Selecting the appropriate Smart Materials using Multi-criteria decision AHP in Hot and Dry climates (Case study: Central Iran)

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ABSTRACT— ***Nowadays, with introduced modern systems and new materials in building construction industry and competitiveness, the decision to apply the most appropriate structural system in semi-traditional architecture system of the project is not easy for architects who don't have enough information about smart material performance in each climate. During designing and performance, it is one of the major challenges in engineering and construction management especially in Iran. Appropriate Smart Materials could be selected on many and varied criteria such as economics, social and technical bases. As regards, the modern manufacturing techniques have benefits such as, product standards, durability and stability, quality components, speed of implementation, lower cost compared with traditional systems, easy assembling and dismantling , they need using professional, semi-skilled and skilled worker to decrease energy consumption, flexibility of design and architecture. Considering to the history of Iranian Architecture and varied climates in Iran, selecting of smart materials is a complicated issue. However, other factor such as providing users' comfort is necessary, too. Since smart materials are so varied and each of them reacts to different external stimulus, smart materials which have been chosen in this paper are sensitive to sunlight due to central Iran's climate specifications. After introducing the smart materials, they have been evaluated with criteria such as sustainability, environmental and saving energy bases, lifetime, durability and economical factors. In addition, the final decision has been made with regard to the opinions of experts and decision-makers including, consultants and contractors based on fuzzy multi-criteria decision making method AHP. Finally, with this method, some of materials which were evaluated as best will be recommended for hot and dry climates in Iran.***

Keywords— Smart materials, Hot and dry climate, AHP decision, Adaptive Architecture

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1. INTRODUCTION

In a large part of Iran, which is located in a dry belt, the climate is hot and dry. Most of these areas have high temperature, so it is required to control the sunlight, radiation and the high temperature which causes by the light, despite the sun it is a great source of energy and could be converted in to the other format of energies.

Moreover, consumption of fossil fuels and the resulting pollution and climate change have become a problem for human societies**.** Constructions in cold weather need to maintain the temperature and should have a strategy for preventing internal heat loss, as well as in the warm weather, they also need to control the indoor air flow and prevent energy loss. According to purpose of sustainable architecture, which guides designers and architects to emphasize the minimum use of energy consumption, using of renewable materials, energy conservation and renewable non-polluting will be necessary. Smart materials are one of the best tools to reach these goals. Buildings are a kind of technology and they could use technology to provide a comfortable, secure and energy-conscious environment. Although, according to the variety of smart materials, in this paper, the application of one kind of smart materials in this climate will be discussed.

1.1 Methodology selection

For choosing proper smart material, many methodologies have been proposed, including modelling methods, Simulation and analytical hierarchy process (AHP). Choosing materials with multi- criteria is not easy and needs professional decision making. The analytic hierarchy process (AHP) is a structured technique for organizing and analysing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s [1]. In AHP process there are some alternatives (here these are smart materials) that will be evaluated with some criteria (such as adaptive criteria, saving energy and other sustainable criteria). At the end the evaluated materials will be presented for designers and architects.

1.2 Order allocation

In the process of choosing proper smart materials, after first level (choosing smart material who are sensitive to light stimuli), the most important criteria should be selected. By analyzing the hot and dry climates (in Iran) and users' needs for having comfortable living, the most criteria will be determined. In next level, the materials that are in this group will be evaluated with certain criteria such as sustainable architecture, climate factors, saving energy, materials potential, etc.

2. Problem Description

In the past, materials were used only as a tool to construct. But today there are different expectations about materials; they are not only a means of construction, but also the response of users' needs. On the other hand, the demands of users in each climate can be different. In Iran, most parts of dry and hot areas are located in the east and the central part. Winters in these regions, are very cold and summers are very hot. Rainfall is very low and temperature difference between day and night is enormous. So, the materials which are used in these weather conditions should vary with the other ones. Although, a variety of smart materials is enormous, but selected smart materials in this research, should have proper response to one or more external stimulus and had to providing users convenient, other necessary factors (such as cost estimates, availability of materials, reducing energy consumption, harmony with the environment and culture).

Therefore, selecting the proper materials for these climates becomes crucial. This study proposes a model to handle proper order based on potential materials ranking.

3. AHP methodology

The application of advanced technologies, based on smart materials, has the capacity to significantly improve the sustainability of buildings by focusing on phenomena and not on material artefact [2].

The method of AHP is based on three principles: the model constructs pairwise comparisons of criteria, finding the weight of each criterion and determining the preferred alternatives. In the first step, a complex decision problem will construct as a hierarchy [3]. The hierarchy of at least three levels: the general purpose of the question above (goal), in mid-level, multiple criteria which will evaluate alternatives (criteria) and decision alternatives at the bottom (alternative). In the process of evaluation, method of AHP modeling is considered three important keys (Fig. 1).

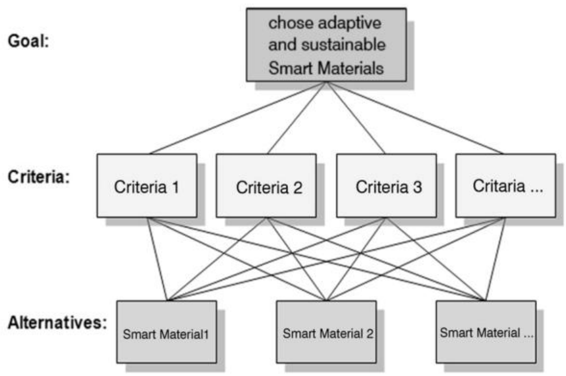


Figure 1: General hierarchy for Smart materials selected.

1–Goal: the purpose of the assessment and evaluation.

2–Alternatives: options proposed to evaluate and compare with the each other's.

3-Criteria: the criteria for evaluation, that each of them can have one or more sub criteria.

After analyzing the hierarchical structure, the second stage is to compare alternatives with specific criteria. For this level, for converting the quality to quantity, the importance intensity is shown by number (Table 1). Then, paired judgment begins at the second level and finishes at the lowest level where all the alternatives are there. In this process, every two alternative due to their impact will compare with one criterion as pairwise comparison. Multiple pairwise comparisons are performed according to the following scale [3].

Table 1: The fundamental scale of absolute numbers [4].

Intensity of importance	definition
1	Equal Importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

Table 2: Smart materials with similar stimuli, which are chosen for evaluation [5].

Type of smart material		INPUT	OUTPUT	EXPECTATIONS
Property changing	Thermochromics	Temperature difference	Color change	Control of solar radiation transmitting
	Electrochromics	Electric potential difference and Temperature difference	Color change	Control of solar radiation transmitting
	Liquid crystals	Electric potential difference and Temperature difference	Color change	Control of solar radiation transmitting
	Photochromic	Radiation (Light)	Color change	Control of solar radiation transmitting
	Thermotropic	Temperature difference	Color change	Control of solar radiation transmitting
Exchange Energy	Thermoluminescent	Temperature difference	light	Control of interior heat generation
	Thermostrictive	Temperature difference	Transformation	Control of conductive heat transfer
	Photostrictive	Radiation (Light)	Transformation	Control of conductive heat transfer
	Phosphorescence	Radiation (Light)	light	Use of saved light
	Photoluminescent	Radiation (Light)	light	Control of interior heat generation
	Photovoltaic	Radiation (Light)	Electric potential difference	Control of conductive heat transfer
	Photoelectric	Radiation (Light)	Electric potential difference	Control of conductive heat transfer

3.1. Goal

To enhance building's respond and comfort, firstly the smart materials should be classified in commercially world. As is clear from the title, the goal of this research is to provide the most appropriate smart materials for dry and hot climate in Iran due to Iranian architectural factors.

3.2. Alternatives

"Smart, intelligent, selective, adoptive and active" all of them are attributed to the materials that can respond to the outer stimulus [5]. Smart materials properties are designed to have active property-changing and energy-exchanging, they can respond intelligently to external stimulus and external conditions [6]. In these two types, with different input (stimuli) smart materials can have different output (property changing or energy exchanging).

In this research, due to variety smart materials and their behaviour, the group of smart materials are selected which sensitive to light, radiation and temperature stimulus, although some of them have ability to respond to more than light stimuli (table2):

In type 1 (property changing):

Photochromic, Thermochromic, Electrochromic, Liquid crystal.

In type 2 (exchange energy):

Photovoltaic, Photoluminescent, Thermoluminescent, Phosphorescence, Photostrictive, Thermostrictive.

3.3. Criteria

The Smart materials selection process is based on the AHP model, which is consisted the numbers of smart materials that will be evaluated in terms of multiple Criteria. For finding the suitable smart materials, having specific criteria is necessary for comparison them. In this paper, smart materials are selected according to the purpose goal (Tabale3), to rank this group of smart materials to use in the construction projects in hot and dry climate.

3.4. Gathering process of comments

The validation of making decisions in the AHP method is dependent on the questionnaire (in terms of quality and quantity). The questionnaire is set and completed; with the help of a team of professionals, individuals and organizations that have effects on the decision-making process, and planning. According to the questionnaire and collected information from trusted sources, pair-wise comparison matrix tables are regulated. The collected information on the selection of the preferred options, the questionnaires was designed and expert opinions were collected.

Table 3: Common Quality Attributes with brief description [7].

Category of criteria	Sub-criteria	Description
Climate	Optical transmittance	Control the amount of incoming sunlight into building, and using the light source to exchange to type energy.
	Thermal transmittance	Controlling heat transformation in hot-dry climate in day and night, (temperature difference in day and night is enormous).
	Thermal absorption	Reduce heat absorption during the day in order to control the temperature inside the space.
Saving Energy	Solar radiation transmitting control	Control the sunlight into spaces in order to control the temperature and reduce energy consumption.
	Reduce cost for user in long time	Reduce Energy costs of users.
	Control of interior heat generation	Control of the internal temperature and prevent to reduce or increase in temperature.
	Reduction in fossil fuel consumption	Reducing fossil energy by using compensable energies
Utilization	Maintainability	The ability to modify the system and conveniently the system and extend it in future.
	Simplicity	Those attributes of the software products that provide maintenance and implementation of the functions in the most understandable manner and also ease for using.
	Supportability	It refers to the ability of technical support personnel to install, configure, and monitor computer products, identify exceptions or faults, and provide hardware or software maintenance in pursuit of solving a problem and restoring the productive into service. Incorporating serviceability facilitating features typically results in more efficient product maintenance and reduces operational costs and maintains business continuity.
	Economic and Affordability cost for buying smart materials	The expense of the building, maintaining, and operating the system.
Architectural	Control of view	Having the suitable windows for better visibility and view whilst inside of building is not visible from outside.
	Harmony with Current Iranian Architecture	Control and Having the harmony with contemporary architecture with it, while these groups of smart materials should not have any bad effect on the architectural face of Iran's past.
Performance criteria	Runtime	A system's ability to adapt to an increase in user requests, in short time.
	Lifetime	The period of time that the product is alive before retirement.
	Harmony with environment	Usability includes matters of completeness, correctness, compatibility, as well as friendly environmental materials.
	Availability and satisfaction	The level of human satisfaction from using the system. Take advantage and availability of smart materials is one of the other of criteria for consumers

3.5. Calculation of the consistency of matrix

Each smart material have been measured and marked in previous steps, the intensity important of each material is marked by 9 different levels with every Criteria. The process of selecting Smart materials is based on the AHP model which consists of a number of smart materials that are evaluated in terms of multiple Criteria. For comparing Criteria and alternatives to each other, relative concept must have changed to the quantity. Then, this numbers are set in a matrix. In the matrix of pair-wise comparison, the amount of each element indicates the degree of importance of each criteria of the row to the columns.

In each matrix, each sub-criterion has been compared to each other to realizing the weight of each main criterion. It should be mentioned that this matrix, is the result of geometric mean of the various decision makers' views with assuming equal decision-making power. In this paper, one of the approximate methods (arithmetic mean method) has been used to calculate the weight matrix [7].

Table 4: Pair-wise comparison matrix; main criteria.

criteria	value percent
Saving energy	30.1%
Climate	26.5%
Utilization	15.9%
Architectural	8.9%
Performance	18.6%

In addition, the value of each sub-criteria of main criterion is measured in a separate matrix. So, the value of each sub-criteria are obtained in separate matrices. At the end, the value of each criteria and sub-criteria are shown with percentage (Table 4&5).

Finally, with respect to the weight of each criteria and sub-criteria, smart materials are compared. As shown in chart1, the weight of each smart material is indicated in each criterion.

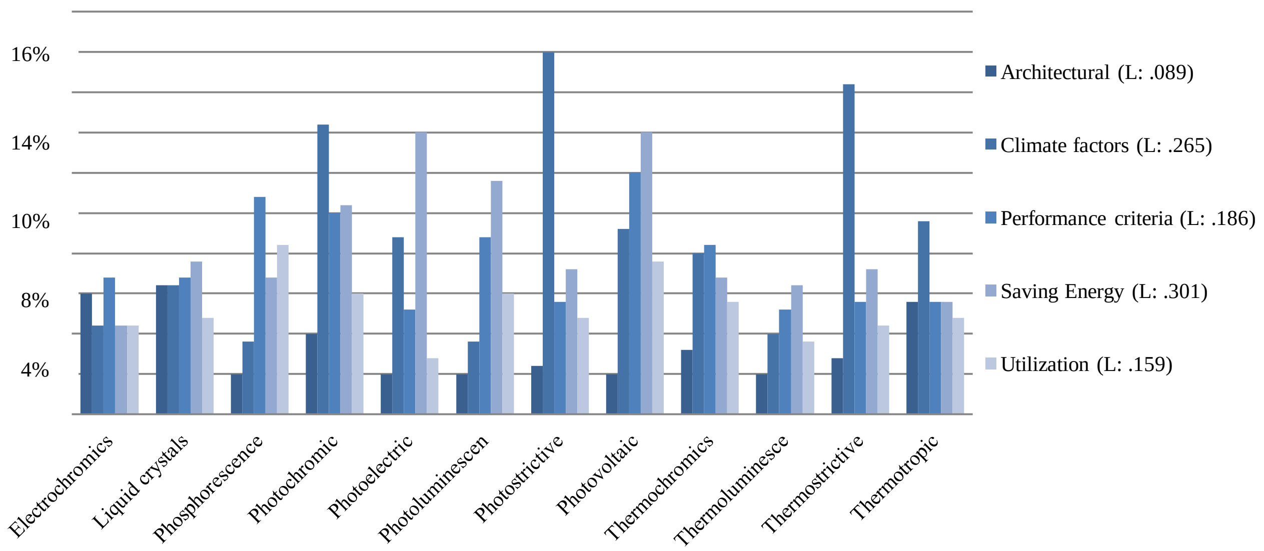
3.6. Sensitivity Analysis

The major limitations of this study are related on literature review limitation that will be affected on the decision method procedure. These are such as, lack of practical experience, lack of literature support, the limitation of time and the rapid advancement of technology and innovation of smart materials. So sensitivity in AHP could increase by these limitations. Sensitivity analysis indicates that how the opinion of decision-makers can have effect on criteria weights, and therefore how the rank obtained by this method (AHP) could be changed. Due to table 6, the value of some materials is exactly as the others' or very close, so this table indicates that how, the opinion and decision of professional person are important and can effect on the smart materials' rank. For example, the rank of Liquid

Table 5: The value of each sub-criterion

Criteria	Sub-criteria	value percent
Saving Energy	Solar radiation transmitting control	19.8%
	Reduce cost for user in long time	45.1%
	Control of interior heat generation	25.7%
	Reduction in fossil fuel consumption	9.4%
Climate factors	Control optical transmittance	19.8%
	Control thermal transmittance	45.1%
	Control thermal absorption	25.7%
Utilization	Maintainability	24.4%
	Simplicity	9.8%
	Supportability	24.4%
	Economic and Affordability cost for buying smart materials	45.5%
Architectural	Control of view	66.7%
	Harmony with Current Iranian Architecture	33.3%
Performance criteria	Runtime	12.1%
	Lifetime	43.1%
	Harmony with environment	26.7%
	Availability and satisfaction	18.1%

Chart 1: Smart materials are evaluated in each criterion.



crystal, Phosphorescence and Thermotropic could change if the value of criteria changes (it shows the sensitivity of professional decisions).

Table 6: The Smart materials' final rank; according to criteria.

Criteria	Saving Energy	Climate	Utilization	Architectural	Performance	Score %	Rank
Criteria Weight	30.1%	26.5%	15.9%	8.9%	18.6%		
Photochromic	0.105	0.139	0.097	0.096	0.114	11.4%	1
Photovoltaic	0.137	0.087	0.120	0.054	0.136	11.3%	2
Photostrictive	0.071	0.166	0.076	0.064	0.059	9.4%	3
Thermostrictive	0.069	0.153	0.072	0.074	0.059	9%	4
Photoelectric	0.140	0.082	0.041	0.052	0.057	8.2%	5
Photoluminescent	0.115	0.035	0.098	0.049	0.096	8%	6
Thermochromics	0.065	0.076	0.085	0.077	0.094	7.9%	7
Liquid crystals	0.071	0.057	0.076	0.155	0.074	7.7%	8
Phosphorescence	0.066	0.035	0.136	0.049	0.113	7.7%	8
Thermotropic	0.051	0.091	0.080	0.135	0.061	7.7%	8
Electrochromics	0.043	0.043	0.066	0.147	0.078	6.5%	9
Thermoluminescent	0.066	0.037	0.053	0.047	0.058	5.3%	10

4. DISCUSSION

In the result section, it presents a multi decision selection process, which is supported by sufficient data and information and effective mathematical method, AHP.

A precondition of selecting proper smart materials is collecting a number of new materials that are more known for using or offer to use. So, in this paper, 12 smart materials are selected and classified in 2 groups which are based on their property responds (change property, exchange energy). Then each smart material is measured with sub-criteria (Table 5), so by determining the value of each sub-criterion, the importance of main criteria will be define. The AHP model is a proper model that can consider the problems that always designers and architects face with them. Some researchers have investigated this area before, but by comparison between some similar researches, this study would have three advantages:

First, because of the variety of smart materials, in this research, they have been chosen with specific input and are classified by their properties and responds.

Second, a special point of this research is that, this group of smart materials has been categorized by their respond to hot and dry climate and other different factors. In the AHP method, many different and important criteria due to buildings and users' needs could be chosen and selected; it means that this research avoids unnecessary comparison and computation.

Last but not least, this method could be a suitable process for choosing another type of smart material with different criteria for the future research. Also, AHP procedure is a mathematical method that could be understandable for engineers and can make a discussion on positive or negative alternatives' points for them.

5. SUMMARY AND CONCLUSION

Smart materials selecting is the crucial phase in adaptable and sustainable design. Adaption has key role in green and sustainable design where suitable decision is important. The systematic selection process is powered by Analytic Hierarchy Process (AHP) and ends by finding out the most appropriate smart materials for research's target. It would be an effective method with ease of use for Iranian users who lack expertise and experience to find proper smart materials for their buildings in hot and dry climate. In this AHP decision, the efficiency of this method with respect to choosing of smart materials for hot and dry climates is shown and the proper materials were rated due to the most important criteria.

The new materials which have been introduced to the construction industry and building systems are able to meet the quality and quantity of users' needs.

In this process, among the smart materials group which are sensitive to light and radiation (table 2), some of them such as Photochromic, photovoltaic and Photostrictive could have the best response to hot and dry climate users (Table 6), but some of them such as Electrochromic and Thermoluminescent are located at the end of the table because of the importance of other criteria like cost, availability and supporting.

Although this paper has some limitations, it paves a way to continue this research with different research questions and alternatives for the future in so it can covers a wide range of smart materials and variety criteria, it could be available for more researchers and types of materials.

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