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Decision making criteria for Optimal Selection of Innovative Daylighting Systems in Buildings, Using Integrated Delphi/Dematel/AHP Approach

Mostafa Gholipour Gashniani

Department of Architecture, Arts and Architecture, University of Mazandaran, Babolsar, Iran

Email: mostafa.gholipour4@gmail.com

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Abstract

Nowadays, dense cities have led towards the decrease of daylight penetration into the interior space. Daylight crisis in buildings brings significant challenges to architecture, in three domains of economic, health - wellbeing and environment. "Light well" as one of the most common means of daylight tolls in building, experiences severe limitations and requires special attention. The question is which strategy is the best for increasing the daylight penetration to the depth of buildings. One of the main challenges in deep plan is to guide daylight into the building core and this can be performed through daylighting strategies, but the choice of the proper innovative daylighting system (IDS) with several parameters is the problem. This paper aims to find elements for optimal choice and selecting context-compatible tools for light well. The result shows that four macro factors were found at the interaction of building and IDS. Identifying the integration components can play an effective role in decision-making or design a new tolls consistent with the physical conditions of light well and building to overcome the daylight crisis. The present study aimed to identify, evaluate, and weigh the factors affecting the selection of appropriate and innovative daylighting systems for buildings. To this end, a three-phase study was planned and carried out. In the first phase, the factors affecting the selection of daylighting systems for the building were screened and finalized by using the Delphi method in three steps. In the second phase, interactions between criteria and sub-criteria were evaluated by the DEMATEL technique and then the network of communications and significant relationship between them were determined. The analytic hierarchy process (AHP) was employed in the third phase to evaluate the criteria and determine their importance in the selection of daylighting systems. Finally, the relevant sub-criteria were extracted and prioritized. The results indicated that structural, economic, and technical criteria were more effective than functional criteria in the selection of daylighting systems for buildings.

Keywords: *Daylighting; Innovative Daylighting System, System Selection, Deep Plan Buildings*

1. Introduction

Considering the escalated crisis of daylight in buildings and in order to increase the use of natural light, new daylighting systems have been designed to deliver natural light to parts of the buildings which are beyond the range of window functions [1], [2]. Given the multitude of parameters involved, the selection of appropriate optimal daylighting systems for buildings has always been a challenging process [3], [4], [5]. Review studies have shown that, in addition to light performance, many other parameters are involved in the evaluation and selection of such systems for buildings. Failing to consider the internal and external criteria will result in the non-compliance of daylighting systems with buildings [6], [7], [8].

Many research have been conducted in this field to evaluate the effect of parameters namely, Pazhoohesh et al. have studied in thermal comfort by image processing [9-11], Ghayouraneh has worked on ODM method to evaluate On-Demand Mobility [12-14]. Therefore, different methods have been used to evaluate the problem like neural network [15-16] and wireless sensor networks [17-19].

Given the importance of the subject and the potential of innovative daylighting technologies in promoting the lighting efficiency of buildings, it is necessary to discover the challenges of selecting the right daylighting tools to pick the one out of the many technologies that proves compatible with the conditions of the platform on which it is implemented. Hence, a comprehensive review study was conducted on the daylight crisis in buildings in order to identify the criteria affecting the compatibility of new daylighting systems with buildings [20], [21]. Accordingly, the factors affecting the performance of daylighting systems were extracted and classified under 4 major areas and 7 aspects. The 4 major areas include performance, utilization, building compatibility, and social, and each of them can be evaluated in a variety of aspects by its corresponding criteria. Finding the proper research methodology to analyze and evaluate the criteria and to determine the role of each in the compatibility of systems and buildings would be the focus of the study.

2. Methodology

The present research was an applied, descriptive-analytical study. The criteria and sub-criteria were evaluated using the Delphi method in the first phase and then an initial model was proposed. In the next phase, AHP was employed to evaluate the criteria and determine their weight. To this end, a three-level model of the criteria and sub-criteria affecting the selection of compatible daylighting systems for buildings was developed. Then, a questionnaire was developed and distributed among the experts to perform pairwise comparisons and determine relationships between criteria and sub-criteria. Finally, the data collected from questionnaires and prioritization of criteria and sub-criteria were analyzed in Super Decisions.

3. Research Phases

3.1. First stage: Classification of criteria

At this stage, the Delphi method was used to classify and consolidate the criteria and sub-criteria affecting the selection of optimal and compatible daylighting systems for buildings. Based on their expertise and in compliance with the effective criteria (performance, utilization, building compatibility, and social platform), the decision-making experts were selected using non-random and purposive sampling. Finally, a total of 20 academic and executive experts in the research area were selected as the sample [22-25].

The data obtained from questionnaires were statistically analyzed in SPSS. The student's t-test, the Friedman test, mean, and the mean difference in the first stage, Kendall's W and the Chi-square in the second stage, and student's t-test, the Friedman test, and mean in the third stage were performed and calculated (Table 1).

Table 1 - The one-sample t-test and the Friedman test outputs (Questionnaire 3)

result	Mean diff	Average rating	average	Sub-Criteria	Criteria
confirm	0.00	16.44	4.6250	**Light distribution**	**Daylight quantity**
confirm	0.00	9.25	3.6250	**Amount of illuminance**	
confirm	0.125	14.63	4.3750	**IR resistance**	**Daylight quality**
confirm	0.00	14.75	4.3750	**Perception daylight possibility**	
confirm	0.00	16.44	4.6250	**Daylight distribution over time**	
confirm	0.00	14.56	4.3750	**Daylight distribution over space**	
confirm	0.125	9.88	3.7500	**Glare**	
confirm	0.00	6.63	3.2500	**Initial cost**	**Economical**
confirm	0.00	12.75	4.1250	**Maintenance cost**	
confirm	0125	6.13	3.3750	**Ease of Installation**	**Technical**
confirm	0.00	11.13	4.0000	**Ease of maintenance**	
confirm	0.00	9.50	3.7500	**Maturity**	
confirm	0.00	9.13	3.7500	**Reliability**	
confirm	0.00	10.19	3.8750	**Technology challenges**	
confirm	0.125	6.88	3.250	**Safety - Fire hazard**	
confirm	0.00	7.88	3.6250	**Sky condition**	
confirm	0.00	16.44	4.6250	**Building shape Compatibility**	**Quantitative Compatibility**
confirm	0.00	13.81	4.2500	**Structural Compatibility**	
confirm	0.00	12.13	4.0000	**Mech. Elec. Compatibility**	
confirm	0.125	10.44	3.8750	**Form Compatibility**	**Qualitative Compatibility**
confirm	0.00	15.63	4.5000	**Interior Compatibility**	
confirm	0.125	8.44	3.6250	**City image Compatibility**	

The results showed that the value of Kendall's W increased compared to the second round of the Delphi method. In this phase, 6 criteria and 22 sub-criteria were agreed upon by experts based on the statistical analysis of the median test. Like the previous steps, the level of agreement between experts was measured by calculating the mean difference of stages 2 and 3. If the calculated difference was smaller than 0.2, the Delphi method was stopped [26]. As shown in Table 1-1, the mean difference (0.125) was smaller than 0.2. Therefore, the intended consensus was achieved, and the Delphi method was stopped in the third round. Accordingly, daylight quantity, daylight quality, economic issues, technical issues, quantitative compatibility, and qualitative compatibility were picked by the experts as the most important criteria affecting the selection of daylighting systems for buildings.

3.2 Second Stage: Prioritization of Criteria

In this study, AHP was employed to determine the weight of criteria and sub-criteria. For this purpose, the criteria were compared in pairs based on the research objective. The geometric mean was used to summarize the views of experts and determine the final weight of criteria. The next step was to calculate the geometric mean of each row to determine the weight of the criteria

$\pi_1 = 2.239.\ \pi_6 = 1.031\ \pi_5 = 1.368\ \pi_4 = 0.876\ \pi_3 = 0.353\ \pi_2 = 1.250$

Since the inconsistency rate of pairwise comparisons (0.082) was smaller than 0.1, the results of pairwise comparisons were found reliable. (Table 2).

Table 2 - Prioritization of criteria

Daylight quality	Daylight quantity	Qualitative Compatibility	Quantitative Compatibility	Technical	Economical	Daylight quality	Daylight quantity	
0.378	2.6868	2.6076	3.4524	3.8676	5.1576	1.746	1	**Daylight quantity**
0.2112	1.5	1.4676	1.1856	1.8288	3.6108	1	0.687	**Daylight quality**
0.06	0.4236	0.2724	0.3576	0.4476	1	0.3984	0.233	**Economical**
0.1476	1.0512	1.1904	0.9996	1	3.2184	0.7872	0.310	**Technical**
0.2304	1.6416	1.6728	1	1.4412	4.0272	4.0272	0.348	**Quantitative Compatibility**
0.174	1.2372	1	0.8604	1.2096	5.2956	0.9816	0.460	**Qualitative Compatibility**

3.3 Third Stage: Determination of Relationships between Criteria

The DEMATEL technique was employed to evaluate internal relationships between the criteria (Table 3).

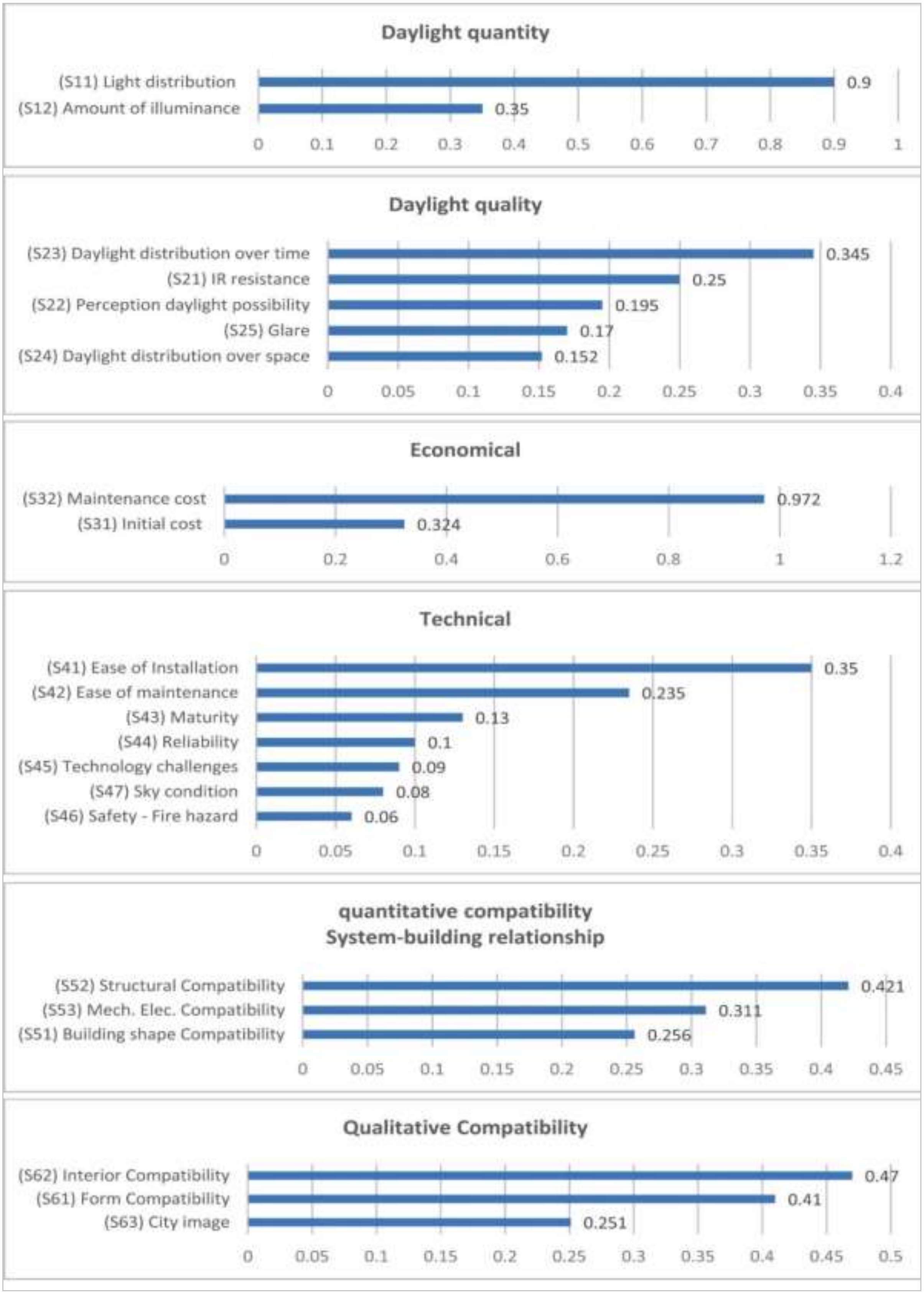
Table 3 - A matrix of all relationships between the criteria

Qualitative Compatibility	Quantitative Compatibility	Technical	Economical	Daylight quality	Daylight quantity	
0.3542	0.3674	0.6006	0.6479	0.517	0.3333	**Daylight**
0.3684	0.3828	0.6252	0.702	0.3504	0.522	**Daylight**
0.4995	0.5175	0.63	0.5328	0.5058	0.5148	**Economical**
0.6104	0.6482	0.5866	0.8764	0.5838	0.5992	**Technical**
0.6448	0.4329	0.7254	0.7904	0.4264	0.4316	**Quantitative**
0.2499	0.40885	0.4012	0.4845	0.25755	0.2601	**Qualitative**

Network relation map (NRM): To determine the NRM, it is necessary to calculate the threshold value. In this study, the threshold value was 0.457. Economic and technical criteria were considered the dependent variables and other criteria were regarded as the independent criteria. Among the effects, economic criteria exhibited the highest interaction with other research criteria. In addition, technical criteria were highly affected by other criteria.

Comparison and prioritization of sub-criteria: In the third phase, the sub-criteria of each criterion were compared in pairs (Fig. 1)

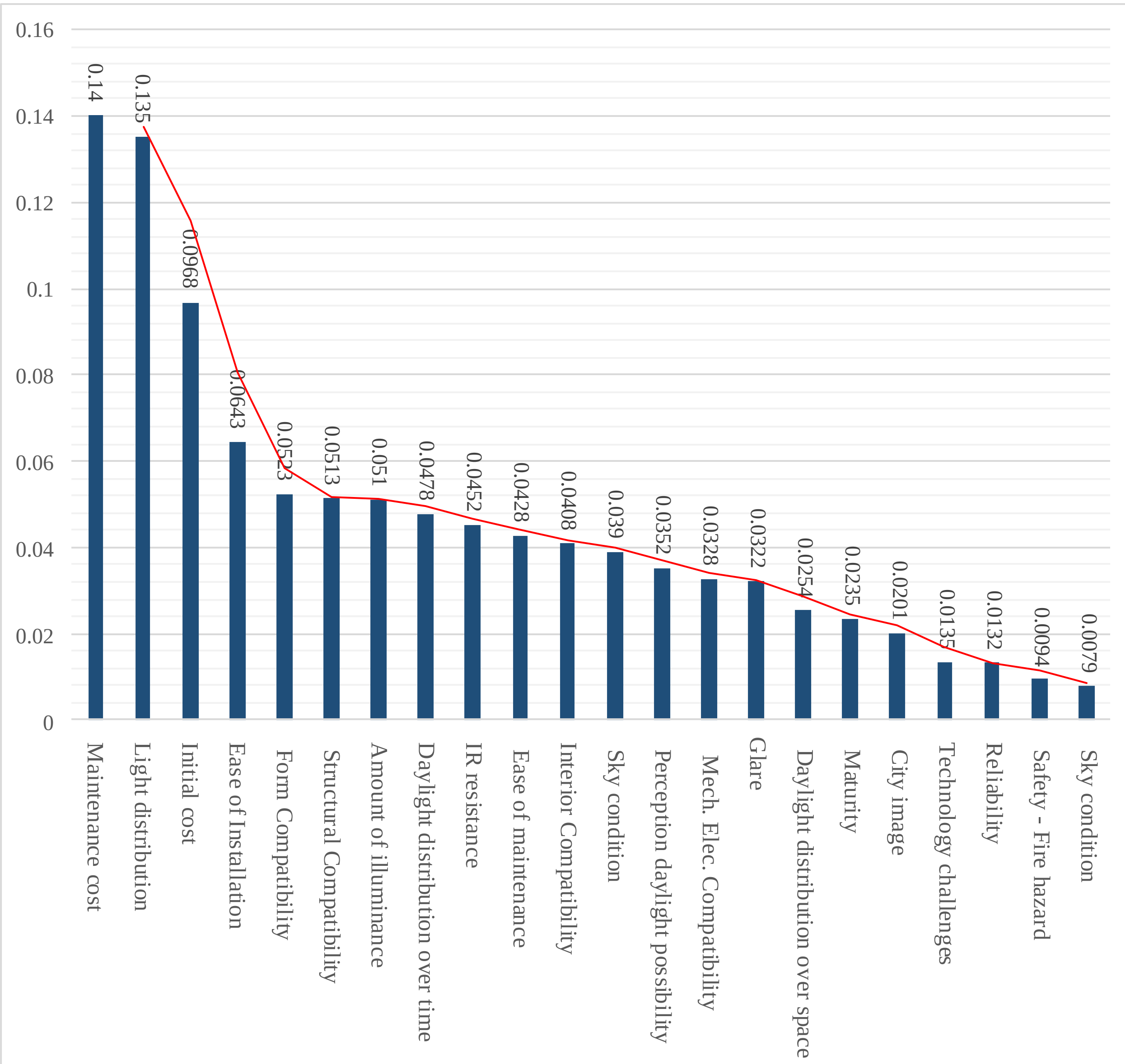
Fig.1 - Prioritization of sub-criteria



Relationships between sub-criteria: The DEMATEL technique was used to show internal relationships between the sub-criteria, like the previous step. The threshold value in the NRM was obtained at 0.41.

Determination of the final weight of criteria by AHP: To calculate the uneven supermatrix, the output of the pairwise comparison of criteria based on the objective and internal relationships between them was presented in a supermatrix. The network model was designed by using AHP in Super Decisions. The final prioritization of criteria based on the supermatrix is shown in Fig. 2.

Fig. 2 - Final prioritization of criteria based on AHP results



This figure shows that, in addition to the promotion of qualitative-quantitative efficiency, many other parameters should be taken into account by architects in the evaluation and selection of optimal daylighting systems for buildings. Inattention to these parameters will result in the non-compliance of daylighting systems with buildings. The results demonstrated that “maintenance cost”, with a normal weight of 0.14, “light distribution”, with a weight of 0.135, and “final cost”, with a weight of 0.0985, ranked first to third in terms of importance in the optimal selection of daylighting systems for buildings.

4. Analysis of Findings and Conclusion

4.1 Performance Criteria

The results showed that performance criteria (light quality and quantity) were more important than other criteria in the selection of optimal and compatible daylighting systems for buildings. This conveys the message to technological designers that they should seriously consider qualitative and quantitative computability and economic and technological issues in order to customize daylighting systems for buildings with different conditions. In fact, mere estimation of efficiency, which has been considerably dealt with in recent studies on technological areas, cannot guarantee the proper function and performance of daylighting systems in buildings.

The results also indicated that “light distribution”, as one of the sub-criteria of light quantity”, was the second important factor in this regard with a weight of 0.135. This shows that architects evaluated “quantitative lighting” more important than other light quality parameters considering the lighting quality crisis in deep plan buildings. In this study, “light intensity”, with a weight of 0.051, had the lowest rank among the sub-criteria of light quantity. Among the sub-criteria of light quality, “daylight distribution over time”, with a weight of 0.0478, had the lowest rank.

The above-mentioned findings suggested that the quantity of distributed light was more important than its quality in the selection of optimal and compatible daylighting systems for buildings.

4.2 Structural Criteria

The results indicated that structural criteria were ranked higher than performance criteria in the selection of daylighting systems for buildings. This reveals the need for guidelines and standards in the field of construction in various dimensions that lead to changes in geometrical dimensions, structures, installations, form, interior space, and urban landscapes in order to make new systems compatible with buildings. However, one-way computability of tools with buildings has caused them to turn into a non-integral and posed many challenges for architects. This two-way interaction will require architecture to provide the necessary platform for the adoption of new daylighting systems. In addition, new systems should be modified in a way to be compatible with different dimensions of a building.

“Geometric computability” or “Building shape computability”, with a weight of 0.0532, was ranked first among the sub-criteria of structural criteria. This indicates the major role of architecture in the compatibility of new systems with buildings. The second rank was related to “interior computability”, with a wright of 0.0408. “Form computability”, with a weight of 0.0523, ranked third. This emphasizes the role of architecture in the computability of tools with buildings. The fourth and fifth rankings among the structural criteria belonged to “mechanical=electrical computability”, with a weight of 0.0328, and “structural computability”, with a weight of 0.0513, respectively. These results suggest that the computability of innovative daylighting systems with buildings is more dependent on internal functional criteria) light quantity and quality) rather than external criteria (technical, structural, and economic).

4.3 Economic Criteria

The results indicate that “maintenance cost”, with a weight of 0.14, was the most important economic sub-criteria affecting the computability of daylighting systems with buildings. This shows that the construction experts believe that new daylighting systems are semi-active and static elements of a building and, as a result, reduction of maintenance cost can increase their computability. This finding can provide solutions in three different areas; development of new systems with low maintenance cost and technological complexity as well as development of semi-static systems in the area of technological design, establishment of incentive policies to pay for maintenance costs in order to increase the computability of such systems in the area of governments and institutional policymakers, and providing free maintenance services in the early stages of operation to increase the level of adoption and computability of new construction systems in the area of investors and developers.

4.4 Technical Criteria

The results demonstrated that “ease of installation”, with a weight of 0.0643, and “ease of maintenance”, with a weight of 0.0428, were the most important technical sub-criteria from the perspective of architects and beneficiaries. This indicates the high sensitivity and importance of the technical issues directly related to building users and technical experts.

4.5 Plug and Play

This is a generally accepted and widely investigated rule in the field of construction technology. This rule aims to make technologies “user-centered” and bridge the gap between “product preparation” and “operation”. The weight difference between “ease of installation” and “ease of maintenance”, which are among the indicators of user-centrism and expert-centrism, was one of the interesting results of this study.

Conclusion

The present study aimed to identify, evaluate, and weigh the factors affecting the selection of appropriate and innovative daylighting systems for buildings. To this end, a three-phase study was planned and carried out with regard to comprehensiveness and continuity of the process. In this study, the position and weight of relevant criteria and sub-criteria affecting the selection of innovative daylighting systems and the relationship between them were investigated. The results indicated that structural criteria (quantitative computability: geometry, structure, and mechanical-electrical facilities, qualitative computability: form, space, urban landscape), technical criteria, and economic criteria were evaluated more effective than performance criteria (light quality and quantity) in the selection of optimal daylighting systems for buildings.

The study findings suggest practical recommendations to planners and policymakers in order to develop the rules and regulations to provide conditions for the adoption of appropriate systems compatible with the study platform. The results can also help daylighting technology designers or technology transfer specialists to achieve a list of criteria and priorities in order to develop, construct, and redesign new daylighting technologies tailored to the features of each region. Finally, energy investors and policymakers can apply the study findings to achieve a new structure for evaluating appropriate systems for different conditions.

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