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Fuzzy Analytic Hierarchy Process for the Evaluation of Old Dwelling Façade Design Factor

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Abstract

The purpose of this paper is to evaluate facade design factors of old dwellings using a Fuzzy Analytical Hierarchy Process (AHP) based on a pairwise comparison analysis using "Façade Design Factors" as evaluation criteria. Traditional old dwellings were presented and evaluated. A Fuzzy AHP based model was used for pairwise comparison of traditional old dwellings, whereby seven criteria and nine alternatives were described through a questionnaire and constructional data. The Fuzzy AHP was used to determine the impact of the facade design factors, because "Traditional" old dwellings are identified by the combination of their facade design factors. Furthermore, the fuzzy AHP is used to verify the feasibility and efficiency of this approach as well as for extent analysis to comprehend the priority of the traditional old dwellings using a sensibility measuring scale.

Key words : Fuzzy AHP, Old Dwelling, Facade Design Factor, Pairwise Comparison, Sensibility Evaluation

요 약

생활양식이나 형태 변화에 따른 전통적인 주거건축들의 전통성, 공공성과 사유권의 균형, 계승 발전, 보존에 부가되는 공동체의 활성화와 효용성 등 환경 개선이라는 과제에 직면하고 있으며, 이들 역사 경관 권역의 경관 훼손 가능성이 점증하고 있는 상황에서, 지역적 경관의 고유한 특성과 다양성을 가질 수 있도록 전통적 주거건축의 입면디자인 속성에 대한 이해가 선행되어야 한다. 본 연구는「전통적 주거건축의 입면디자인 평가」에 영향을 미친 속성을 파악하기 위해, 입면디자인 평가척도 (지붕, 창호, 기둥, 벽면, 마루, 주초석, 기단)를 기준으로 쌍대비교를 실시하여 도출된 Synthetic Evaluation Value를 Fuzzy 방법을 통해 Fuzzy Integral (Choquet Integral) value를 추정하여, 가치속성을 규명하였다. 속성 간 가중치 산정결과에 λ-value를 이용하여 Sensitivity Analysis를 실시하여 유효함을 검증하였다. 전통적 주거건축의 입면디자인 평가에 영향을 미친 가치속성을 추정하는데 있어 유의미한 방법론이며, 복합 가치속성을 도출하였다는데 의의를 갖는다.

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1. Introduction

Laws related to landscape and various other regulations have been established with the purpose of giving people a comfortable environment. As such, a method of evaluating public landscape evaluation on a rational basis is needed. But the evaluations of the traditional old dwellings that have been done so far are not sufficient. There are many ways in preservation to define what a traditional old dwelling is. It is necessary to continuously improve the preservation techniques of the traditional old dwellings by taking into consideration. The concept of "Traditional" is something that we sense from a building facade. "Traditional" is generally judged on the basis of the form of the facade design factors. The general problem-solving method used in making comprehensive decisions (e.g., multi-criteria decisions) is based on variables that cannot be quantified. It is possible to determine the relative importance of the design factors in the facade or the rankings of traditional old dwellings by applying the Analytic Hierarchy Process (AHP) by Saaty (1980), which decomposes the decisional process in a hierarchy of criteria, sub-criteria, attributes and alternatives through a set of weights that reflect the relative importance of alternatives. Accordingly, several fuzzy extensions of AHP have been proposed (Takahagi, 2000,2005; Murofushi, 1992,2004). This paper designates the priority of the façade design factors by using sensibility evaluation. Then, the ambiguity of the human sense to make selections is confirmed by using fuzzy measuring in fuzzy AHP. The results also show what kind of important factors influence the recognition of the "Traditional" character and the knowledge of these factors is essential to preserve the traditional character of the old dwellings. This study focuses on old dwellings of the Kumandong traditional building (KTB) district located in Naju, Korea. Today, KTB district old dwellings are intended to be used for recreation and are promoted as attractions to entice tourism, and industrial development the challenge, which is attempted to adapt these practices into current needs while continuing to make use of the traditional knowledge and maintaining the cultural traditions. In many cases, the traditional houses can no longer be maintained because of uncontrolled and irreversible mutation of the KTB district. The KTB district is not regarded as "Traditional" by the Urban Planning Bureau of Naju City. The concept of "Traditional" that we sense from Kumandong old dwellings are based on complicated by high degree knowledge of uncertainty about the patterns of architectural composition, the structured pattern of perceptual effects, the previously-unseen characteristic of an old dwelling facade. It is difficult to interpret its meaning fully when using explicitly architectural data such as building parts and components. The sensibility evaluation and interpretation of the data cannot be explained properly with architectural data because of the gap between data generation and data understanding. Clearly, tools and techniques make it able to extract unknown interesting rules that are essential to compensate the gap.

This research aims to present fuzzy AHP based approach to select right combination of their façade design factors. We believe this decision support concept is necessity before repair and Maintenance of old dwellings. In order to bring structure in the evaluation process, we employ the fuzzy AHP by Takahagi, and the one by Murofushi. In Section 2 presents a brief review of related work. Then Section 3 we present a methodology based on fuzzy Choquet integral. In Section 4 an old dwelling façade design factor is used to establish the proposed approach. Finally, in Section 5, conclusion remarks are given.

2. Related studies

The existing literature does not indicate a comprehensive and systematic fashion of old dwelling façade design factor research. However, the study of old dwelling façade design factor has a long and extensive spanning many general research field including proportion features research, elevation composition, comparison changho. Studies linking human sense to design are progressing mainly in the field of product design. Using genetic programming, Takizawa A. et al. (2000) quantified personal tastes in furniture design. From the human ability to evaluate an object intuitively and comprehensively, Matsushita D. et al. (2004)

attempted to relate personal tastes in facades with values for the glass properties using an interactive genetic algorithm. Saito D. et al. (2005) attempted to clarify the form elements of building facades as factors for the intuitive judgment from sensibility measuring evaluation by employing the rough set theory. The Analytical Hierarchy Process (AHP), developed by Saaty (1980), decomposes the decisional process in a hierarchy of criteria, sub-criteria, attributes and alternatives through a set of weights that reflect the relative importance of alternatives. In fact, the AHP has been widely applied to numerous complex environment and landscape problems (Kouichi et al., 1994; Yin et al., 1999; Moriya et al., 2000). The fuzzy theory developed by Zadeh (1965) provides a mathematical method that can deal with thought processes which are too imprecise to be dealt with using classical mathematical techniques. Saaty's AHP was later expanded (Laarhoven et al., 1983; Buckley, 1985) by using the fuzzy theory (Yamashita., 2005), which provides a mathematical method able to deal with feelings and cognitive processes. Although the Fuzzy ratings used by the fuzzy AHP could incorporate the ambiguity of the human sense, the uncertainty about the final fuzzy weights might make it more difficult for the human to choose a specific alternative. The study investigated the sensibility evaluation (as "traditional" or "non-traditional") to select the best from a number of old and currently evacuated dwelling with respect to several design factors of the old dwelling façade. The results confirmed that Fuzzy measure and fuzzy integral (Takahagi., 2000) in fuzzy AHP could incorporate the fuzziness of human senses. Moreover, the fuzzy AHP method for determines the impact of the facade design factors, because "Traditional" old dwellings are identified by the combination of their facade design factors.

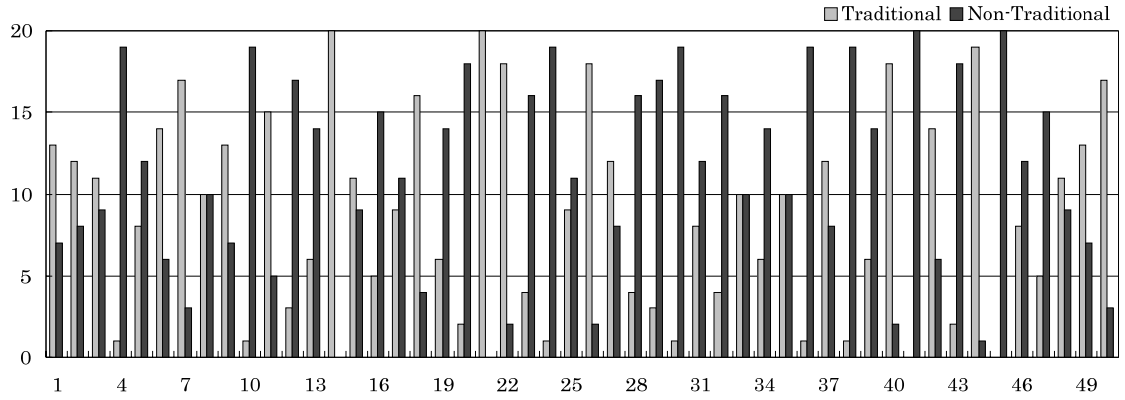

Figure 1. Sensibility Evaluation of Old Dwellings

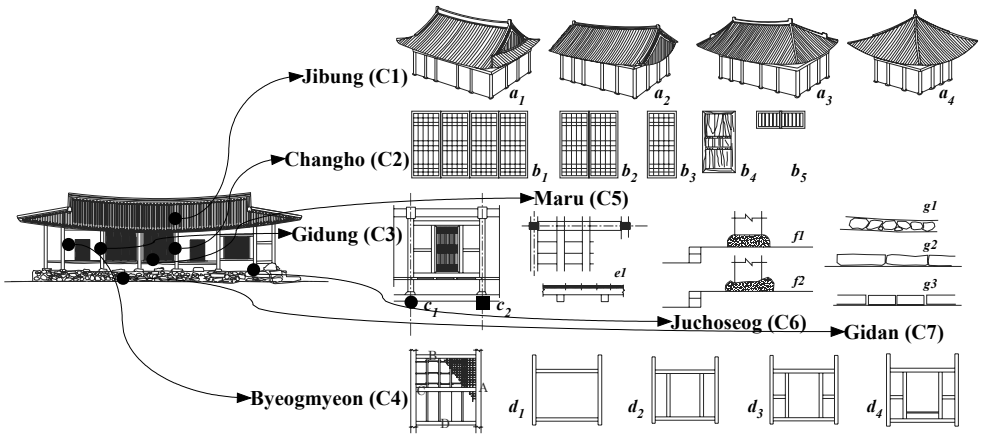

Figure 2. Old Dwelling Façade Design Factor

3. Fuzzy AHP and the steps of the methodology

3.1. Basic concepts

To clarify the present condition of old dwellings in the KTB district, surveys on old dwelling facades were carried out Bansong Village and Inchon Village in Kumandong, from a report of surveys on Urban Planning Bureau of Naju City. Of the 50 old dwellings analyzed. The old dwellings under evaluation were photographed from the front and from a diagonal perspective. By showing these photos to each participant, we aimed to test the participants' sensibility evaluation as to whether they feel that an old dwelling façade is "Traditional" or "Non-Traditional". To check how greatly this concept varies among groups with different knowledge backgrounds, 20 university students studying architecture were selected (Figure 1). The facade design factors selected from architecturally defined items are observed in old dwellings of the Kumandong District, and are considered common to the district. The façade elements were categorized into 7 criteria: Jibung (C1), Changho (C2), Gidung (C3), Byeogmyeon (C4), Maru (C5), Juchoseog (C6), and Gidan (C7). Figure 2 shows the evaluation criteria given by the participants to each old dwelling.

Based on their evaluation, old dwellings were ranked into 9 alternatives with the highest score: Dwelling07 (A1), Dwelling15 (A2), Dwelling19 (A3), Dwelling21 (A4), Dwelling22 (A5), Dwelling26 (A6), Dwelling40 (A7), Dwelling44 (A8), and Dwelling50 (A9), as shown in Figure 3.

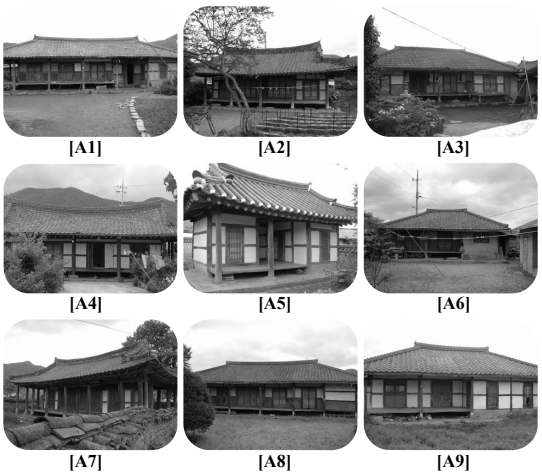

Figure 3. Traditional Old Dwelling Facade

Analytic Hierarchy Process (AHP) is a method of measurement for formulating and analyzing decisions. The AHP decomposes the Selection of traditional old dwelling into façade design factors, according to their common characteristics, and levels, which correspond to the common characteristic of the façade design factors. The topmost level is the "goal" of the problem; the intermediate levels correspond to criteria while the lowest level contains the "decision alternatives." (Figure 4)

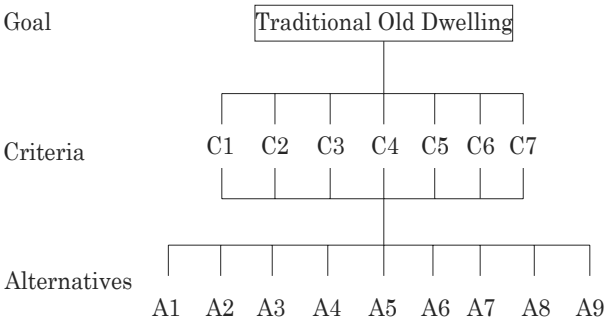

Figure 4. A hierarchy for AHP

The elements of each level are compared in a pairwise manner with respect to a specific element in the immediate upper level. The preferences are quantified by using a nine-point scale. The mining of each scale measurement is explained in Table 1. It allows the converion of the qualitative judgments into numerical values, also with intangible attributes. The consistency index is calculated as per the following steps:

(1) For calculating the priorities of the elements, a judgmental matrix is assumed, as follows:

$$A=[a_{ij}]=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} a_{ij}=w_i/w_j, a_{ij}=1/a_{ji}, W=\begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix}$$

$$(i,j=1,2,\cdots,n)$$

(2) Calculate the eigenvector of the relative weights and $\lambda_{\max}$ for each matrix of order n

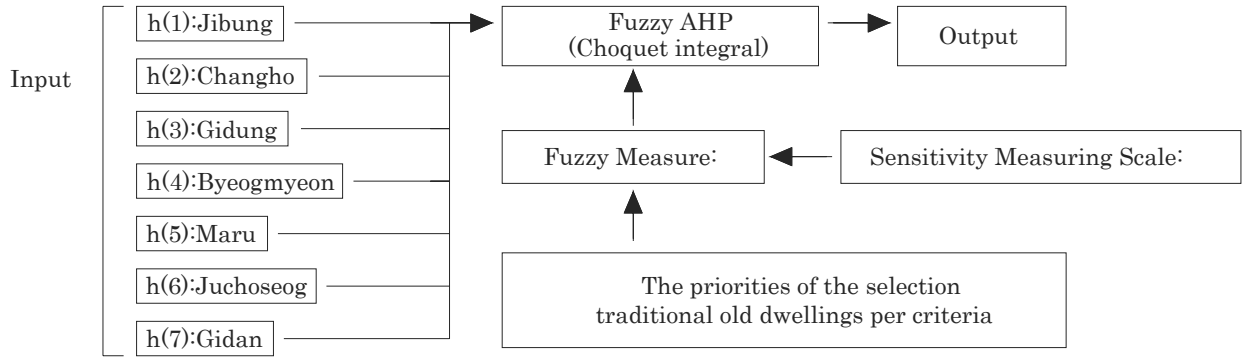

Figure 5. Fuzzy AHP (Choquet Integral)

(3) The consistency radio is then calculated using the formula:

$$CR = CI/RI$$

Where CI is the consistency index and RI is the Random Index.

(4) Compute the consistency index for each matrix of order n using the formula:

$$CI = \frac{\lambda_{max} - n}{n-1}$$

A consistency index of 0.15 or less is considered acceptable. If the value is higher, the judgments may not be reliable.

Table 1. Scale of preference between two façade design factors

Numerical Values	Verbal Scale
1	Equal importance of both factors
3	Moderate importance of one factor over another
5	Strong importance of one factor over another
7	Very strong importance of one element over another
9	Extreme importance of one element over another
2,4,6,8	Intermediate values

3.2. Decision making methodology based on fuzzy Choquet integral

Fuzzy theory provides a mathematical method able to deal with processes which are too imprecise to be dealt with using classical mathematical techniques. Therefore, several fuzzy extensions of AHP have been proposed, and we use the fuzzy AHP by Takahagi (2000,2005), and the one by Murofushi (1992,2004). Takahagi's fuzzy AHP is a useful tool for global evaluation models. However, the number of parameters of fuzzy measure is large. The fuzzy measure (μ) is a class of fuzzy measure which can be identified by the sensibility measuring scale (ξ), and priorities of individual evaluation form elements of facade. As shown in Figure 5, the sensibility measuring scale used by fuzzy AHP, described by ξ= [0,1]. If ξ=1 then the output value of the Choquet integral is the maximum value of inputs and if ξ=0 then the output value is the minimum. In the next session of the application, façade design factor evaluates the criteria and criteria sets correlations, considering their contribution to the main goal.

4. Analyzing the results

The pairwise comparison was performed from Aug. 10th, 2012. In the test, 20 architecture students were surveyed, and multiple criteria evaluation data of 10 participants were successfully collected. When the consistency among paired comparisons in AHP was proved to be ineffective based on the value of the consistency index (CI), inconsistent comparisons were examined. This method examines the consistency among paired comparisons. The pairwise comparison matrix of the seven form elements is then normalized to obtain Weights vector or eigenvector of each rating scale as shown in Table 2.

Table 2. Matrix of Criteria comparison

Criteria	C1	C2	C3	C4	C5	C6	C7	Weights vector
C1	1	1	5	4	1	4	1	0.248
C2	1	1	3	3	1	2	1	0.191
C3	1/5	1/3	1	1/4	1/5	1/2	1/3	0.040
C4	1/4	1/3	4	1	2	2	2	0.151
C5	1	1	6	1/2	1	1	1	0.144
C6	1/4	1/2	2	1/2	1	1	2	0.104
C7	1	1	3	1/2	1	1/2	1	0.122

By applying the procedure previously outlined, the Weights vector of Jibung(C1), Changho(C2), Gidung(C3), Byeogmyeon(C4), Maru(C5), Juchoseog(C6), and Gidan(C7) are calculated, which are equal to 0.248, 0.191, 0.040, 0.151, 0.144, 0.104 and 0.122, respectively. The principal eigenvalue of participant02 (S2) is λ_{max}=7.770, with a consistency index CI =0.128. Thus, the results are consistent.

Table 3. Matrix of Alternatives comparison per criteria

Criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	0.116	0.129	0.047	0.084	0.190	0.063	0.264	0.072	0.035
C2	0.121	0.133	0.024	0.048	0.073	0.042	0.125	0.211	0.224
C3	0.087	0,084	0.075	0.064	0.163	0.144	0.262	0.088	0.033
C4	0.073	0.106	0.081	0.091	0.141	0.140	0.234	0.090	0.043
C5	0.092	0.108	0.090	0.085	0.149	0.099	0.237	0.090	0.050
C6	0.081	0.108	0.080	0.164	0.090	0.163	0.234	0.044	0.037
C7	0.055	0.147	0.026	0.116	0.096	0.029	0.293	0.203	0.036

Table 3 reports the priorities of the dwellings for each criteria. Dwelling40 (A7) turns out to have the highest priority for any criteria. In particular, for the criteria C1, C3 and C7, the priority of A7 is slightly higher than 25%. For criteria C2, the priority of A7 is the lowest of the seven, at 12%. The priority for the remaining criteria is almost equal. By using the fuzzy AHP, we defined 7 criteria selected as explanatory values for the selection of traditional old dwellings. In the study, fuzzy measure using Choquet integral multiple regression analysis was used as the fuzzy AHP. The dependent variable was intention to select traditional old dwellings, and independent variables were explanatory variables and composite variables obtained by combining the explanatory variable (hereinafter called Composite Variables). In terms of the number of combined variables, the fuzzy measure was slightly higher than {C5} (="Byeogmyeon") at 0.042 and lower than {C3} (="Gidung") at 0.021 under one combined variable. Under 2, 3, 4 and 5 combined variables, the fuzzy measure were the highest for {C2, C4}(="Changho, Byeogmyeon"), {C1, C2, C4}(="Jibung, Changho, Byeogmyeon"), {C1, C2, C4, C6}(="Jibung, Changho, Byeogmyeon, Juchoseog") and {C1, C2, C4, C6, C7}

Table 5. Evaluation of varying ξ (participant04)

ξ	A1	A2	A3	A4	A5	A6	A7	A8	A9
0.1	0.121	0.077	0.042	0.098	0.061	0.040	0.095	0.084	0.048
0.2	0.138	0.088	0.045	0.119	0.065	0.048	0.105	0.090	0.054
0.3	0.154	0.099	0.048	0.138	0.069	0.055	0.116	0.094	0.059
0.4	0.170	0.111	0.052	0.155	0.074	0.062	0.128	0.098	0.064
0.5	0.186	0.123	0.056	0.172	0.079	0.070	0.141	0.101	0.070
0.6	0.202	0.136	0.061	0.189	0.085	0.077	0.157	0.105	0.077
0.7	0.219	0.149	0.066	0.206	0.092	0.085	0.174	0.108	0.085
0.8	0.236	0.164	0.073	0.223	0.101	0.092	0.195	0.112	0.095
0.9	0.254	0.183	0.082	0.243	0.115	0.100	0.223	0.115	0.109
1	0.275	0.266	0.114	0.278	0.262	0.109	0.341	0.120	0.214

(="Jibung, Changho, Byeogmyeon, Juchoseog, Gidan") respectively at 0.103, 0.191, 0.310 and 0.504. Under 6 combined variables, the fuzzy measure was the highest for {C1, C2, C4, C5, C6, C7}(="Jibung, Changho, Byeogmyeon, Maru, Juchoseog, Gidan") at 0.746. Furthermore, we ran the sensibility analysis to test under which conditions the ranking of alternatives may change. The method involved specifying a certain number of sensibility measuring scales (ξ), which set different possible combinations of the criteria weights. We obtained Fuzzy integrated values from the data of the 10 participants (Table 5). The sensibility results, reported in table 5, confirm the ranking of the old dwellings in table 3.

As a result, the Table 5 and Figure 5, we present the results of the sensibility tests performed with varying ξ using fuzzy AHP. For example S6 (participant08), A2 (Old dwelling15) is most preferred old dwelling when $\xi < 0.21$ that is, the evaluator places in importance on a strong balance among evaluation facade design factors. In the other cases, $\xi > 0.21$, that is, the evaluator does not place a strong importance in the balance among the

evaluation form elements. In that case, A7 (old dwelling40) is the most preferred traditional old dwelling.

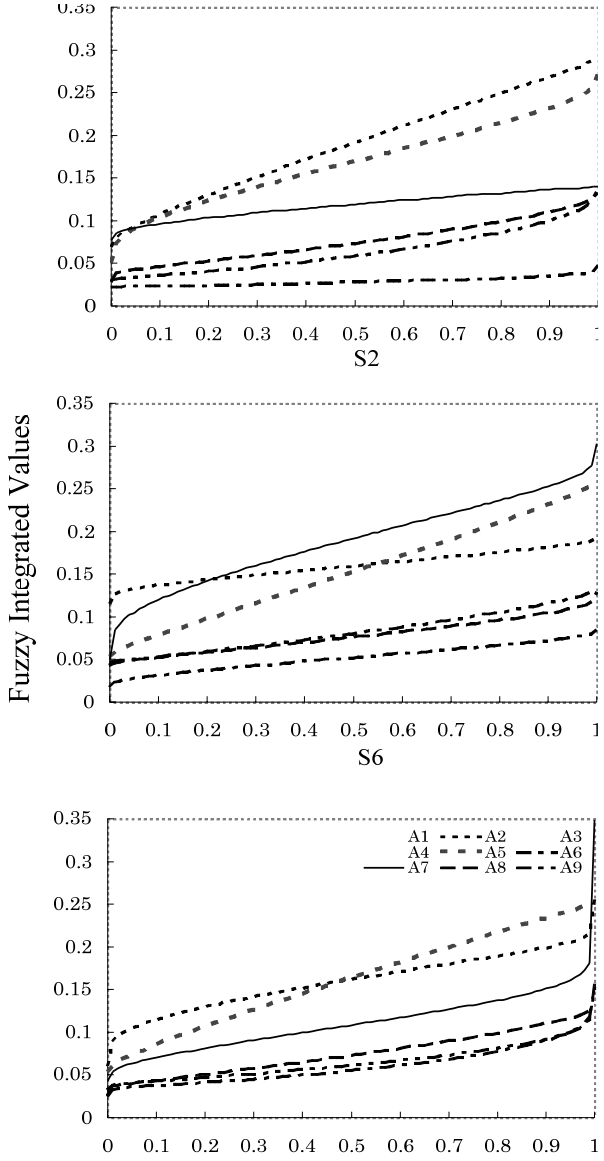

Figure 5. Result of sensibility analysis using sensibility measuring scale (ξ)

5. Conclusions

This study proposed an AHP-based model in order to help remodel and repair old dwellings and to evaluate the defining features of "Traditional" old dwellings. Old dwellings were surveyed and a pairwise comparison was performed using the AHP model. By applying fuzzy AHP to the results of a pairwise comparison, we acquired explanatory and composite variables of façade design factors affecting sensibility evaluation of the facades, which were described explicitly. As a result of fuzzy AHP using Choquet integrals, of the explanatory variables selected out of the important façade design factors with traditional old dwellings, "Jibung (a_1)" was found to have the highest value in terms of its relevance for the selection of a traditional old dwelling. Also, for c_1 and g_2, factor's evaluations are about the important degree considering the other criteria sets. Additionally, satisfying criteria set ($\{a_1\}$-$\{b_1, b_2\}$-$\{d_3, d_4\}$-$\{f_1\}$) together has more importance than satisfying criteria set ($\{a_1\}$-$\{b_3\}$-$\{d_3\}$-$\{f_1\}$) together and a_1 has better evaluation results considering the first criteria set. By doing so, vagueness in the design evaluation environment is taken into account using fuzzy Choquet integral. The unique feature of our approach is that the flexibility to be applied to different important levels of old dwellings, by allowing designers to remodel and repair their old dwelling, making us different criteria sets that reflect their own priority considerations. As a future research direction, the number of evaluated design factors of traditional building district, like building and furnishing components.

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