cm <sup>2</sup> )	20-40	40-60	60 and upper	
	Service life (Year)	10-19	20-39	40 and upper	Expert Questionnaire
	Thermal resistance (m <sup>2</sup> .k/w)	Less than 1	1-2	More than 2	INBC (part 19)
	Recyclability (%)	10-39	40-79	80 and upper	Expert Questionnaire
	Disposal Value (%)	10 and upper	5-9	1-4	Expert Questionnaire
	Fire – resistance (Minute)	60-179	180-239	240 and upper	INBC (part 3)
	Amount of debris in case of destruction	High (Winning parts)	Moderate (Non-winning parts)	Low (Non-winning parts)	Expert Questionnaire
	Weighted Sound Reduction Index (rw)	30-39	40-49	50 and upper	INBC (part 18)

## Conclusion

The review of theoretical foundations and literature shows that the prefabrication approach as one of the basic requirements of industrialization contains three main criteria; quality, construction speed, and reduction of costs. Based on the prefabrication literature if necessary arrangements for industrial manufacturing and assembly of different components of the building were forecasted, the prefabrication concept would be assigned to the manufacturing process of each component of the system and consequently the whole construction system theoretically. However, an investigation of the peripheral wall samples shows that if the components of the system are larger, lighter, and needless of finishing or mortar to be assembled, it is practically more in line with the nature of prefabrication concept. The importance of prefabrication criteria may be different due to the

project type, scale, financial resources, the place of the construction site, and so on. The existence of a wide range of different materials and systems based on the prefabricated approach in many cases, especially mass housing projects, has made the optimal selection for project participants a complex matter. This indicates the necessity of the development of a systematic order of the selection of materials and methods of construction and the various components of prefabricated systems based on the importance of prefabrication criteria. In this research, the conceptual design of this system regarding the selection of peripheral walls in the form of an updatable database is presented. Due to the possibility of differences in the value of criteria related to prefabrication, a selection approach based on AHP has been adopted in the system. It is possible to generalize this system to the other components of the building in future research.

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