SELECTION OF RESIDENTIAL CONSTRUCTION SITE USING GEOGRAPHIC INFORMATION SYSTEM BASED AHP RATING MODEL

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ABSTRACT

An appropriate site selection is one of the most crucial decisions need to be fulfilled by project development team in the preliminary phase of construction projects. In this study, 6 potential sites for a residential construction were ranked in Pendik district of İstanbul. An AHP Rating model was applied to obtain rankings with respect to Total Floor Area, Market Value, Environmental Position and Legal Status criteria. Data of each alternative were collected from national Geographic Information System for every criterion. According to results, "Environmental Position" is found to be the most important criterion in serving the goal as well as "Comfort" is found to be the most important sub-criterion within Environmental Position. Thanks to the applied model, it was taught that the firm was able to ensure the long-term customer benefits and gained a remarkable competitive advantage.

Keywords: AHP Rating Model, GIS, Site Selection, Construction Industry, SME
JEL: C02, C44, D81, L74, M31, R14

Coğrafi Bilgi Sistemi Temelli AHP Dereceleme Modeli Kullanarak Konut İnşaatı Arsası Seçimi

ÖZET

Uygun bir arsa yeri seçimi inşaat projelerinin başlangıç aşamasında proje geliştirme ekibi tarafından verilmesi gereken en önemli kararlardan biridir. Bu çalışmada, bir konut inşaatı için İstanbul'un Pendik bölgesinde bulunan 6 potansiyel arsa sıralanmıştır. Bir AHP Dereceleme modeli uygulanarak Toplam İnşaat Alanı, Pazar Değeri, Çevresel Pozisyon ve Yasal Durum ölçütlerine göre sıralamalar elde edilmiştir. Bütün ölçütler için her bir alternatife ait veriler ulusal Coğrafi Bilgi Sisteminden toplanmıştır. Elde edilen sonuçlara göre, "Çevresel Pozisyonun" amaca hizmet etmede en önemli ölçüt olduğu ve bunun yanında "Konforun" Çevresel Pozisyon ölçütünün içindeki en önemli alt ölçüt olduğu bulunmuştur. Uygulanan model sayesinde firmanın uzun vadeli müşteri yararını gözetebileceği ve böylece önemli bir rekabet avantajı kazanacağı düşünülmüştür.

Anahtar Kelimeler: AHP Dereceleme Modeli, CBS, Arsa Seçimi, İnşaat Sektörü, KOBİ

1. INTRODUCTION

The construction industry is one of the prominent industries of economies particularly in developing countries in the world. Thanks to numerous of business branches it relates and area of employment it creates, this industry provides significant contributions to economies (Kargı, 2013; Özorhon, 2012). As one of the most outstanding case, economic growth has been remarkably triggered by construction industry between the period of 2002 and 2014 in Turkey (Dalkılıç, 2015). Though construction industry has barely received the share of 5.7% of GDP, it expands to 30% considering the main industry together with -over 200- sub-sectors in 2015, namely $81.4bn (İNTES, 2016; MarketLine, 2016). It makes the second biggest industry after food and beverage sector in Turkey (Çelik, 2007; Şat, 2016). On the other hand, it is forecast that the Turkish construction industry will have received the value of $132.6 billion until 2020, after an increase of 62.9% since 2015 (MarketLine, 2016).

Construction industry can be divided into three market segment which are the residential segment with houses, dwelling and similar buildings, the non-residential segment including commercial, industrial and social buildings i.e. hospitals, schools, factories and the civil engineering segment covering infrastructure investments such as power plants, airports, highways, dams etc. Not only in the world, but also in Turkey residential segment is the largest market with a total value of $42.8bn, equivalent to 52.5% of the whole value of industry among all other market segments of the industry (MarketLine, 2016; Şat, 2016). Sector statistics indicate that residential sales have been notably increasing during the last decade. Considering socioeconomic, demographic and cultural dynamics of Turkey as well as international mobilization of the region, this situation does not seem surprising at all. Between the period of 2002 and 2014, nearly 7 million residences have been produced by TOKİ (8.5%), corporate firms (as prestige project of brands with high prices, 1.5-2%) and SMEs (as apartments with 15-20 flats in average, 89-90%) (Dincel, 2015). This picture illustrates the extent of market share in SMEs' scope of operation. Due to urban transformation projects become widespread in the metropolis, it is predicted that share of SMEs may rise more in the medium and long term.

Since urbanization has been enlarging steadily for ages, a wide range of residential projects is conducted in the province of İstanbul. In 2015, 239 767 residents were sold in İstanbul, which is 18.5% of entire sales in the country. In addition, 46.9% of total sales of 2015 in İstanbul consist of first-hand residents (TÜİK, 2016). Such charming developments in the sector allures investors to start up new business enterprises. 19 254 new company of which the main area of activity is construction has been found since 2012. Last three years, the number of companies within the scope of instruction has increased by 40% (MEED, 2016).

As understood from the statistics, there is an intense competition among SMEs operating within the residential segment. Therefore, firms need to increase productivity and provide more value to customers regarding their business so that they can survive in such competitive environment of the sector. There are three main stages of residential projects that conductors need to handle being planning, design, and construction. Even though design and construction

stages are principally well documented, no suitable tool for collecting, organizing and analyzing data required for planning exists. However, in order to focus on long-term benefits of both firms and customers, it is crucial to evaluate customer expectations associated with site location. Thus, this study aims to formulate an appropriate preliminary planning model to be used in early stages of a residential construction development project. AHP rating model with GIS approach has been implied for this purpose as described later on.

2. LITERATUR REVIEW

Lots of studies in the literature have been dedicated to merge AHP and GIS approach on the basis of site selection for various objectives.

Chaudhary et al. (2016) applied Group Decision Making (GDMP) method via AHP in the Geographic Information System (GIS) interface for determining appropriate fire station sites in Kathmandu Metropolitan City. There were for different criteria being the distance from roads, land cover, distance from rivers and population density. According to results, only 13.46% of the study area was available for fire station location. Kumar and Bansal (2016) reviewed former studies identifying side selection techniques, building codes and existing standards of safe site selection. GIS was developed for modeling locational and topographical aspects of suitable areas. Fernandez-Jimenez et al. (2015) presented a new model illustrating feasible construction places for photovoltaic power plants in any zone. The model was applied in a GIS perspective which visually demonstrates the results of outstanding locations. Aguirre-Salado et al. (2015) implemented a linear combination method for classifying areas according to various availability levels related to tree plantation establishment purpose. This method merged climatic, edaphic, topographic factors as well as constraints e.g. land availability. Results showed that over %80 of study areas were available for tree plantation. Thus, industrial demand for forest product might be supplied from such areas but not natural forests. Satman and Altunbey (2014) offered feed forward neural networks and Google Places API method in order to examine the relation between environmental attributes and financial rankings of existing retailers. In consequence, it was revealed that suggested model works better than survey data and MCDM methods on location selection problem. Emir and Saracli (2014) used AHP method for determining priorities of factors regarding the problem of selecting the most appropriate thermal hotel location. Results showed that environmental factors are more important than features of the construction, the cost of investment, the location of the construction, competitive factors, and demographic structure. Ardeshir et al. (2014) ranked the potential construction sites of a river bridge according to the level of suitability by using fussy AHP and GIS. Results indicated that the existing bridge has one of the best locations but not the best one. Özdağoğlu (2008) applied a fussy AHP approach in order to select the best plant site among four different alternative places in Istanbul for a private company. There were five criteria being distance, traffic, demand potential, foundation facilities and environmental factors. McIntyre and Parfitt (1998) formulated a decision support model based on AHP for the preliminary planning phase of residential site selection in that decision makers can benefit from during the phase of the project. Site characteristics, regulatory conditions, and off-site factors were employed as main criteria within the conceptual plan.

1. ANALYTIC HIERARCHY PROCESS (AHP)

Since real world problems have complex nature, decision makers may fail to perceive whole aspects of the problem together. This situation may lead wrong decisions. Multi-Criteria Decision Making (MCDM) techniques provide facilities in that decision makers can tackle with structuring multi-dimensional problems.

Analytical Hierarchy Process (AHP) is one of the MCDM tool, developed by Thomas Saaty. So far, many researchers have paid attention on AHP thanks to pleasant mathematical attributes and easy-to-understand algorithm of the method. During the decision process, AHP combines tangible and intangible variables affecting the goal together as a remarkable benefit. Therefore, many kinds of metric factors as well as perceptions, feelings, judgments etc. are organized into the same framework. AHP transforms several kinds of problems into a multilevel structure of criteria, sub-criteria, and alternatives. Briefly, the procedure of AHP is as follows (Rahimdel & Ataei, 2014):

Step 1: The hierarchical structure is found from the top level (the main goal of research) through subsequent levels being criteria, sub-criteria, and alternatives (Saaty, 2001, pp. 29-36).

Step 2: The importance weights of criteria and sub-criteria are derived from pairwise comparisons. These comparisons are also used for obtaining relative performance of alternatives in terms of each criterion. Hence, verbal judgments are converted into a numeric score by using Saaty's 9 point scale and demonstrated in an *n x n* pairwise comparison matrix (Saaty, 2006, p. 69).

$$A = \begin{bmatrix} 1 & a_{12} & ... & a_{1n} \\ a_{21} & 1 & ... & a_{2n} \\ ... & ... & ... & ... \\ a_{n1} & a_{n2} & ... & 1 \end{bmatrix} \tag{1}$$

Step 3: Just as pairwise comparison matrix is found, priority vector bringing the weights of elements is calculated. Let the importance degree of *ith* criterion is w_i then;

$$w_i = \frac{(\prod_{j=1}^{n} a_{ij})^{1/n}}{\sum_{i=1}^{n}(\prod_{j=1}^{n} a_{ij})} \qquad i, j = 1, 2, ..., n \tag{2}$$

Step 4: In this stage consistency level of criteria priorities are checked whether assessment of pairwise comparison matrix makes sense and acceptable or not. Let *c* stands for an *n*-dimensional column vector which depicts the sum of the weighted scores as the priorities of criteria, then;

$$c = [c_i] = A.W_{nx1}^{T}, \qquad i = 1, 2, ..., n \tag{3}$$

In which

$$A.W^T = \begin{bmatrix} 1 & a_{12} & ... & a_{1n} \\ a_{21} & 1 & ... & a_{2n} \\ ... & ... & ... & ... \\ a_{n1} & a_{n2} & ... & 1 \end{bmatrix} \cdot \begin{bmatrix} w_1, & w_2, & ..., & w_n \end{bmatrix}^T = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix}$$

The vector $\overrightarrow{CV} = \begin{bmatrix} cv \end{bmatrix}_{nx1}$ stands for consistency scores for each group of criteria. A typical element of cv_i is defined as the follow:

$$cv_i = \frac{c_i}{w_i}, \quad i = 1, 2, ..., n \tag{4}$$

In case consistency of criteria is not satisfactory, AHP has a mechanism in order to compensate for this problem. Saaty suggested using the maximal Eigenvalue λ_{max} to overcome inconsistency which diminishes the effectiveness of measurement. The maximum Eigenvalue λ_{max} is calculated as follow:

$$\lambda_{max} = \frac{\sum_{i=1}^{n} cv_i}{n}, \quad i = 1, 2, ..., n \tag{5}$$

The consistency index CI, taking the maximal Eigenvalue into consideration, is calculated as follow:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

Here, when the difference between maximal Eigenvalue λ_{max} and n decreases, the consistency level CI gets rise until pairwise comparison matrix is completely consistent in which the situation $CI = 0$. In order to interpret the level of consistency, a *consistency ratio* (*CR*) is described as $CR = CI/RI$ in which the *RI* stands for the average random index (see Table 1). As long as *CR* is lower than 0,1 consistency of criteria weights are considered to be reasonable.

Table 1: Random consistency index

| r	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

Source: (Saaty, 1988, p. 21)

Step 5: Priorities regarding approximate importance degrees of criteria are identified. Then, ranks of alternatives are determined to what extent each of alternative performs in terms of every single criterion in total is calculated.

3. METHODOLOGY

The case study has been carried out on behalf of a medium-sized construction company (Özbekİnşaat, 2016) whose scope of activity is merely on the low-cost resident segment. Mode of its operation bases on "flat for land" manner. The objective of the study is to select the most appropriate residual construction site among 6 alternatives, all of which are in Pendik district of İstanbul. For this purpose, an AHP rating model has been proposed via SUPER DECISIONS software. Data basically collected from official GIS system of General Directorate of Land Registry and Cadaster (GIS, 2016), as well as market research.

Figure 1: Flowchart of Proposed Model
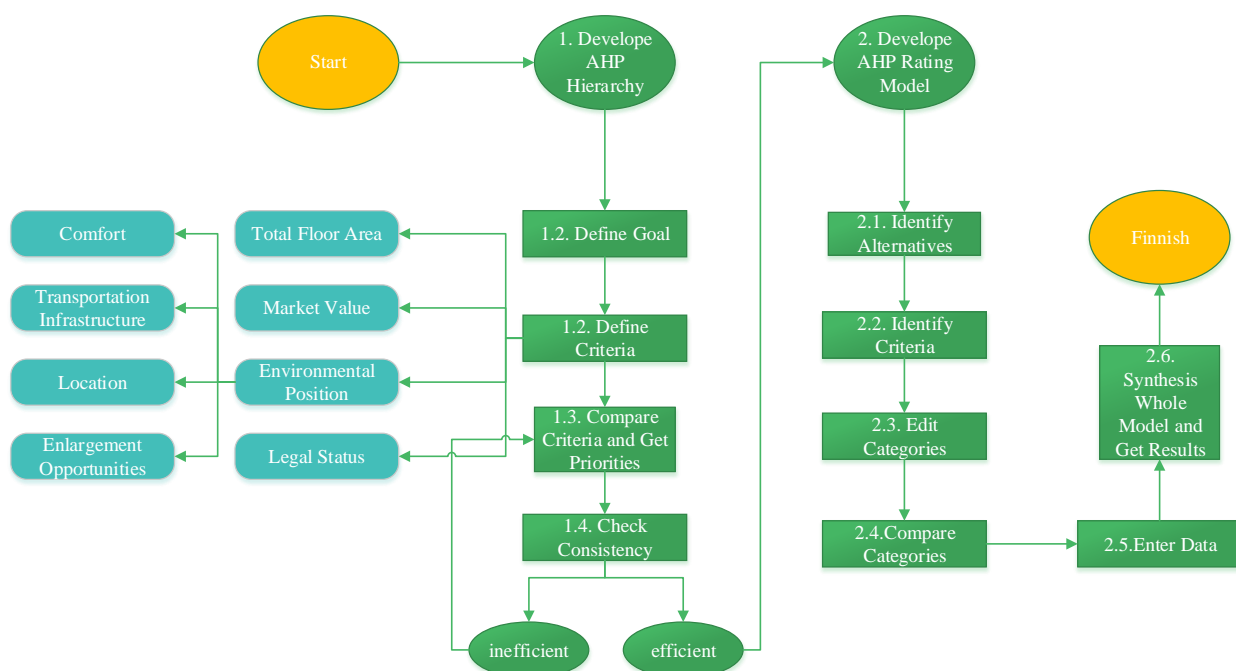
Source: Author

Figure 1 illustrates the process of decision making. This process basically consists of two main stages. At the first stage, the hierarchical frame of the proposed model including criteria and sub-criteria has been organized. Furthermore, reciprocal comparisons among criteria have been executed by experts that firm employed through group decision-making method so that ultimate priorities of criteria are clarified with respect to company's shared vision.

At the second stage, AHP rating model has been found. What makes AHP rating model distinguish from AHP relative model is that AHP rating model establishes standards for alternatives before the evaluation process; whereas AHP relative model reveals the relative superiority of one alternative against others through pairwise comparisons at the end of the evaluation process. The underlying advantage of AHP rating model is that it allows scaling in

editing categories stage and "direct data entry option" it facilitates in the stage of category comparison (Coşkun, 2015).

3.1. Factors Affecting Site Selection

Total Floor Area: This criterion compounds building coverage ratio (TAKS) and floor area ratio (KAKS) as it calculates scores for each alternative. What extent a site promises value depends on floor area ratio which verifies from site to site related to characteristic attributes i.e. being close to Sabiha Gökçen International Airport which diminishes the ratio due to security problems. These scores were then transformed into three level interval scale as they remain between 0-999 m^2; 1000-1999 m^2; above 2000 m^2 in AHP rating model.

Market Value: This criterion represents the average resident prices in the region that expectant alternative is placed over there. In other words, it is the market value of the site which mostly vary according to psychological factors, such as socioeconomic status of dwellers around there or reputation of the region in people's mind. What extent alternatives meet this criterion was scaled as low, medium and high.

Legal Status: This criterion explains whether or not legal regulations restrict the architectural and engineering range of motion. Certain regional specialties may cause such restrictions, for instance, close distance to earthquake fault lines. It scaled as "restricted" and "unrestricted" in the model. The first option is two times superior to the second option.

Environmental Position: This criterion describes remarkable attributions of the sites regarding what extent they assure life quality for dwellers in terms of environmental position. It also has four sub-criteria explained in follow:

- *Comfort*: This sub-criterion refers to characteristics of settlement plan of the environment, that is, whether the neighbor buildings stand so close to each other that they cover the perspective of the site or not. It was scaled as very poor, below average, above average, excellent.
- *Transportation Infrastructure*: This sub-criterion means if the distance from the location of the site to transportation points such as bus, tram or metro station is reasonable enough. It was scaled as poor, below average, above average, excellent.
- *Location*: This sub-criterion shows whether the site located on the main street or backstreet. Since main street locations are strongly preferred by customers, it was scaled as four-time superior to backstreet option.
- *Enlargement Opportunities*: It is rather technique issue as it represents for if there is another parcel adjoint to the site. Two options were defined in the scale as "available" and "unavailable". The available situation is decided as three-time superior to the unavailable situation.

3.2. Results

As it is shown in Table 2, the most important factor affecting the site selection decision is "Environmental Position" and the most important sub-criteria of which is "Comfort". Since consistency ratios are smaller than 0.10, they are both acceptable.

Table 2: Criteria Weights and Consistency Ratio

		Normalized Weights	Idealized Weights	Consistency Ratio
Criteria	1. Environmental Position	0,494	1,000	
	2. Total Floor Area	0,269	0,546	0,089
	3. Legal Status	0,082	0,166	
	4. Market Value	0,154	0,313	
Sub-criteria	1.1. Transportation Infrastructure	0,204	0,396	
	1.2. Enlargement Opportunities	0,156	0,302	0,078
	1.3 Location	0,124	0,239	
	1.4 Comfort	0,516	1,000	

Source: Author

Table 3 indicates performance measurements of alternatives on each criterion according to AHP rating scales determined before. Preference rank has derived from the appropriate combination of these measures and criteria weights within the concept of AHP algorithm.

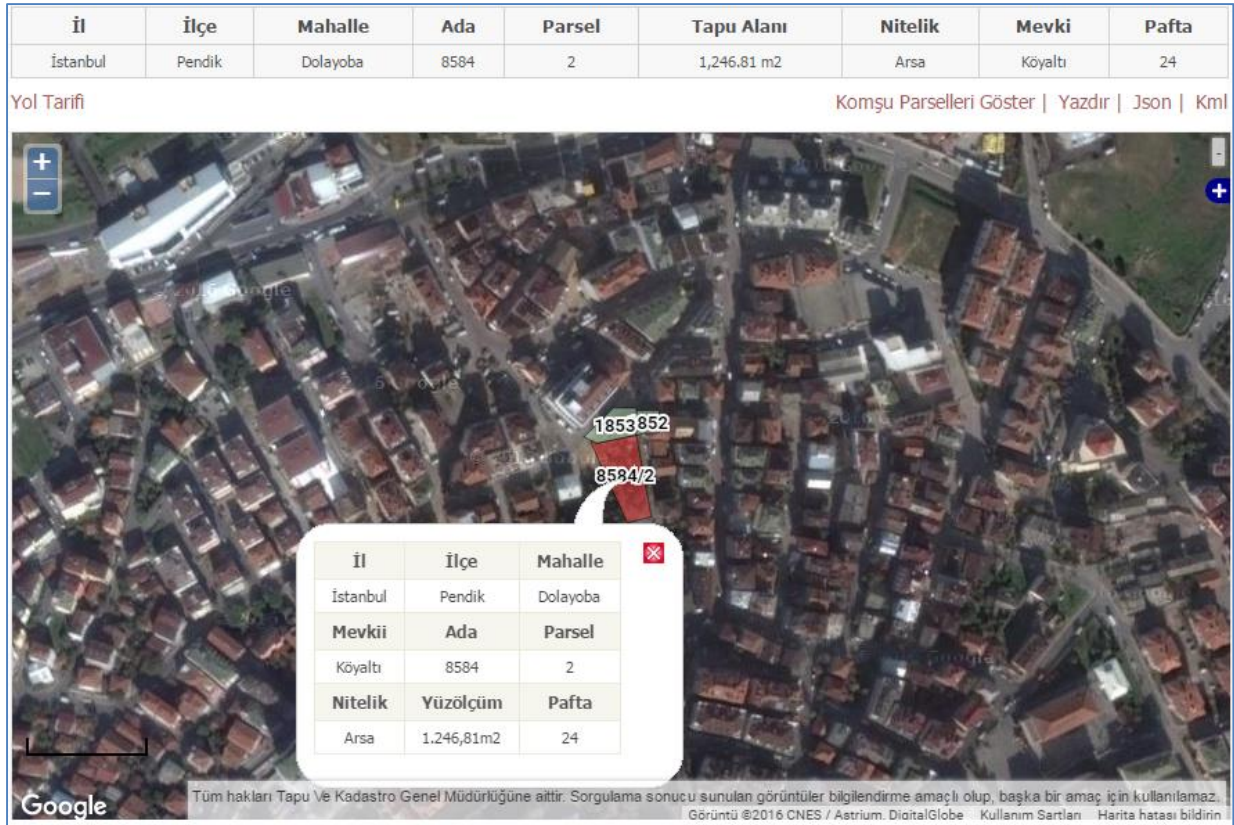### Table 3: AHP Ratings and Overall Synthesized Priorities

Criteria and Sub-criteria	Alternatives					
	0/2223	0/4359	1930/279	3165/11	3165/13	8584/2
1.Environmental Position						
1.1.Transportation Inf.	above average	excellent	excellent	above average	below average	above average
1.2.Enlargement Opp.	unavailable	available	unavailable	unavailable	available	available
1.3.Location	main street	main street	backstreet	backstreet	backstreet	main street
1.4.Comfort	above average	above average	excellent	excellent	below average	above average
2.Total Floor Area	0-999	0-999	1000-1999	1000-1999	0-999	above 2000
3.Legal Status	restricted	restricted	unrestricted	unrestricted	unrestricted	unrestricted
4.Market Value	high	high	medium	medium	medium	high
Normal Scores	0,157	0,167	0,174	0,168	0,123	0,211
Ideal Scores	0,744	0,793	0,822	0,796	0,581	1,000
Ranking	**5**	**4**	**2**	**3**	**6**	**1**

Source: Author

According to ultimate synthesis results, the most appropriate site is 8584/2 (block number / parcel number) with the 0,211 performance score. In figure 2, the selected site is presented with adjoint parcels namely enlargement opportunities, which derived from official GIS system.

Figure 2: Ultimate Decision

İl	İlçe	Mahalle	Ada	Parsel	Tapu Alanı	Nitelik	Mevki	Pafta
İstanbul	Pendik	Dolayoba	8584	2	1,246.81 m2	Arsa	Köyaltı	24

Source: (GIS, 2016)

4. CONCLUSION

The main objective of this paper is to develop a decision support model in order for a medium-sized instruction company can optimize the site selection decision for one of its residential projects. Thanks to the lack of efficient tools for gathering data in preliminary phases of the residual construction project, this study tries to compensate for a notable gap in the literature. No matter how complicated nature has the planning stage of any project, the proposed AHP rating model organizes and structures many sorts of tangible and intangible variables so that leaders can make the accurate decision for the benefits of company and customers. Thus, usage of this model during the early stages of projects may bring significant competitive advantage to operators.

In consequence of the study, it was found that criteria are ranked according to their priorities as Environmental Position, Total Floor Area, Market Value and Legal Status in descending manner. Considering the fact that Environmental Position versus Total Floor Area is strictly contradicted with each other, this position keeps some wise clues regarding the strategies that firms need to focus on. As the most important criterion, Environmental Position assures the life quality of settlers. It means what makes a residential project more "humanistic" should always come first in site selection decision. The thing promising more value in terms of primary humanistic needs is sufficient living space in the neighborhood as represented in Comfort sub-criterion. However, this space is restricted by Total Floor Area to some extent.

Firms normally attach a significant importance to Total Floor Area (TAKS and KAKS ratios) when making the site preference as to maximize the profit in a subsequent project. Thus, this criterion cares the benefits of firms, but not customers. Then, results acknowledge that being customer-oriented sometimes requires sacrificing substantial benefits in order that the strategy may bring more and more value in revenge across the long-term.

The criterion of Market Value is mostly derived from Environmental Position and Total Floor Area as a result of their combination. Hence, it is understandable that it pursues the first two criteria in priority level. On the other hand, Legal Status surprisingly has the smallest weight in all criteria. It indicates that decision-makers in project team dedicate relatively less importance to legal boundaries of site selection in their mind. It may arise from two potential reasons. The first reason may be that legal restrictions are not so stiff associated with regional attributions, that they affect site selection decisions in practice. Or else, legal restrictions can be stretch somehow to overlook the intervention of their unfavorable regulations. Considering the fact that Istanbul has certain risks i.e. associated with earthquake danger, in particular, the second scenario immensely threatens the future of the city. Therefore, policy-makers should take necessary precautions for these potential hazards.

The apparent limitation of the study is that only one MCDM method was used. However, the ranking could be compared with at least one another derived from different methods in that reliability of results are proved. It is also crucial that criteria worked in the model rather focus on firm's and customer's benefits, but social, cultural and environmental aspects of urbanization are ignored. However, it is not easy to ensure sustainable development in any branches of human life without underlying these points. For this reason, the model could be modified as it surrounds a larger outline of the problem in future researches.

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