The Fuzzy AHP approach for intelligent building assessment model

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Abstract

The main objective of this thesis is to probe into how Taiwanese building investment and development companies rate the analytical framework and weights of artificial intelligence buildings. Document Analysis, the Delphi method, and the Fuzzy Analytic Hierarchy Process (FAHP) are applied to conduct a FAHP questionnaire survey among 20 building investment and development companies in Tainan. Based on the calculation of composite weights, the findings are: (1) The most crucial evaluation indicator for security and hazard prevention is the "access control system". (2) The most crucial evaluation indicator for energy-saving management is "energy-saving technology". (3) The most crucial evaluation indicator for health and comfort is the "interior comfort system". (4) The most crucial evaluation indicator for intelligent innovation is the "intelligent innovation concept".

Keywords: Intelligent Building, Fuzzy Analytic Hierarchy Process, Expert Decision Evaluation

1. Introduction

In the 21st century, humankind is facing the problems of global warming, climate change, urban overdevelopment, and the greenhouse effect, which have led to high global temperatures, depletion of forests, destruction of the ozone layer, and the frequent occurrence of extreme weather phenomena. As humankind is unable to resist the relentless forces of nature, in order to mitigate the damage to the earth's environment and pursue the goal of global sustainable development, many developed countries have embarked on the construction of intelligent and sustainable cities, and further developed the concept of Intelligent Buildings (IB). Therefore, the main reason for the growing trend of intelligent buildings in Taiwan and abroad is the transition of the human living environment.

This thesis proposes two connotations for intelligent buildings. One is to create a human living space based on a combination of green architecture and green building materials, which must provide users with safer, healthier, more convenient, comfortable, and energy-efficient living environments. The second is to introduce the concept of Intelligent Innovation into the planning and design of buildings to create a new value of intelligent buildings. The introduction of intelligent systems and devices helps maintain and extend the life cycle of buildings, and provides the best solution to the energy consumption of buildings.

Objectives of this study are to:

(i) Construct an initial hierarchical structure of intelligent building evaluation models, as based on the theories described in the Intelligent Building Evaluation Manual.

(ii) Adopt an expert decision-making approach to evaluate the analytical framework of intelligent buildings and construct a definitive hierarchical structure of intelligent building evaluation models.

(iii) Apply AHP to calculate the respective weights of the 4 primary dimensions and 12 evaluation indicators of the intelligent building evaluation model.

2. Literature Review

The term "Intelligent Building" originated in the late 1970s and early 1980s with the emergence of an intelligent building that was converted from an old financial building in 1984 in Hartford City, Connecticut, USA. The following year, the Aoyama Building in Tokyo, Japan further improved the functionality of building intelligence, and maintained that a highly functional building is an intelligent building. These intelligent concepts of creating human living spaces through automated technology have not only created a new vision of architecture, they have also given rise to new architectural terms, such as intelligent buildings, intelligent houses, intelligent communities, and intelligent cities.

Based on the requirements of the main occupants and building facilities, intelligent buildings can be classified as automated buildings, intelligent homes, green buildings, efficient buildings, and energy efficient buildings that exchange with the grid[1-3]. Automated buildings focus on building electrics and automated mechanical facilities, while intelligent homes emphasize the design of a user-friendly environment for the occupants. Green or sustainable building study is centered on the creation of a productive interior environment and an environmentally friendly journey through the life cycle of a building, from its design, construction, and operation, to maintenance, renovation, and demolition. The study of energy-efficient buildings also focuses on the full life cycle of a building, in order to minimize energy consumption over that period.

Dounis et al. reviewed the control systems built up to 2008, and proposed a framework to analyze intelligence-led energy and comfort control systems[4]. Shaikh et al. reviewed the building control systems optimized up to 2013, which were divided into intelligent controllers and intelligent methods of managing energy and comfort calculations[5]. Nguyen et al. reviewed, analyzed, and classified the different building optimization problems, as well as the algorithms, tools, and operations used to optimize building energy management systems until 2013[6]. Evins et al. encapsulated the construction, operation, and energy production of intelligent and sustainable buildings for design and control systems until 2012[7].

For building developers, the key reason for introducing intelligent systems and devices is cost, hence, it is essential to understand what design requirements can satisfy an intelligent home. The 2016 edition of the Intelligent Building Standards Evaluation Manual includes eight evaluation criteria, incorporates convenience features into health and comfort, and adds intelligent innovation.

3. Evaluation Model Building for Intelligent Buildings

3.1. *Hierarchical Structure*

This thesis combines the results of two rounds of Delphi questionnaires to construct a definitive hierarchical structure for the intelligent building evaluation model, which consists of 4 primary dimensions and 12 evaluation indicators, as shown in Figure 1.

3.2. *Subject of this study*

In order to investigate how Taiwanese building investment and development companies rate the analytical framework and weights of intelligent buildings, this thesis took the building developers in Tainan as the study subject, and 8 experts were selected for the Delphi method and 20 for the FAHP questionnaire. In addition, prior to the FAHP questionnaire survey, the researcher first explained the objective of this thesis to the FAHP questionnaire subjects, and conducted the FAHP survey among building developers who were willing to participate.

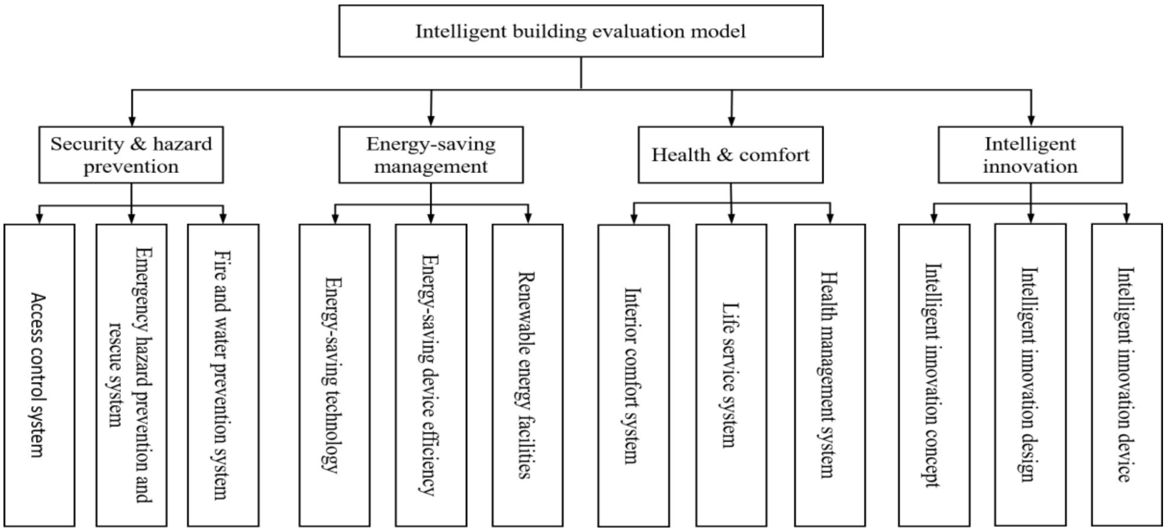

Fig. 1. Intelligent building evaluation model

4. Empirical Study of the Intelligent Building Evaluation Model

In this thesis, 9 evaluation indicators are multiplied by their respective dimensions to obtain the composite weights. Table 1 presents the composite weights of the intelligent building evaluation model.

As indicated in Table 1, the most crucial evaluation indicator, as perceived by the 12 building developers, is the "access control system" (with the composite weight of 0.235), and "energy-saving technology" (with the composite weight of 0.175) is ranked 2nd. The 3rd indicator is the "emergency hazard prevention and rescue system" (with the composite weight of 0.102), 4th place is the "interior comfort system" (with the composite weight of 0.085), and 5th is the "intelligent innovation concept" (with the composite weight of 0.073). Ranked from 6th to 12th place, respectively: "energy-saving device efficiency" (with the composite weight of 0.064), "fire and water prevention system" (with the composite weight of 0.061), "renewable energy facilities" (with the composite weight of 0.060), "life service system" (with the composite weight of 0.053), "intelligent innovation design" (with the composite weight of 0.034), "intelligent innovation device" (with the composite weight of 0.030), and "health management system" (with the composite weight of 0.028).

Table. 1. The composite weights of the intelligent building evaluation model

Dimension	Weight	Evaluation Indicator	Weight	Composite Weight
Security & hazard prevention	0.375	Access control system	0.593	0.235
		Emergency hazard prevention and rescue system	0.257	0.102
		Fire and water prevention system	0.150	0.061
Energy-saving management	0.303	Energy-saving technology	0.588	0.175
		Energy-saving device efficiency	0.232	0.064
		Renewable energy facilities	0.180	0.060
Health & comfort	0.164	Interior comfort system	0.495	0.085
		Life service system	0.237	0.053
		Health management system	0.178	0.028
Intelligent innovation	0.158	Intelligent innovation concept	0.622	0.073
		Intelligent innovation design	0.246	0.034
		Intelligent innovation device	0.132	0.030

5. Conclusions

The four key findings of this study are listed below:

5.1. *The most crucial evaluation indicator for security and hazard prevention is the "access control system"*

Building developers considered "Security and hazard prevention" as the most crucial dimension, with "access control system" being the most significant. This finding is aligned with the results of a survey conducted by the Taiwan Architecture & Building Center and the Taiwan Intelligent Building Association in 2013 regarding the "Application of Intelligent Building Adoption in

Taiwan". For the public, whether they choose a traditional or intelligent building, the primary evaluation factor is whether life and property are protected. It is also worth noting that the added value of intelligent homes is ex-ante proactive prevention of hazards by using various modern technologies to make homes intelligent, which allows for both burglary and hazard prevention, thereby reducing the chance of hazards occurring in homes, as well as minimizing the loss of life and property.

5.2. *The most crucial evaluation indicator for energy-saving management is the "energy-saving technology"*

Building developers considered "energy-saving management" as the second most crucial dimension, with "energy-saving technology" being the most significant, which implies that the majority of building developers agree that the application of energy-saving management systems in intelligent homes is both an important design trend and a major marketing pitch. This is probably due to the fact that energy-saving is an important indicator for evaluating whether an intelligent home can achieve significant energy savings after the introduction of energy-saving devices, such as intelligent air-conditioning and lighting with intelligent energy control technology. In other words, in addition to the need for ex-ante proactive prevention of burglary and hazard, the main consideration for intelligent homes includes the benefits of using energy-saving devices, such as economic efficiency and energy-saving effectiveness.

5.3. *The most crucial evaluation indicator for health and comfort is the "interior comfort system"*

Building developers considered "health and comfort" as the third most crucial dimension, with the "interior comfort system" being the most significant, which is probably because the main objective of intelligent buildings is to create a safe, comfortable, and healthy home environment. This objective relies heavily on the integration and linkage between the respective automated systems and energy-saving devices; for example, through intelligent technology, people can remotely activate or set a fixed time to switch on the power, which allows intelligent air conditioning to create a comfortable living environment, and people can enjoy cool air when they return home.

5.4. *The most crucial evaluation indicator for intelligent innovation is the "intelligent innovation concept"*

Building developers considered "intelligent innovation" as the least crucial dimension, with the "intelligent innovation concept" being the most significant. The main reason for this is the recent surge of intelligent cities across the world, and the increasing popularity of intelligent systems and devices, which indicates that many people have a certain level of understanding of the concept of intelligent buildings, including security, energy saving, health, and comfort.

References

1. J. Wong, H. Li, S. Wang, Intelligent building research: a review, Autom. Constr. 14 (1) (2005) 143–159.
2. M. Wigginton, J. Harris, Intelligent Skin, Architectural Press, United Kingdom, 2002.
3. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Grid-interactive Efficient Buildings Technical Report Series- Whole-Building Controls, Sensors, Modeling, and Analytics, US Department of Energy, December 2019.
4. A.I. Dounis, C. Caraiscos, Advanced control systems engineering for energy and comfort management in a building environment - a review, Renew. Sustain. Energy Rev. 13 (2009) 1246–1261.
5. P. Shaikh, N. Nor, P. Nallagownden, I. Elamvazuthi, T. Ibrahim, A review on optimized control systems for building energy and comfort management of smart sustainable buildings, Renew. Sustain. Energy Rev. 34 (2014) 409–429.
6. A.T. Nguyen, S. Reiter, P. Rigo, A review on simulation-based optimization methods applied to building performance analysis, Appl. Energy 113 (2014) 1043–1058.
7. R. Evins, A review of computational optimisation methods applied to sustainable building design, Renew. Sustain. Energy Rev. 22 (2013) 230–245.

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