Environment and Planning B: Planning and Design 2002, volume 29, pages 589 – 606

DOI:10.1068/b2779

The usefulness of the GIS – fuzzy set approach in evaluating the urban residential environment

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Received 11 October 2000; in revised form 30 October 2001

Abstract. The authors' focus was to determine the usefulness of the fuzzy set approach in evaluating the urban residential environment, compared with the crisp (or Boolean) approach. Particular emphasis was placed upon the comparison of evaluation results produced by the two methods within a geographic information system (GIS). This comparison highlighted the advantages of the GIS – fuzzy set approach as follows. First, it was revealed that the fuzzy set approach could reduce excessive abstraction or exaggeration in environmental phenomena. Hence, without the loss of valuable information, more accurate decisionmaking can be rendered. Second, by integrating membership functions into GIS, greater efficiency of the entire evaluation process was achieved.

1 Introduction

The residential area is significant because it generally occupies the largest portion of urban areas, and it is also the area in which urbanites spend a significant amount of their time. With the increase in concern for quality of life, more efforts are being made towards maintaining a sound and comfortable residential environment, and subsequent improvements. Although various housing policies in Korea's cities have been and are being implemented, increased focus is being placed upon housing redevelopment for quantitative supply, rather than qualitative improvement. Particularly problematic is the absence of adequate methods for improvement based on the physical and socioeconomic context of the area. Consequently, this deficiency has led to the degradation of residential areas in Seoul. In resolving these problems, therefore, top priority needs to be placed upon the accurate evaluation of the quality of the residential environment in order to prepare relevant management strategies.

Fortunately, the present-day decisionmaking environment is information rich, and advancements in information technology have made various forms of spatial and aspatial data widely accessible to decisionmakers (Leung, 1997). Geographic information systems (GIS) in particular enable planners to manage urban spatial data effectively and efficiently. There has been widespread application of the crisp (or Boolean) approach in conventional GIS for evaluating the quality of physical environments. There are problems with such a method, however, which are as follows:
(1) expressive inadequacy may lead to a loss of valuable information and a reduction in the accuracy of analysis;
(2) problems of loss of information or error propagation have been identified in situations where the land/site-attribute data defy (Boolean) binary classification; and
(3) there is no room for imprecision in information, human cognition, perception, and thought processes (Banai, 1993; Hall et al, 1990; Leung and Leung, 1993a).
In resolving these problems, an evaluation method employing 'fuzzy set theory' (Zadeh, 1965) may provide more accurate representation of values underlying environmental phenomena. Moreover, through the integration of this method into GIS, efficient data management and analysis can be pursued.

In this study therefore, we aim to investigate the usefulness of the GIS–fuzzy set approach compared with the crisp approach to the evaluation of the urban residential environment. First, four qualitative objectives to be maintained in the urban residential environment were identified and twelve related physical factors were investigated. Second, the relationship between qualitative objectives and physical factors was established by application of the analytical hierarchy process (AHP) methodology. Next, the relative weights for qualitative objectives and physical factors were determined, and evaluation criteria and membership functions were established. Fourth, the quality of the residential environments in the study area was evaluated and the results of the evaluations from the two approaches compared.

2 Fuzzy set approach

According to Banai (1993), the crisp approach has some major drawbacks. In the crisp approach, classification of unit data is either accepted or rejected on the basis of a given attribute threshold. All land values within a given (attribute) value threshold may be defined as representing the class or set of acceptable land units. All land units with values that exceed the given threshold fall outside the class or set of acceptable land units and are thus rejected. Situations where there is uncertainty in the precise delineation of a threshold value pose a problem for the logic of the crisp (Boolean) classification as a tool for spatial analysis (Banai, 1993).

Zadeh (1965) originally suggested a 'fuzzy set theory' to solve problems caused by the crisp approach. Fuzzyness is a type of imprecision characterizing classes which, for various reasons, cannot have, or do not have, sharply defined boundaries: for example, the ambiguity in subjective labeling such as 'approximately 7', 'about 5 km', 'old woman'. These imprecisely defined classes are called 'fuzzy sets' (Burrough and Frank, 1996). Fuzzy sets defined over continuous domains have a membership function that defines a degree of membership for each value in the domain (Altman, 1994). The membership function can generally be represented by one of three types: S-shaped (sigmoidal), J-shaped, and linear. The choice of the type of membership function depends upon the characteristics of the spatial phenomena being dealt with. In general, S-shaped or linear membership functions are used.

The fuzzy set approach can provide an alternative approach to cope with logical constraints in the crisp approach in the understanding and evaluation of environmental phenomena. In a case study comparing the results obtained by Boolean and fuzzy methods, Burrough et al (1992) argued that fuzzy methods produce contiguous areas and reject less information at all stages of analyses and are, therefore, much better than Boolean methods for the classification of continuous variation. And, in comparison with Boolean logic, fuzzy logic is a more appropriate foundation for spatial classification with and without GIS (Leung and Leung, 1993b).

A number of studies have demonstrated the effectiveness of fuzzy set theory in characterizing a region or assigning a spatial unit of a region. These include the application of simple climatic classification to demonstrate how fuzzy set theory can be applied to regional classification problems (Leung, 1987); the integration of fuzzy logic and expert systems for approximating human reasoning and enhancing the level of intelligence in GIS technology for decisionmaking for land-type or climatic classification, etc (Leung and Leung, 1993a; 1993b); the use of fuzzy sets in evaluating the vulnerability of coastal waters (Urbanski, 1999); identification of the effectiveness of fuzzy logic by comparing the results from Boolean logic in land-suitability analysis and evaluation projects (Davidson et al, 1994; Hall et al, 1990; 1992); and the application to fuzzy set theory in handling uncertainty originating from imprecision in spatial delineation or from intentional vagueness expressed by a user in spatial analysis (Altman, 1994).

Integration of fuzzy methods or simulation methods for decisionmaking is also a significant area in which fuzzy set theory is being applied. Banai (1993) applied AHP for dealing with fuzziness, factor diversity, and complexity in problems of land evaluation involving the location of public facilities. And Davis and Keller (1997) combined fuzzy logic and Monte Carlo simulation to address two incompatible types of uncertainty present in most natural resource data—thematic classification uncertainty and variance in unclassified continuously distributed data.

Limits have been found, however, in these previous studies. First, there is a lack of adequate research on the application of fuzzy set theory to the urban environment. And second, the basic unit of analysis is often too broad, incorporating districts and regions, as opposed to designating more specific buildings and parcels.

3 Evaluation of the residential environment

3.1 The study area

The case-study area used in the comparison of the two evaluation methods involved parts of Shinlim3-dong, Shinlim7-dong, and Shinlim13-dong, in Seoul (figure 1).[(1)] The study area is one of the most overcrowded residential areas in Seoul. The population density of the area is very high (over 300 people ha^{-1}) and the size of the multifamily housing units which are typically found in the area is fairly small. The average dwelling area per capita is under 13 m^2 in these units, which make up more than 50% of the total housing units. Although most housing units are under 20 – 30 years old, they are not maintained properly. Moreover, narrow roads (width under 4 m) constitute 32.4% of the total road network therein (table 1, see over). Moreover, parked vehicles are often left at the roadside. Poor accessibility to parks is also problematic.

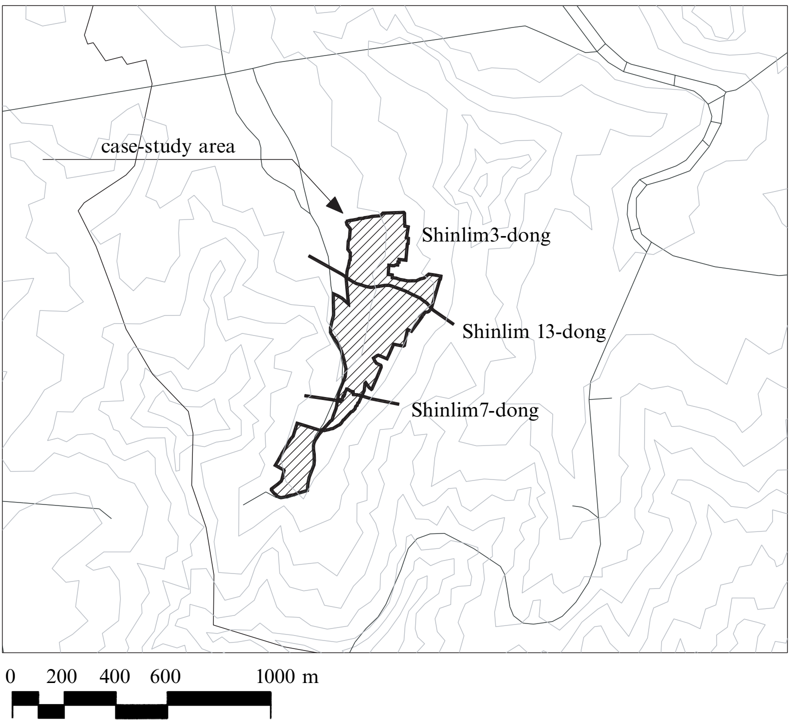

Figure 1. The case-study area.

(1) 'Dong' is an administrative spatial unit representing a local area in Korea.

Table 1. Current conditions in the study area.

Population density	312 persons ha^{-1}	
Dwelling area per capita	mean: 12.3 m^2	50.4% under 13 m^2
Road width	mean: 5.2 m	32.4% under 4 m, 76.9% under 6 m
Distance from parks	mean: 970.3 m	68.5% over 1000 m

3.2 Qualitative objectives and evaluation factors

Qualitative objectives to be provided in the urban residential environment are identified generally by physical, socioeconomic, cultural, and other local conditions. The World Health Organization (WHO) declared four main objectives as the basic conditions for human life: safety, health, efficiency, and comfort (WHO, 1961). In this study we employed these basic conditions as major qualitative objectives to be achieved in planning and managing the urban residential environment. These qualitative objectives are indicative notions in the determination of desirability, but are still too general and abstract. Therefore, with these objectives as a basis, more specific factors for evaluating the residential environment were developed in this study.

The WHO (1961) also defined the residential environment as the physical structure that a human uses for shelter and the environs of that structure, including all necessary services, facilities, equipment, and devices needed or desired for the physical and the social well-being of the family of the individual. Thus, in developing an evaluation method for housing and its environment, consideration should be given to inclusion of information of a wide and diverse nature. According to the report by the WHO (1967), the public health scope of housing involves town and country planning, the design and arrangement of the dwelling unit, the materials and methods of construction, the use of space by occupants, the maintenance of the structures and dwelling areas, and the availability of community facilities and services—including those for local circulation and transport.

In order to understand better the environmental characteristics of single-family houses, Bender et al (1997) used eight environmental criteria to describe the external quality of houses: quietness of the area, public transportation, distance to city centers, favorable view, social value of the area, distance to schools, distance to commercial facilities, and distance to a green area. Turkoglu (1997) employed evaluative variables of a house and its environment in the measurement of the residents satisfaction with housing environments, such as the age of the building, dwelling size, dwelling type, physical condition of the building, average density in the neighborhood, and distance to the city center.

Table 2. Evaluation factors.

Qualitative objective	Evaluation factors	Basic spatial unit of analysis
Safety	building age (S1)	building
	building structure (S2)	building
	road width (S3)	building
Health	type of bathroom (H1)	block
	number of bathrooms per household (H2)	block
	type of kitchen (H3)	block
Efficiency	accessibility to public facilities (E1)	building
	accessibility to parks (E2)	building
Comfort	dwelling area per capita (C1)	building
	lot coverage (C2)	parcel
	lot area (C3)	parcel
	number of residents per room (C4)	block

The evaluation factors used in the present study were investigated in light of these aspects. A set of evaluation factors, listed in table 2, was determined in consideration of the current conditions of the study area, the data availability, and particularly the transferability of data from the urban information system being developed by the City of Seoul to ensure efficient data acquisition.

3.3 Evaluation criteria and functions

3.3.1 *Deriving relative weights*

The relative weights for qualitative objectives and evaluation factors of the residential environment were determined by a pairwise comparison method. The method allows a relative measure of merit to be obtained by the comparison of a series of factor pairs. The advantage of this method is that it is fairly easy to judge relative importance accurately when the number of factors is not large. The relative weights shown in table 3 (over) were derived from a survey which involved pairwise comparisons by planning professionals. The coefficients of the matrices represent the reciprocal intensities of importance between factor pairs. Saaty's (1980) comparison method through the eigenvalue procedure, was applied to obtain the relative weights. These pairwise comparison matrices are normally considered to be consistent because the consistency ratio does not exceed 10%.

The overall evaluation scheme for this study was prepared as shown in figure 2. The score for each qualitative objective was derived by adding the products from the scores for the evaluation factors times its corresponding weight (1). Likewise, the overall score for the quality of the residential environment was calculated by adding the products from the scores for the qualitative objectives times its corresponding weight (2).

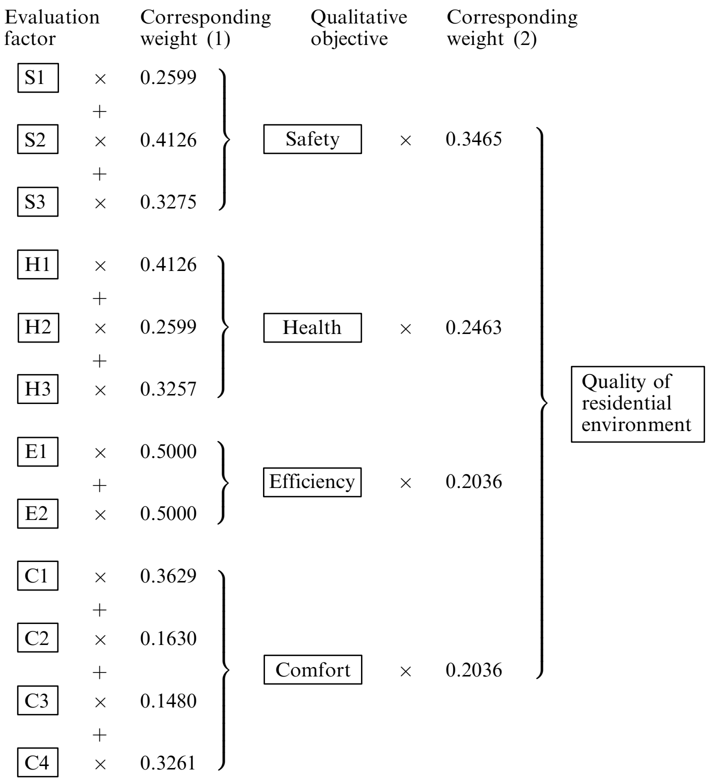

Figure 2. Evaluation scheme. The scores for each evaluation factor (which are explained in table 2) and for each qualitative objective range from 0 to 1.

Table 3. Relative weights for qualitative objectives and evaluation factors.

Qualitative objectives

	Safety	Health	Efficiency	Comfort	Weight
Safety	1	1	2	2	0.3465
Health	1	1	1	1	0.2463
Efficiency	1/2	1	1	1	0.2036
Comfort	1/2	1	1	1	0.2036
Consistency ratio = 0.02					1.000

Factors for safety

	Building age	Building structure	Road width	Weight
Building age	1	1/2	1	0.2599
Building structure	2	1	1	0.4126
Road width	1	1	1	0.3275
Consistency ratio = 0.05				1.000

Factors for health

	Type of bathroom	No. of bathrooms per household	Type of kitchen	Weight
Type of bathroom	1	2	1	0.4126
Number of bathrooms per household	1/2	1	1	0.2599
Type of kitchen	1	1	1	0.3275
Consistency ratio = 0.05				1.000

Factors for objective efficiency

	Accessibility to public facilities	Accessibility to parks	Weight
Accessibility to public facilities	1	1	0.5000
Accessibility to parks	1	1	0.5000
Consistency ratio = 0.00			1.000

Factors for comfort

	Dwelling area per capita	Lot coverage	Lot area	Number of residents per room	Weight
Dwelling area per capita	1	2	3	1	0.3629
Lot coverage	1/2	1	1	1/2	0.1630
Lot area	1/3	1	1	1/2	0.1480
Number of residents per room	1	2	2	1	0.3261
Consistency ratio[a] = 0.01					1.000

[a] Upper limit of consistency ratio equal to 10% is a measure of good consistency (Saaty, 1980).

3.3.2 *Evaluation criteria for the crisp approach*

The evaluation criteria used in this study for the crisp approach included two or three discrete values between 0 and 1 (table 4). For example, for building age, safety against disasters generally declines and the outer conditions of the building deteriorate as it becomes older. In this case, it was determined that the minimum quality level is 30 years old, and the optimum level is less than 20 years old.

Table 4. Evaluation criteria used for the crisp approach.

Factor	Minimum level (0)	Intermediate level (0.5)	Optimum level (1)
Building age (years)	>30	20 – 29	<20
Building structure	wood	brick	reinforced concrete
Road width (m)	<4	4 – 8	>8
Type of bathroom	conventional		modern
Number of bathrooms per household	<0.5	0.5 – 1.5	>1.5
Type of kitchen	conventional		modern
Accessibility to public facilities (m)	>500	350 – 500	<350
Accessibility to parks	>1000	500 – 1000	<500
Dwelling area per capita (m^2)	<13	13 – 21.5	>21.5
Lot coverage (%)	>60	35 – 60	<35
Lot area (m^2)	<60	60 – 140	>140
Number of residents per room	>2	1.5 – 2	<1.5

3.3.3 *Membership functions for the fuzzy approach*

To implement the fuzzy set approach, a series of membership functions were established for the evaluation criteria corresponding to those used for the crisp approach (figure 3, see over). The Sigmoidal type function, which is the most widely used, was employed. Otherwise the factor was measured on a nominal scale, and two critical points (thresholds) were determined as corresponding to two levels in table 4. Thus, the degree of membership of each function was determined. The membership function for a road in figure 3, for example, can be defined as

$$\mu_{\text{road}} = \begin{cases} 0, & w < 4, \\ \cos\left(\dfrac{w-4}{4}\dfrac{\pi}{2}\right), & 4 \leqslant w \leqslant 8, \\ 1, & w > 8. \end{cases}$$

4 Results

4.1 Overview of the evaluation results

Table 5 (over) shows a summary of the evaluation results. All figures in the table are mean values. In the crisp approach, the residential environment of the case-study area represents the most favorable conditions in terms of health, and the lowest conditions in efficiency. The fuzzy approach gives similar results to those of the crisp approach, although the estimated values tend to be lower.

Table 6 (over) shows the correlation between the raw data of evaluation factors and values estimated by the two approaches (data for these factors were measured on the basis of individual buildings or parcels). The correlation coefficient was much higher when the fuzzy approach was employed. This implies that the fuzzy approach reflected the actual phenomena more precisely.

4.2 Comparison of raw data and evaluation results for the qualitative objectives in safety and efficiency

We conducted a series of specific quantitative analyses of data. Comparison was made of the evaluation results primarily for safety and efficiency. No detailed comparison of evaluation results could be made for the objectives health and comfort because these involved block-based or district-based data, in other words, data which were not based upon individual buildings or parcels.

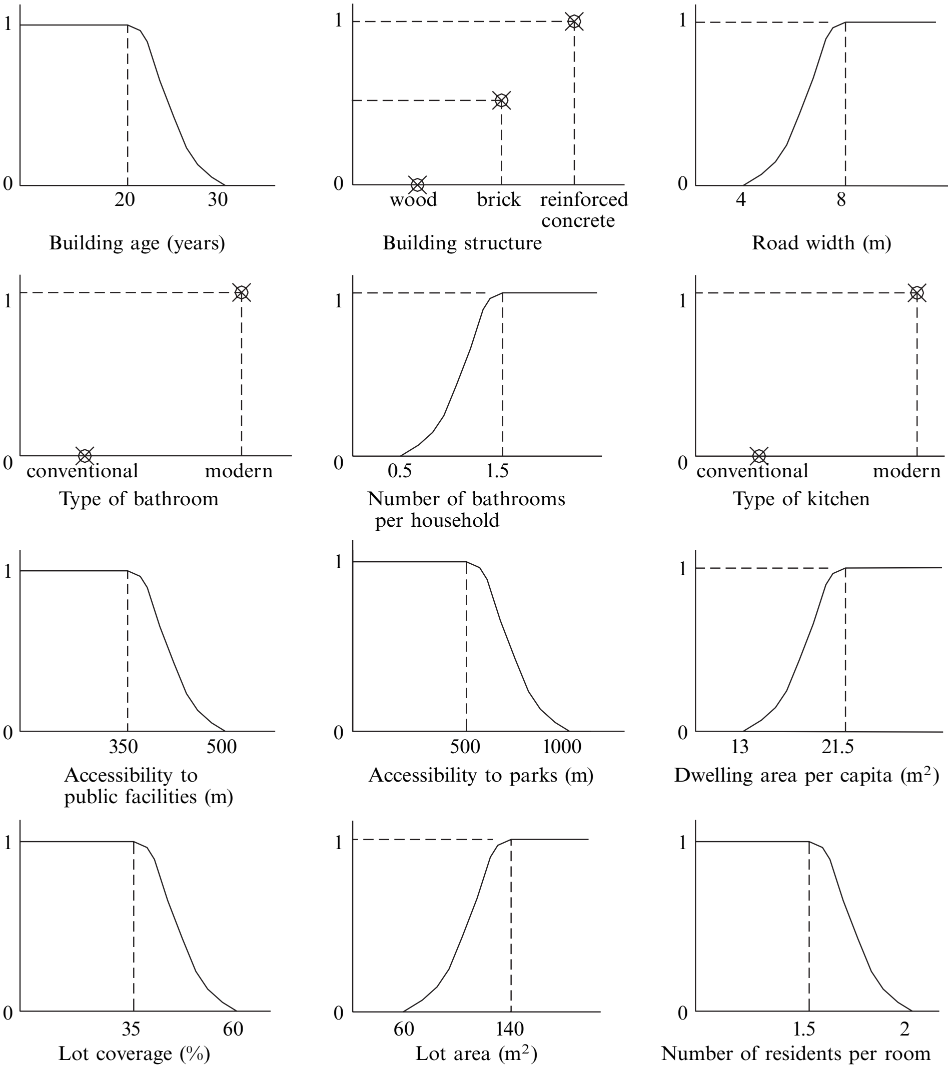

Figure 3. Membership functions for evaluation criteria for the fuzzy set approach.

Table 5. Evaluation results from the two approaches (standard deviations are given in parentheses).

Area	Safety		Health		Efficiency		Comfort		Quality[a]	
	crisp	fuzzy	crisp	fuzzy	crisp	fuzzy	crisp	fuzzy	crisp	fuzzy
Shinlim3-dong	0.58	0.58	0.85	0.81	0.70	0.60	0.53	0.53	0.66	0.63
	(0.15)	(0.15)	(0.00)	0.00)	(0.10)	(0.10)	(0.05)	(0.06)	(0.06)	(0.06)
Shinlim13-dong	0.60	0.55	0.85	0.82	0.52	0.50	0.69	0.52	0.67	0.60
	(0.14)	(0.15)	(0.00)	(0.00)	(0.08)	(0.00)	(0.05)	(0.06)	(0.06)	(0.05)
Shinlim7-dong	0.57	0.53	0.85	0.72	0.33	0.35	0.51	0.51	0.58	0.53
	(0.17)	(0.17)	(0.00)	(0.00)	(0.19)	(0.20)	(0.05)	(0.06)	0.07)	(0.07)
Total	0.59	0.55	0.85	0.80	0.55	0.51	0.61	0.52	0.65	0.60
	(0.15)	(0.15)	(0.15)	(0.04)	(0.17)	(0.13)	(0.10)	(0.06)	(0.07)	(0.07)

[a] Quality of the residential environment.

Table 6. Correlation coefficients between raw data and estimated values.

Evaluation factor	Crisp	Fuzzy
Building age	−0.45	−0.96
Road width	0.59	0.97
Accessibility to public facilities	−0.81	−0.99
Lot coverage	−0.48	−0.97
Lot area	0.61	0.96
Accessibility to parks	−0.83	−0.97

Figures 4 (safety), 5 (efficiency), and 6 (overall quality) (see over) illustrate levels of environmental quality in the case-study area. The difference between the results from the two methods is not readily apparent. However, when analyzed quantitatively, the fuzzy approach revealed more diverse qualitative levels than did the crisp approach. This is because the crisp approach assigns a limited number of discrete values to the quality distributed between the minimum and optimum levels, whereas the fuzzy approach assigns a value corresponding to an inherent feature of data through the membership function. In order to investigate this difference between the approaches more precisely, 50 samples (one sample building from each cell with the identical size) out of 1012 buildings were randomly selected (figure 7, see over).

In the comparison table of evaluation results for safety and efficiency, differences between some estimated values were observed (tables 7 and 8, see over). With regard to safety, it had been determined that for building age, 30 years old was the threshold for the minimum level and 20 years was the optimum age. For efficiency, it was concluded that, for accessibility to public facilities, 500 m was the threshold for the minimum level and 350 m was the optimum.

For the qualitative objective of safety, and for the evaluation factor of building age, the crisp approach treated the quality between the two levels as 'deteriorated' uniformly, whereas with the fuzzy approach, the older the age of the building, the lower the estimated value. For building structure, the results were the same with both approaches because the evaluation criteria for the two approaches were identical. However, in the results for road width, the crisp approach assigned an equal level of safety to all data between the minimum and optimum levels. The fuzzy approach, on the other hand, evaluated the differences in safety according more precisely to the width of the road.

In the estimation of efficiency, involving accessibility to public facilities, the crisp approach determined 'poor accessibility' between the two levels—minimum and optimum. In contrast with the fuzzy approach, the closer the distance from the public facilities, the higher the estimated value. For accessibility to parks, the crisp approach assigned an equal value between the minimum and optimum levels, whereas the fuzzy approach more accurately evaluated the difference in efficiency according to the distance from the park. Thus the fuzzy approach was able to extract information on the *degree* of environmental quality, which is useful in the decisionmaking process.

When applying the crisp approach, the precision of the evaluation results for safety and efficiency is decreased by simplifying various levels of environmental quality; subsequently, error propagation accumulates throughout the evaluation process.

Figures 8 and 9 (over) display a series of graphs in which raw data are compared with the evaluation results for the qualities safety and efficiency derived from the two approaches. In the cases both of safety (building age and road width), and of efficiency (accessibility to parks and accessibility to public facilities), values estimated by the fuzzy approach were closer to the raw data than those derived from the crisp approach.

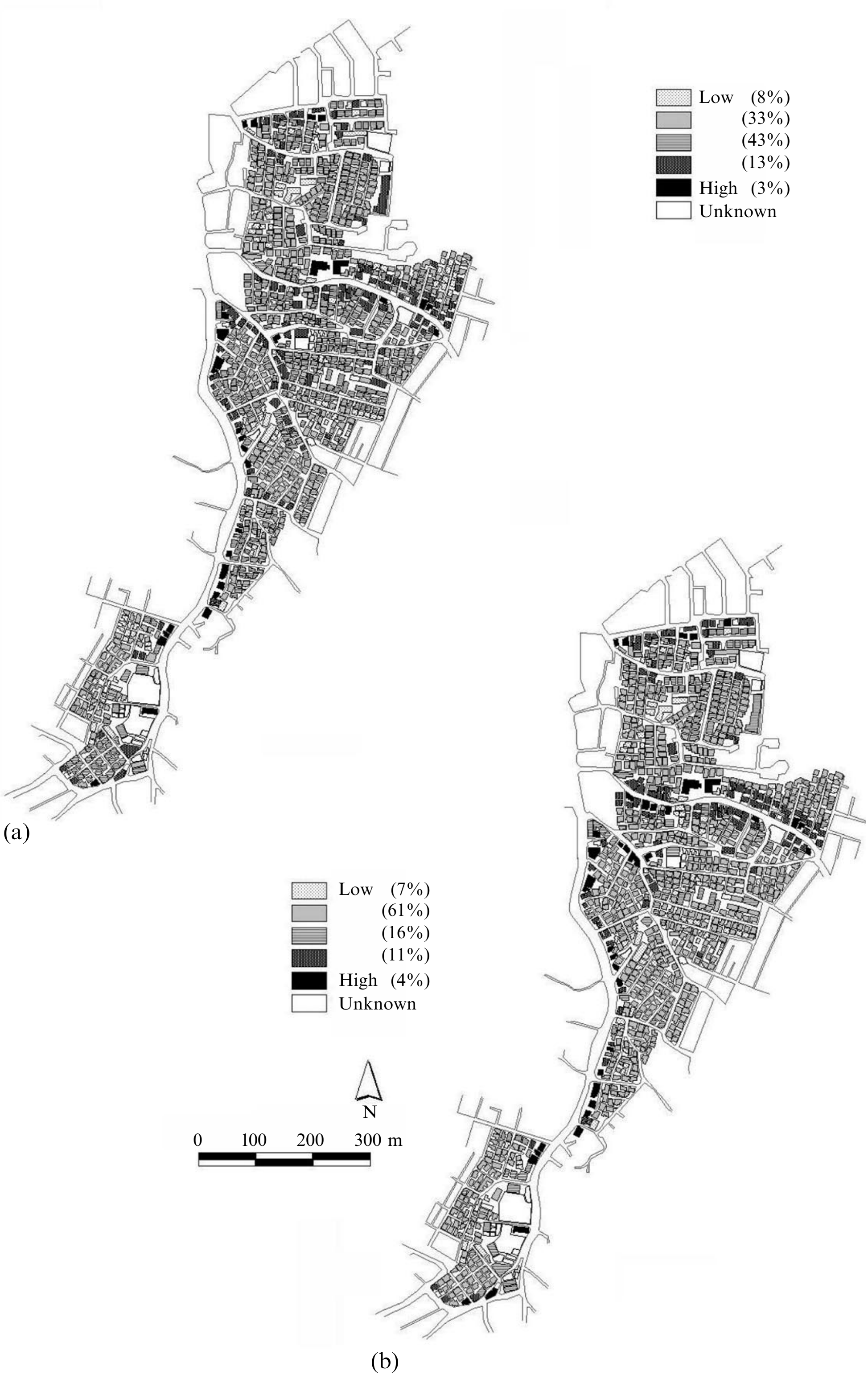

Figure 4. Evaluation results for safety: (a) crisp approach, (b) fuzzy approach.

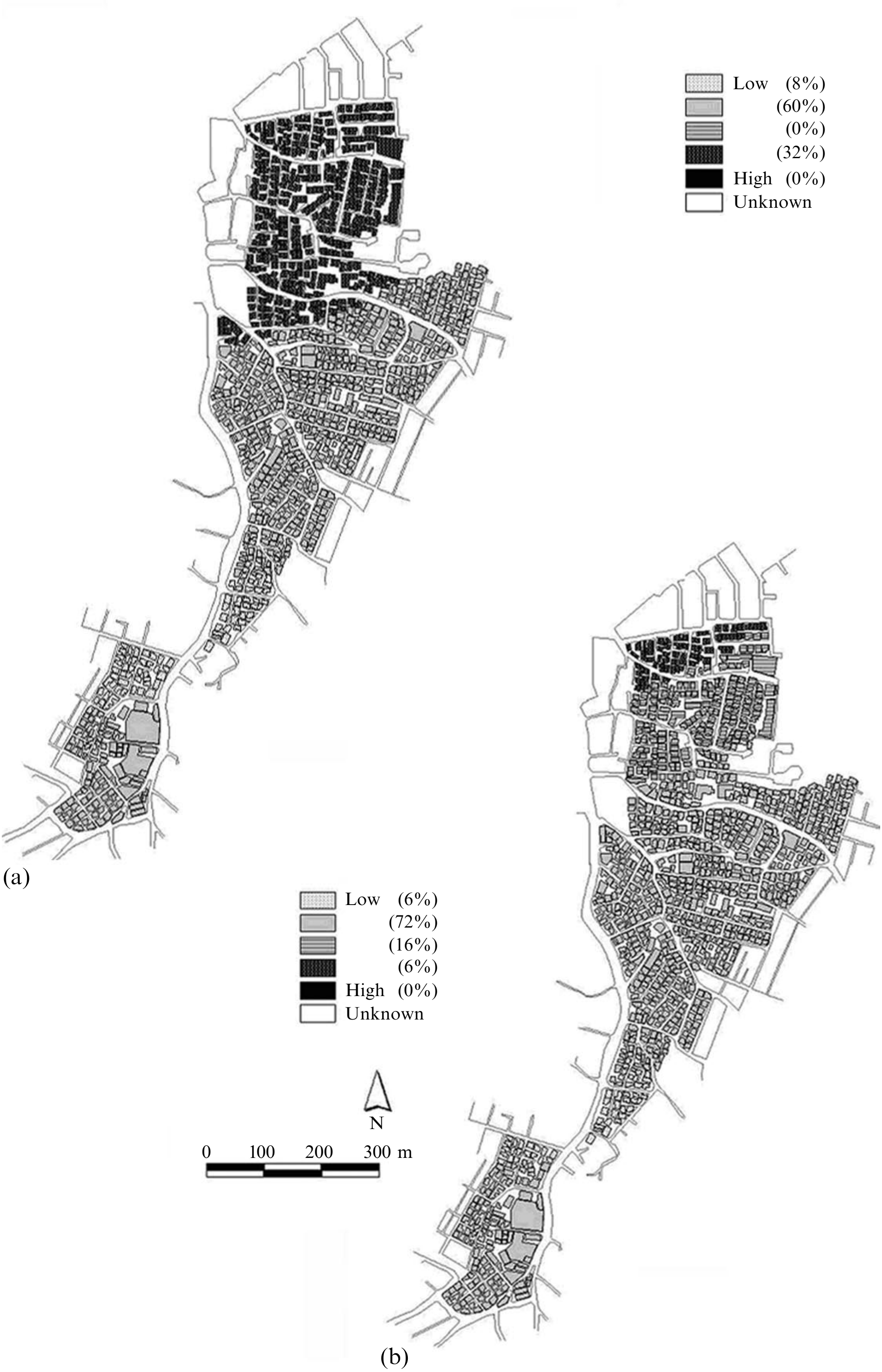

Figure 5. Evaluation results for efficiency: (a) crisp approach, (b) fuzzy approach.

Figure 6. The overall quality of the environment: (a) crisp approach, (b) fuzzy approach.

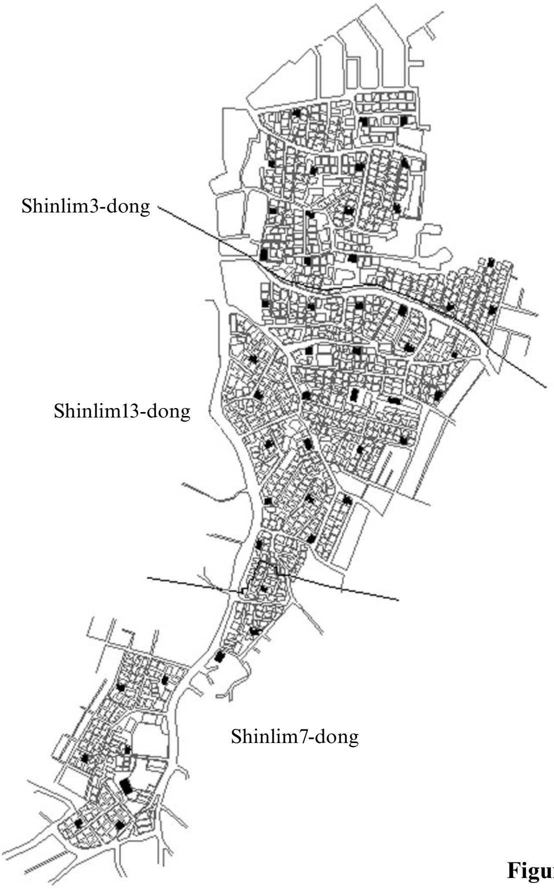

Figure 7. Sample buildings.

Evaluation results were, of course, the same for building structure. Therefore, for estimations of both qualitative objectives safety and efficiency, the fuzzy approach yielded values which fitted the raw data better than those yielded by the crisp approach.

5 Conclusion

In order to maintain the quality of the residential environment effectively, careful, precise evaluation is required. However, evaluation derived from the conventionally used the crisp logic approach often leads to inaccurate assessment of environmental quality. The fuzzy approach has been suggested as a solution to this problem.

In this study, the usefulness of the fuzzy approach was investigated by comparing the results from the two approaches quantitatively. The fuzzy approach was shown to be more effective than the crisp approach in evaluating the environmental quality of urban residential areas for the following reason: the fuzzy approach prevents information loss, so that evaluation results reflect the actual phenomena more precisely. The fuzzy approach is able not only to display more diverse qualitative levels in the distribution of the residential environment, but also to allocate proper values within threshold points; whereas the crisp approach is more restrictive. The implication is that the fuzzy approach may be used to reduce excessive abstraction and exaggeration, which can produce information loss, in representing environmental phenomena. Therefore, the fuzzy approach reflects the actual phenomena in the evaluation process more reliably than does the crisp approach.

Table 7. Evaluation results for the qualitative objective 'safety'—estimated values; values with significant differences from the two approaches shown in bold.

Building number	Evaluation factor									Safety	
	building age			building structure			road width			crisp	fuzzy
	years	value		material	value		meters	value			
		crisp	fuzzy		crisp	fuzzy		crisp	fuzzy		
21	13	1.0	1.0	brick	0.5	0.5	8.5	1.0	1.0	0.79	0.79
32	18	1.0	1.0	brick	0.5	0.5	5.7	**0.5**	**0.38**	**0.63**	**0.59**
38	8	1.0	1.0	brick	0.5	0.5	5.7	**0.5**	**0.38**	**0.63**	**0.59**
92	9	1.0	1.0	brick	0.5	0.5	6.1	**0.5**	**0.54**	**0.63**	**0.64**
96	5	1.0	1.0	brick	0.5	0.5	2.8	0	0	0.47	0.47
100	10	1.0	1.0	brick	0.5	0.5	6.1	**0.5**	**0.54**	**0.63**	**0.64**
106	22	**0.5**	**0.9**	brick	0.5	0.5	6.1	**0.5**	**0.54**	**0.50**	**0.62**
164	9	1.0	1.0	brick	0.5	0.5	1.9	0	0	0.47	0.47
168	9	1.0	1.0	brick	0.5	0.5	5.7	**0.5**	**0.38**	**0.63**	**0.59**
170	9	1.0	1.0	brick	0.5	0.5	3.5	0	0	0.47	0.47
176	2	1.0	1.0	brick	0.5	0.5	3.5	0	0	0.47	0.47
225	9	1.0	1.0	brick	0.5	0.5	3.0	0	0	0.47	0.47
230	9	1.0	1.0	brick	0.5	0.5	4.4	**0.5**	**0.02**	**0.63**	**0.47**
238	2	1.0	1.0	brick	0.5	0.5	2.5	0	0	0.47	0.47
240	18	1.0	1.0	brick	0.5	0.5	3.1	0	0	0.47	0.47
319	6	1.0	1.0	RC	1.0	1.0	4.0	**0.5**	**0**	**0.84**	**0.67**
334	10	1.0	1.0	brick	0.5	0.5	2.5	0	0	0.47	0.47
338	23	**0.5**	**0.79**	brick	0.5	0.5	9.3	1.0	1.0	**0.66**	**0.74**
342	9	1.0	1.0	brick	0.5	0.5	7.4	**0.5**	**0.95**	**0.63**	**0.78**
347	2	1.0	1.0	brick	0.5	0.5	9.3	1.0	1.0	0.79	0.79
351	9	1.0	1.0	brick	0.5	0.5	4.0	**0.5**	**0**	**0.63**	**0.47**
447	10	1.0	1.0	brick	0.5	0.5	5.4	**0.5**	**0.27**	**0.63**	**0.55**
458	13	1.0	1.0	brick	0.5	0.5	10	1.0	1.0	0.79	0.79
460	4	1.0	1.0	brick	0.5	0.5	4.4	**0.5**	**0.02**	**0.63**	**0.47**
469	6	1.0	1.0	brick	0.5	0.5	5.3	**0.5**	**0.24**	**0.63**	**0.54**
498	24	**0.5**	**0.65**	brick	1.0	1.0	4.5	**0.5**	**0.04**	**0.50**	**0.39**
569	4	1.0	1.0	RC	1.0	1.0	1.6	0	0	0.67	0.67
575	10	1.0	1.0	brick	0.5	0.5	2.3	0	0	0.47	0.47
576	4	1.0	1.0	brick	0.5	0.5	4.5	**0.5**	**0.04**	**0.63**	**0.48**
577	4	1.0	1.0	RC	1.0	1.0	4.1	**0.5**	**0**	**0.84**	**0.67**
592	18	1.0	1.0	brick	0.5	0.5	3.2	0	0	0.47	0.47
682	24	**0.5**	**0.65**	brick	0.5	0.5	3.7	0	0	**0.34**	**0.38**
684	1	1.0	1.0	RC	1.0	1.0	4.9	**0.5**	**0.12**	**0.84**	**0.71**
686	7	1.0	1.0	brick	0.5	0.5	3.0	0	0	0.47	0.47
695	7	1.0	1.0	brick	0.5	0.5	1.5	0	0	0.47	0.47
758	8	1.0	1.0	brick	0.5	0.5	3.2	0	0	0.47	0.47
759	14	1.0	1.0	brick	0.5	0.5	5.0	**0.5**	**0.15**	**0.63**	**0.52**
763	5	1.0	1.0	brick	0.5	0.5	16	1.0	1.0	0.79	0.79
800	7	1.0	1.0	RC	1.0	1.0	5.0	**0.5**	**0.15**	**0.84**	**0.72**
805	9	1.0	1.0	wood	0.0	0.0	16	1.0	1.0	0.59	0.59
842	6	1.0	1.0	brick	0.5	0.5	4.1	**0.5**	**0**	**0.63**	**0.47**
865	13	1.0	1.0	brick	0.5	0.5	5.2	**0.5**	**0.21**	**0.63**	**0.53**
872	8	1.0	1.0	RC	1.0	1.0	12.3	1.0	1.0	1.00	1.00
877	14	1.0	1.0	brick	0.5	0.5	5.7	**0.5**	**0.38**	**0.63**	**0.59**
889	13	1.0	1.0	brick	0.5	0.5	3.7	0	0	0.47	0.47
936	18	1.0	1.0	brick	0.5	0.5	2.6	0	0	0.47	0.47
941	4	1.0	1.0	brick	0.5	0.5	3.5	0	0	0.47	0.47
962	20	**0.5**	**1.0**	RC	1.0	1.0	4.4	**0.5**	**0.02**	**0.71**	**0.68**
993	6	1.0	1.0	brick	0.5	0.5	4.1	**0.5**	**0**	**0.63**	**0.47**
995	10	1.0	1.0	brick	0.5	0.5	4.6	**0.5**	**0.05**	**0.63**	**0.48**

Table 8. Evaluation results for the qualitative objective 'efficiency' — estimated values; values with significant difference from the two approaches shown in bold.

Building number	Evaluation factor						Efficiency	
	accessibility to public facilities			accessibility to parks			crisp	fuzzy
	meters	value		meters	value			
		crisp	fuzzy		crisp	fuzzy		
21	350	1.00	1.00	700	**0.50**	**0.65**	**0.75**	**0.83**
32	350	1.00	1.00	800	**0.50**	**0.35**	**0.75**	**0.68**
38	350	1.00	1.00	760	**0.50**	**0.47**	**0.75**	**0.74**
92	350	1.00	1.00	840	**0.50**	**0.23**	**0.75**	**0.62**
96	350	1.00	1.00	760	**0.50**	**0.47**	**0.75**	**0.74**
100	350	1.00	1.00	820	**0.50**	**0.29**	**0.75**	**0.65**
106	350	1.00	1.00	800	**0.50**	**0.35**	**0.75**	**0.68**
164	350	1.00	1.00	900	**0.50**	**0.10**	**0.75**	**0.55**
168	350	1.00	1.00	880	**0.50**	**0.14**	**0.75**	**0.57**
170	350	1.00	1.00	840	**0.50**	**0.23**	**0.75**	**0.62**
176	350	1.00	1.00	860	**0.50**	**0.18**	**0.75**	**0.59**
225	350	1.00	1.00	880	**0.50**	**0.14**	**0.75**	**0.57**
230	350	1.00	1.00	940	**0.50**	**0.04**	**0.75**	**0.52**
238	350	1.00	1.00	920	**0.50**	**0.06**	**0.75**	**0.53**
240	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
319	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
334	350	1.00	1.00	960	**0.50**	**0.02**	**0.75**	**0.51**
338	350	1.00	1.00	1000	**0.50**	**0.00**	**0.75**	**0.50**
342	350	1.00	1.00	980	**0.50**	**0.00**	**0.75**	**0.50**
347	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
351	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
447	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
458	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
460	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
469	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
498	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
569	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
575	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
576	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
577	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
592	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
682	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
684	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
686	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
695	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
758	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
759	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
763	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
800	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
805	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
842	510	1.00	1.00	1020	0.00	0.00	0.50	0.50
865	500	**0.50**	**0.00**	1020	0.00	0.00	**0.25**	**0.00**
872	450	**0.50**	**0.25**	1020	0.00	0.00	**0.25**	**0.13**
877	430	**0.50**	**0.45**	1020	0.00	0.00	**0.25**	**0.23**
889	410	**0.50**	**0.65**	1020	0.00	0.00	**0.25**	**0.33**
936	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
941	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
962	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
993	350	1.00	1.00	1020	0.00	0.00	0.50	0.50
995	350	1.00	1.00	1020	0.00	0.00	0.50	0.50

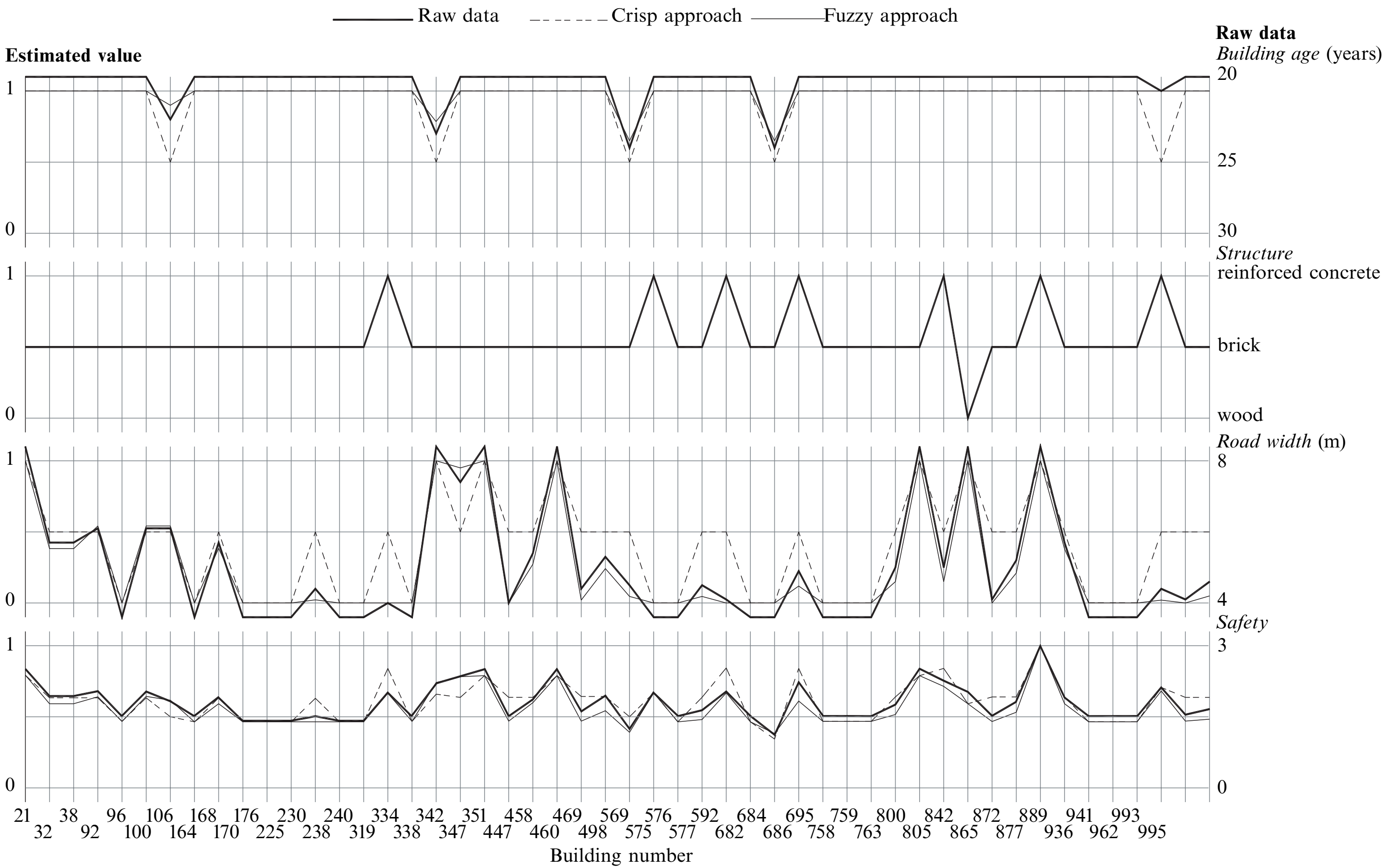

Figure 8. Comparison of values estimated by the crisp and fuzzy approaches with the raw data.

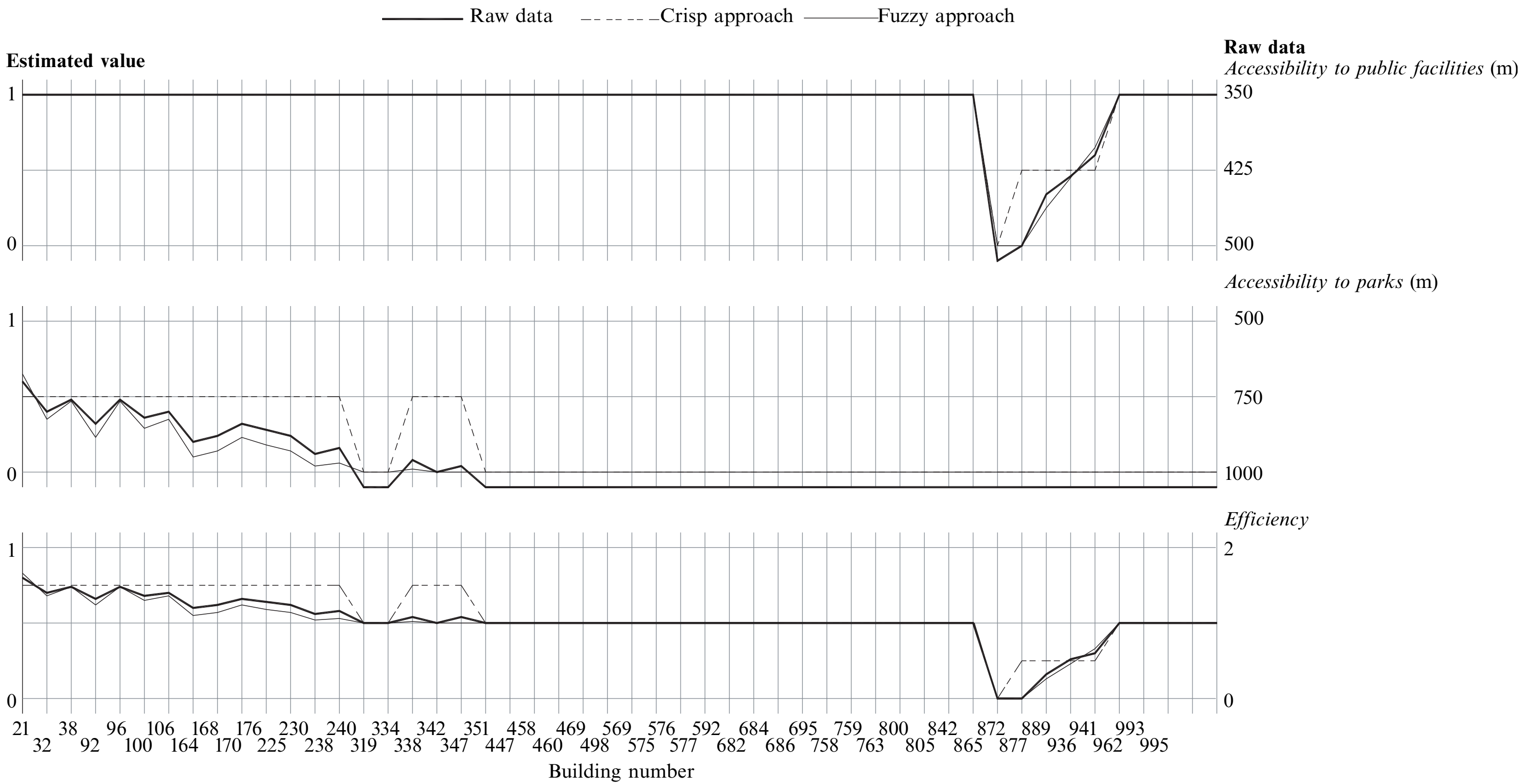

Figure 9. Comparison of values estimated by the crisp and fuzzy approaches with the raw data.

Currently, on the national as well as local levels in Korea, diverse urban information systems are being established. If sufficient databases documenting the quality of the urban environment are prepared, evaluation of the residential environment on a wider and more profound level will be possible; this would provide the opportunity for the GIS – fuzzy approach to support effective evaluation. Most urban planners are still using the crisp approach, which inadvertently tends to exaggerate and/or abstract the relationship between values in the urban environment. This in turn leads to the loss of valuable information. The results of this study suggest that use of the fuzzy set approach can alleviate unnecessary abstraction and exaggeration of information. Hence, it will lead to more precise and practical determination of the quality of the urban environment, and help promote more continuity between values which urban planners tend to isolate when using the crisp approach.

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