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DECISION-MAKING FOR EVALUATION AND SELECTION OF SUITABLE INDUSTRIALIZED HOUSING SYSTEM

Yidnekachew Tesmamma Daget[1] and Hong Zhang[2]*

[12]School of Architecture, Southeast University, China;

*Corresponding Author: Received: 7 May 2018, Revised: 20 May 2018, Accepted: 18 June 2018

ABSTRACT: The evaluation of housing system in order to make the effective decision for application in housing construction has been a challenge for many developing countries. This study examines the novel approach to evaluate and select the industrialized housing system (IHS) that is appropriate for adoption in the rapid housing development project in Addis Ababa, Ethiopia. The method applied in this study comprises critical literature review, experts' interview and questionnaire survey within the Ethiopian construction industry. Data obtained was analyzed using an analytical hierarchy process research technique and an Expert Choice Comparison software platform. The findings revealed that affordability, quality, and innovation are the most important attributes to be considered for decision-making. In addition, semi-industrialized precast concrete systems are preferable for application cost-effective large-scale housing development. All stakeholders involved in housing development can apply the decision-factors and method used in this study in order to make effective decisions.

Keywords: Industrialized housing system (IHS), Decision-making, Analytical hierarchy process (AHP)

1. INTRODUCTION

Decision-making for evaluation of industrialized housing system (IHS) has increased driven by the technological advancement and rapid construction process [**1, 2**]. Such advancement in construction technology has shown technological evolution in different countries. However, the evaluation and application of IHS have been studied more in developed countries than on that in developing countries [**3**]. Subsequently, research gaps have arisen with regard to the IHS evaluation and selection. This paper tries to fill the gap to this body of knowledge and has conducted the evaluation through a novel approach in order to select the suitable IHS for adoption in housing development. As shown in Figure 1, ten IHS were chosen for evaluation based on their wide application for housing development in different countries.

Rapid urbanization and population growth have created enormous pressure on large-scale cost-effective housing development in the city of Addis Ababa, Ethiopia [**4**]. The existing housing demand is excessive than the housing supply capacity of the housing market [**5, 6**]. One of the main challenges is the use of appropriate housing system for cost-effective large-scale housing development [**7**]. The Ethiopian government has also planned to introduce cost-effective industrialized housing systems as a solution for these challenges [**8**]. Although applications of IHS are important for high rate of housing development [**2**], there is lack of study and practice on selection and evaluation of IHS.

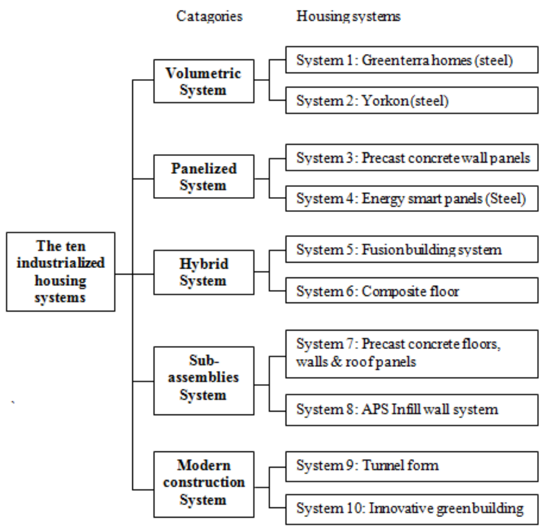

Fig. 1 The ten IHS selected for evaluation

2. HOUSING SYSTEM DECISION CRITERIA

Previous studies revealed the importance of systematic decision-making for identification of suitable IHS [**1, 9, 10**]. A recent study has presented three main sets of decision criteria that help to identify the appropriate housing system for adoption, which are the structural, contextual and behavioral factors [**1**]. Additional sets of factors such as building project management-related include communication and investment [**11**], project procurement and project status [**12**], and the management method employed [**11**]. Whereas, human-related sets of factors include perception [**13**], reasoning [**14**], culture [**15**], skills and knowledge [**16**], knowledge management [**17**], and acceptance [**18**]. Additional factors that influence decision making include technology development [**19**], sustainability features [**20**], stakeholder involvement [**21**], and financial conditions [**22**].

All inclusive approach to decision-factors is important to consider for evaluation of IHS [**23**]. Ilozor, Okoroh, Egbu and Archicentre (2004) have discussed that adoption of suitable housing system has a direct impact on the success of a housing development. Experts' in the construction industry are well aware of the failure caused by incorrect decisions [**24**]. Abdullah and Egbu (2010) have presented the comparative advantage gained from each housing system is the basis for its adoption [**17**]. Therefore, holistic decision-criteria is important to consider in order to make an effective and informed decision according to a given local context.

2.1 Remarks on the review

Previous studies allow to the following remarks:- first, despite the many studies on decision criteria and evaluation of housing system, there is lack of research on regarding developing countries. Second, house builders faced challenges in the systematic process of decision making for housing system selection. Third, it is not common to make comparison among housing systems in overseas in order to identify the suitable one for a given local context. Fourth, a systematic method of decision making is important for making effective and informed decisions.

3. METHODOLOGY

3.1 Research Design

In order to understand the opinion of professionals in the construction industry as well as to provide a detail explanations, this study was conducted based on survey-based study approach [**25, 26**]. A pilot study was conducted prior to the survey questionnaire with the identified ten experts within the Ethiopian construction industry. The experts are selected based on their significant experience on the industrialized building system being as a manufacturer, supplier, contractor and academician and professional practitioners. Ten sample surveys were conducted and the experts were requested to classify the relevant factors, the challenges and the solutions for the implementation of IHS. In addition, they assessed the significance and the consistency of the questionnaire and made necessary modification prior to modification. The evaluation processes were undertaken using the analytical hierarchy process (AHP) research technique to quantify the subjective evaluation of experts [**27**] and Expert Choice Comparison (ECC) software as a tool to conduct the AHP assessment. The outline of the research design is shown in Figure 2.

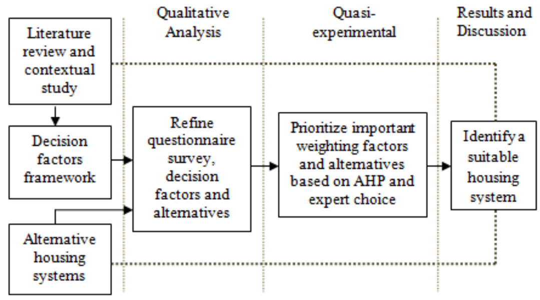

Fig. 2 Outline of the research design

3.2 Evaluation of Decision-factors

Due to the low-level application of IHS, there are limited numbers of experts' available in the construction industry of Ethiopia. A general survey was conducted to select thirty experts with an average of fifteen years of experience in order to engage them in the AHP evaluation. The thirty experts were from government officials, academics, manufacturers, contractors, and engineers. A holistic decision-factors were suggested based on literature review as suggested by Pan, Wong, and Hui to make sure that comprehensive criteria were set for the building system assessment [**2**]. The trustworthy importance of the evaluation was validated through the calculated consistency ratio. Since the consistency ratio for the overall judgment was less than 0.1, the overall evaluation was consistent and valid. Table 1 listed the 6 major and 30 sub decision-factors proposed for evaluation.

3.3 Analysis of Data Collection

Based on the survey data, a different form of data was collected. The data were analyzed following structuring of the decision hierarchy. The overall evaluation process is conducted through the following steps. Initially, as shown in Figure 3, a

Table 1 List of categorized decision-making factors
Source: The table is modified from Pan et al. (2011) based on the literature review and experts' interview

Major factor	Building industry	Supply chain	Infrastructure	Sustainability	Users needs	Socio-cultural
Sub-factor	Labour	Material source	Transportation	environment	Number of stories	Public acceptance
	Expertise and experience	Components	Energy	Pollution	Flexibility	Regulatory laws
	Construction proficiency	Machinery	Water	Exposure	Quality	Vested interests
	Procurement	Production capacity	Sewerage	Reusability	Affordability	Communication
	time	Innovation	waste disposal	efficiency	Site location	Culture

decision hierarchy model was structured in order to conduct the preferential weight evaluation. The priority vector value of the decision-factors was defined based on the pair-wise comparison matrix assessment of the ten experts. Then, the final levels of importance priority vector values of the decision-factors were identified based on a mathematical calculation and normalization of the input values. Furthermore, a pairwise comparison evaluation was conducted to identify the importance weight value of the proposed ten IHSs. Thirty identified professionals and experts are involved in the evaluation. The experts are key players within the Addis Ababa construction industry in the contractors, precast manufacturers, developers; engineers, suppliers, and academician with an average of fifteen years of experience. The evaluation was

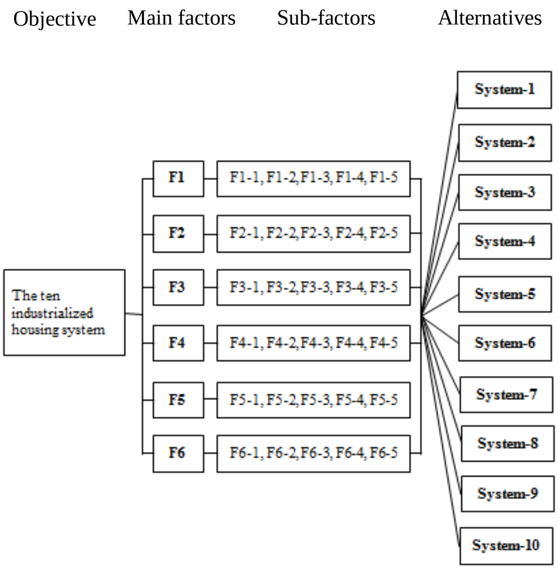

Fig. 3 The AHP decision hierarchy structure

conducted based on the Saaty's pairwise judgment scale of 1-9 conducted to every sub decision-factors. Lastly, the normalized outcomes of the alternatives were weighed accordingly; then, the topmost suitable IHS was selected.

4. RESULTS AND DISCUSSIONS

4.1 Priority of Decision-factors

Based on the results of the normalized priority vector shown in Table 2, the top most important main decision-factors are user needs, supply chain, and building industry. These factors need significant consideration in order to make an effective decision for selection of suitable IHS for an application. Previous researchers have also discussed similarly that the three factors have prime importance for IHS decision-making [**2, 28**]. In addition, these factors are the main focus of attention for the challenges encountered in the development of affordable housing in many developing countries. One of the key encounters is lack of suitable resources with an essential value and reasonable price. This is a communal challenge as the ability of the residents to pay for a better housing is very low and the majority of the population live in the slum. Thus, in order to achieve a high rate of cost-effective housing development, the top three identified decision factors are important to select the appropriate IHS for an application.

The availability of sufficient supply chain and production capacity of building components is a determinant factor for a successful application of IHS for a large scale housing development. In the city like Addis Ababa, Ethiopia, where the manufacturing capacity of affordable building materials and components is not yet well advanced, the situation aggravates the challenge of effective supply chain management [**29**]. These challenges become the obstacles for wide and sustainable application of IHS [**7**]. In order to advance the performance as well as to promote the extensive application of IHS, it is necessary to invest in the innovation research of new building components. However, the finding shows that the priority vector value of sustainability has found to be low. This indicates that the concern assumed for sustainability by building experts is less compare to the focus given to address the challenge of achieving affordable housing with respect to the existing housing demand.

Table 2. Main decision-factors analyzed ranking.

Main Decision-factor	Priority Vector %	Priority ranking
Building industry	14.36	3
Supply chain	25.06	2
Infrastructure	9.60	5
Sustainability	4.59	6
User needs	39.28	1
Socio-political	7.11	4

4.2 Priority of the Ten IHS

The importance level of priority of the ten IHS shows that the top three housing systems are the most suitable for application in large-scale cost-effective housing development. As it is listed in Table 3, the top three IHS are all precast concrete systems (i.e. concrete slab and stairs (System 7), precast concrete column, beam, cross-walls, floors and stairs (System 6), and precast concrete wall panels (system 8)). As it is shown in Figure 4, the results of this study can be categorized into two distinct groups of either precast concrete systems or steel systems. While the preferential importance of precast concrete systems is high, the steel based housing systems got less preferential importance value.

Table 3. Ranking of the alternative housing systems

The ten industrialized housing systems	(Normalized Priority Vector %)	Priority ranking
S1: Green terra homes (steel)	5.96	10
S2: Yorkon (steel)	6.26	9
S3: Precast concrete wall panels	15.38	3
S4: Energy-smart panels (Steel)	8.24	5
S5: Fusion building system (steel)	7.79	6
S6: Precast concrete column, beam, cross-walls	16.24	2
S7: Precast concrete slab and stairs	17.22	1
S8: APS Infill wall system	9.40	4
S9: Tunnel form	6.62	8
S10: Innovative green building system (steel)	6.87	7

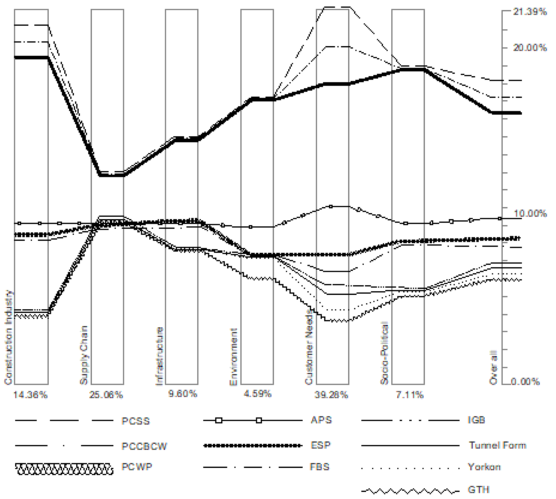

Fig. 4 Performance analysis of the ten IBS with respect to the level-one decision-factors

As it is listed in Table 4, the shared characters of the selected feasible housing systems are similar in terms of the nature of the materials with regard to easy constructability, flexibility in use, compatibility with both conventional and industrialized building components, and cost-effective in terms of large-scale production. The systems help to reduce installation time and engagement of skilled labor [**30**]. In addition, they are about 25% more efficient in production and erection compare to the traditional method of construction [**31, 32**]. The top three selected IHS can be categorized under the semi-industrialized building component parts which exclude other finishing elements. Furthermore, the systems are applied both panelized as well as frame and infill housing techniques of the semi-industrialization process which can be perceived as the favored housing system in Addis Ababa.

The selected top three IHS has better performance priority over the identified top three decision-factors (see Figure 5A-5C). This implies that the housing systems affordable, easily constructible as well as easily adaptable to the context. The application of these housing systems helps to achieve the intended development of rapid and affordable housing in the city of Addis Ababa. The components are produced based on similar standards, standardized shapes, same physical qualities, and content, as well as large-scale production scheme. The standardized component system is flexible to be used by different income groups of beneficiaries. Locally available minerals can be used as input materials for production. The component production minimizes wastage of input resources compare to the traditional method of production. The production process can also

Table 4: Characteristics of the suitable housing system

Structural	Architectural	Industrialized process	Erection	Economic and social
Durability	Flexibility in plan	Concrete components	Easy handling	Lower cost for high quality
Load bearing components	Open system	Middle degree of mechanization	Compatible with conventional system	Adaptability to the needs of various socio-economic groups
Fire, sound and water proof	Medium to high rise residential	Panelised, and frame and infill techniques	Rapid construction	Need for semi-skilled/ unskilled labor

engage both skilled and semi-skilled labors as an opportunity for employment. Additionally, the housing systems help to minimize the use of formwork for construction. In a country like Ethiopia, where wooden formwork is widely used for construction, housing systems that minimize the use of formwork help to reduce the deforestation and protect the environment [**33**]. Therefore, the three top selected IHS are better options for development of affordable and mass housing.

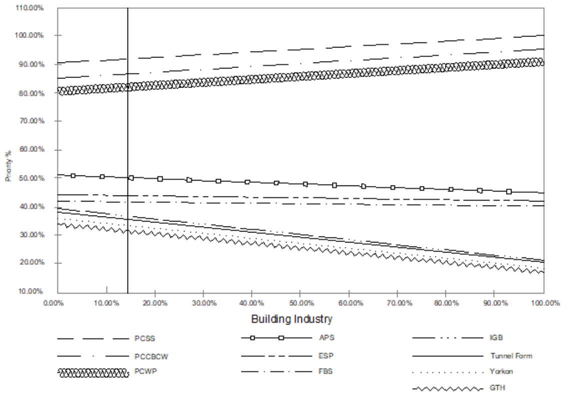

Fig. 5a IBS performance based on the building industry

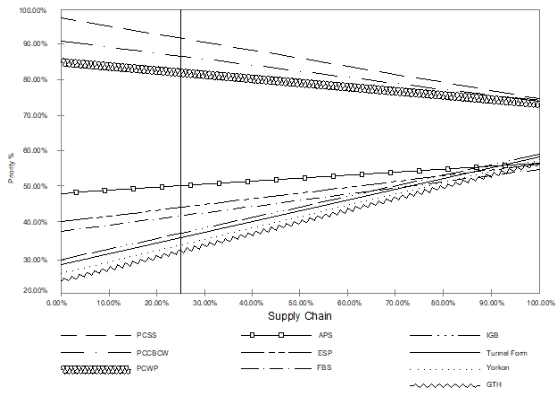

Fig. 5b IBS performance based on the Supply chain

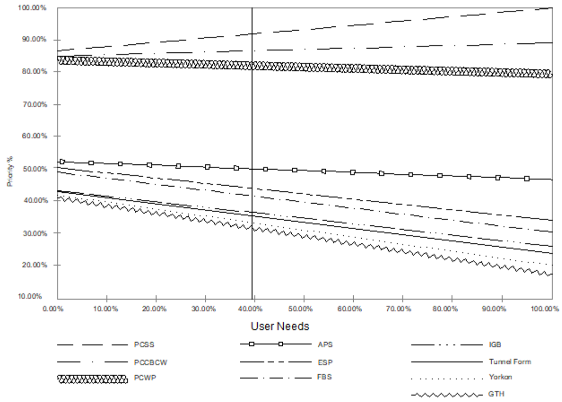

Fig 5c IBS performance based on the user needs

However, there are some limitations to these IHS, such as the need for high investment capital for the establishment of the production facility, heavyweight parts and costly transportation, rigidity for flexible use, and common cracks around joints. An improved method of joint construction and component parts must be promoted to scale-up the application of the housing systems. In addition, the prevailing insufficient supply chain of input resources and building components in the local construction industry is one of the major challenges that need to be addressed.

5. CONCLUSION

The engineering performance of IHS has been the main concern of material research, but the emphasis given to experts' preference and evaluation is overlooked. In this study, the evaluation and selection of IHS were investigated based on the holistic decision-criteria. The study revealed the top most relevant decision-factors and the appropriate IHS for application in the large-scale housing development in the city of Addis Ababa. Hence, in order to decide the most suitable IHS for application affordability, social benefits and environmental aspects of the local context should be significantly considered. Furthermore, the decision-factors should be considered as part of the holistic factors. The identified housing systems are an appropriate option based on their economic competitiveness, efficient use of input materials and energy, use of local resources, compatibility with other traditional construction methods, and simplicity of erection. However, the selected systems have some problems with regard to frequent cracks in the joints and costly transportation due to heavy-weight building component parts. The construction industry in the city of Addis Ababa is yet under-developed and needs more advancement in technology application. To address this challenge, a significant emphasis should be given to innovation of materials and scale-up the capacity of local professionals in the construction industry. To conclude, the evaluation and selection methods applied in this study can help decision-makers and developers make better decisions.

6. ACKNOWLEDGMENTS

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