Evaluation of Multi-criteria Selection Factors of Intelligent Buildings

K. Taghizadeh Azari, E. Asadian, A. Vakili Ardebili

***Abstract*—** The dramatic increase in energy consumption in the world and the resulting environmental issues are amongst the major concerns that have been attracted a great deal of attention in recent years. Taking into account that buildings are one of the largest energy consumers, improving energy conservation and sustainable developments play a critical role in the construction section. The optimized energy consumption management and the control of its usage, has led to the development of a new concept; Intelligent Buildings (IBs) as well as Building management systems (BMS) as one of the most comprehensive and effective intelligent control systems. The main goal of implementation of IBs is to reduce energy consumption through energy saving and conservation however, the wide range of factors involved in the design of such buildings has raised difficulties associated with the design decisions and needs a multi-criteria approach for evaluating influential factors and sub-factors. In the present study, a comprehensive multi-criteria decision-making framework containing 68 sub-factors is proposed in order to provide a major insight into the selection of intelligent buildings. In this regard, 8 quality environment modules were considered as the main factors including environmental and energy indicators, space flexibility, cost effectiveness, user comfort, working efficiency, safety, culture and technological factors. Then in the next step, the validity of the proposed factors were evaluated through a questionnaire survey and gathering the opinions and perspectives of experienced experts active in the field of IBs. The collected data were systematically analyzed using SPSS software and the final weight of each factors were determined through an Analytical Hierarchy Process (AHP) approach. According to the obtained data, three main factors of “Safety and security”, “User comfort” and “Environment and energy” are ranked in importance from first to third. The results can helps the stakeholders (clients, architects, engineers and construction managers) to obtain a better perception on the priority levels of each factor in IBs.

***Keywords*—** Energy consumption, Intelligent buildings, Multi-criteria decision-making, Sustainable construction

I. INTRODUCTION

Among various challenges that the new generation encounter, the environmental and energy concerns have been attracted a great deal of attention in recent years [1]. The rapid growth of energy consumption in the world in the past few decades has raised growing concerns about the depletion of energy resources and finding alternative energy supplies as well as heavy environmental impacts such as energy resources depletion, global warming and carbon emission [2].

The statistics gathered by the International Energy Agency on the energy consumption trends are so alerting; during the last two decades (1984–2004), the primary energy has grown by 49% and CO_2 emissions by 43%, with an average annual increase of 2% and 1.8%, respectively (Fig. 1) [1,2].

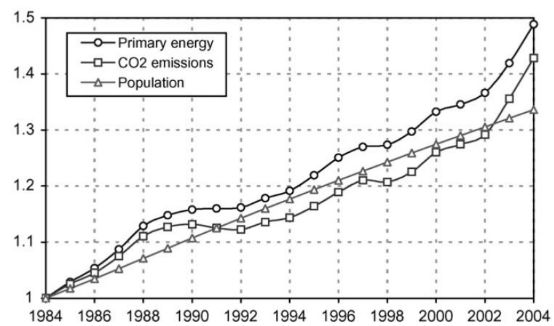

Fig. 1 The plot of world primary energy consumption, CO_2 emission and the population growth between 1984 and 2004 [1]

Although Iran is among the countries with abundant natural energy resources such as oil and gas but it is not an exception in facing the energy issues and according to the International Energy Agency statistic the energy produced in the country is not accountable for its use (Fig. 2) [2].

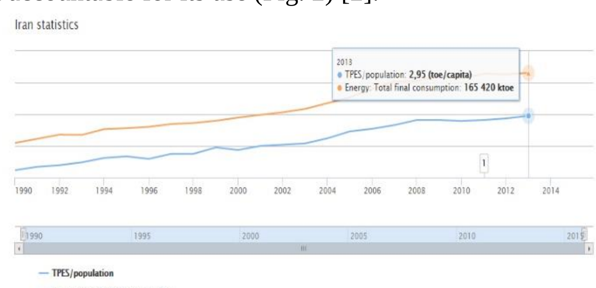

Fig. 2. The plot of total energy production and consumption in Iran[2]

As one of the most energy-intensive countries of the world, Iran per capita energy consumption is 15 times that of Japan and 10 times that of European Union’s [3].

One way to reduce the energy consumption is to increase the prices of energy carriers through implementation of regulatory policies include stringent norms and standards toward energy efficiency. According to the so-called Targeted Subsidies Law which passed by the parliament, energy (petrol, oil, liquefied

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gas and kerosene) prices would increase up to 90 percent of the border prices in five years (at least 75 percent of the export prices for natural gas) as shown in Fig. 3 [4].

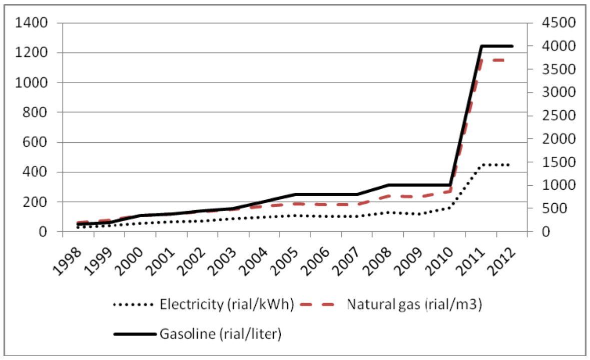

Fig. 3. The energy prices growth in Iran [4]

However, it should be noted that this results in some consequences including the reduction of wellbeing and comfort of users which in turns influences their productivity and satisfaction. Therefore, the efficient management of energy supplies through rational use of present resources and finding ways to optimize energy consumption while maintaining high level of living standards has been the focus of numerous researches [1].

Buildings are one of the largest energy consumers in any developing countries [5]. Hence, the study of energy consumption and the environmental impact of buildings during their life cycles play a critical role in this regard. As an example, 36% of the total energy consumption in Iran is consumed in building sectors as showed in Fig. 4 [3].

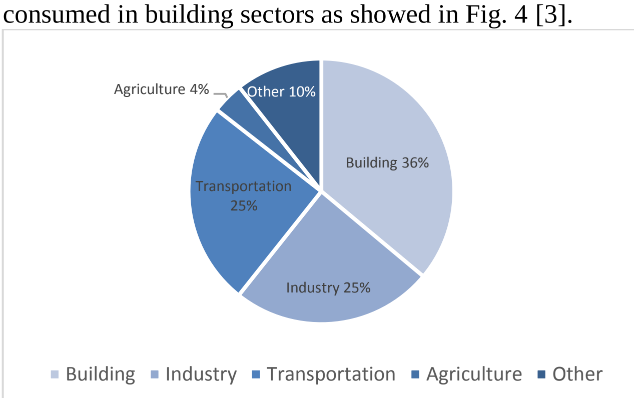

Fig. 4. Iran energy consumptions in different sectors [3]

The increasing need for sustainable or green design has led to the development of a new concept; Intelligent Buildings (IBs), which requires a continuous process of balancing between all three environmental, social and economic sustainability features [6]. IBs not only try to bring flexibility and comfort to their inhabitants and occupants while maintaining the cost effectiveness, but also deal with the user's safety as well as attaining higher environmental performance standards [7].

Based on the fact that a sustainable development should combine three basic issues including People (owners, users, occupants and inhabitants), Products (equipment, materials and facilities) and Processes (maintenance, facilities management and performance evaluation) as well as the relationships between them, a profound survey that integrates all these factors is critical.

However, a brief literature review reveals that there is not a universally accepted definition for IBs which originates from the lack of a general agreement on the selection factors (variables) and critical criteria for the selection and evaluation of the building control systems. For sure, a comprehensive definition which considers all involved parameters is essential for a better decision-making since without a precise understanding, achieving a smart building that gather the best combination of social, environmental and economic values seems impossible. As a result, in the present study we propose a multi-criteria decision-making framework (including 68 sub-factors) which provides a major insight into the selection of sustainable intelligent buildings indicators.

The results can helps the stakeholders (clients, architects, engineers and construction managers) to obtain a better perception on the priority levels of each factor in IBs.

II. INTELLIGENT BUILDINGS (IBS)

The term intelligent building was first used by UTBS Corporation (United Technology Building Systems Corporation) in 1981 in the USA. About 2 years later, their efforts became a reality and the City Place Building in Hartford (Connecticut, USA) was named as the world's first intelligent building [8]. Since then, various definitions have been proposed for IBs. The initial definitions only focused on the technological aspects without taking the user's requirements into account [9]. However, very recent definitions consider occupant's interactions as well as their relation with the surrounding environment [7,10,11]. According to the Intelligent Building Institute of the United States, an intelligent building can be defined as "one which provides a productive and cost-effective environment through optimization of its four basic elements including structures, systems, services and management and the interrelationships between them" [7,12] while the European Intelligent Building Group described it as 'one that creates an environment which maximizes the effectiveness of the building's occupants, while at the same time enabling efficient management of resources with minimum life-time costs of hardware and facilities [7,12]. Besides these general definitions, there exist numerous descriptions for IBs in the literature [7]. For instance, in a literature review which was done by Wigginton and Harris [12] 30 separate definitions were listed in relation to intelligence and building.

In 1983, Cardin defined an intelligent building as "one which has fully automated building service control systems" [7]. However, this definition was further developed as "one which integrates various systems to effectively manage resources in a coordinated mode to maximize: technical performance, investment and operating cost savings, flexibility" by the Intelligent Building Institution in Washington in 1988 [13]. More recently, Seo et al. have proposed that intelligent buildings are not intelligent by themselves, but they can furnish the occupants with more intelligence and enable them

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to work more efficiently [7]. Meanwhile, it is also suggested that intelligent buildings represent a key benefit that can reduce the initial capital outlay, as well as enabling a higher potential return on investment (ROI).

Some researchers [7] introduce the intelligent building as a "multidisciplinary effort to integrate and optimize the building structures, systems, services and management in order to create a productive, cost effective and environmentally approved environment for the building occupants".

As can be seen, there is not a general agreement about the definition of IBs. However, the main goal of implementation of IBs is to reduce energy consumption through energy saving and conservation. The percentage of reduced energy consumption (%) is shown in Fig. 5.

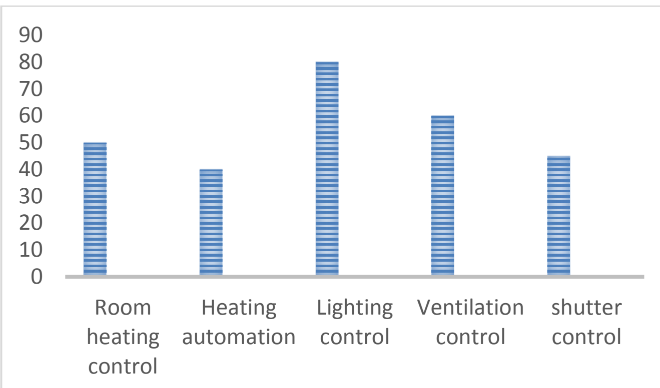

Fig. 5. The percentage of reduced energy consumption (%) [2]

III. METHODOLOGY OUTLINE

Since the IBs are considered as a complex system made up of various components, the best approach to analyze them is to divide the system to its elements. In this regard, a general survey was undertaken in order to identify the perceived critical selection criteria and to gather all the evaluation factors that affect the performance of an IB. for this purpose, the main factors were collected from eight "quality environment modules" (QEMs) (from M1 to M8) including [8]:

- M1; Environmental and energy
- M2; Space utilization and flexibility
- M3; Cost effectiveness
- M4; Human comfort
- M5; Working efficiency
- M6; Safety and security
- M7; Culture
- M8; Technological factors

The pivotal selection factors were collected through a profound and comprehensive literature review. It is noteworthy to mention that since most of the collected criteria gathered from the literature are mostly related to the developed countries such as US, Britain and China, the localization of selection factors and assign them to Iran's context and culture is of great importance.

As a result and to achieve the most appropriate research method for the empirical studies, 5 experts were selected among engineers and architects active in the field of IBs and BMS and their feedbacks were obtained regarding the importance of intelligence indicators. They were also asked to propose any additional factors if necessary. In this regard and according to the experienced building practitioners, two parameters of "Fashion" and "Repair and development costs" were added as the sub-factors to the main factors of "Culture" and "Cost effectiveness", respectively.

Then in the next step, each of these eight key modules were assigned to a number of variables which are marked as "secondary" and "sub-factors" (Fig. 6). In order to achieve a complete and comprehensive set of key elements, a statistical population of 76-members were chose from the experts who are mostly active in the field of Building Management Systems (BMSs). The evaluation criteria of IBs that influence the whole life cycle of building and derived from the previously mentioned 8 main factors (quality environment modules) are shown in Fig. 6.

IV. SELECTION FACTORS FRAMEWORK

The main challenge usually facing the project design team is to choose the optimum configurations that meet the considerations of developers in one hand while strike a balance between these goals and the expectations of the users on the other hand [14]. The wide distribution of these multi-dimensional perspectives augment the complexities involved in the evaluation and selection of the control systems for the intelligent buildings. Therefore, there is an essential need for the selection evaluation tools to be recognized in order to facilitate the achievement a logical decision. As a result, we propose a comprehensive list of evaluation criteria which helps the decision makers to select proper categories and reach the customer's satisfaction.

V. STATISTICAL MEASURES AND ANALYSIS METHOD

As mentioned previously, the collected data from experts were systematically analyzed using SPSS software and the final weight of each factors were determined through an Analytical Hierarchy Process (AHP) approach (Table 1).

Table 1: The importance of main factors

	Variables	Relative importance of indicators	Normalized importance
Main factors	Safety and security	0.210	1.000
	Human comfort	0.189	0.901
	Environmental and energy	0.140	0.667
	Cost effectiveness	0.134	0.638
	Working efficiency	0.113	0.537
	Technological factors	0.079	0.378
	Space utilization and flexibility	0.078	0.371
	Culture	0.058	0.279

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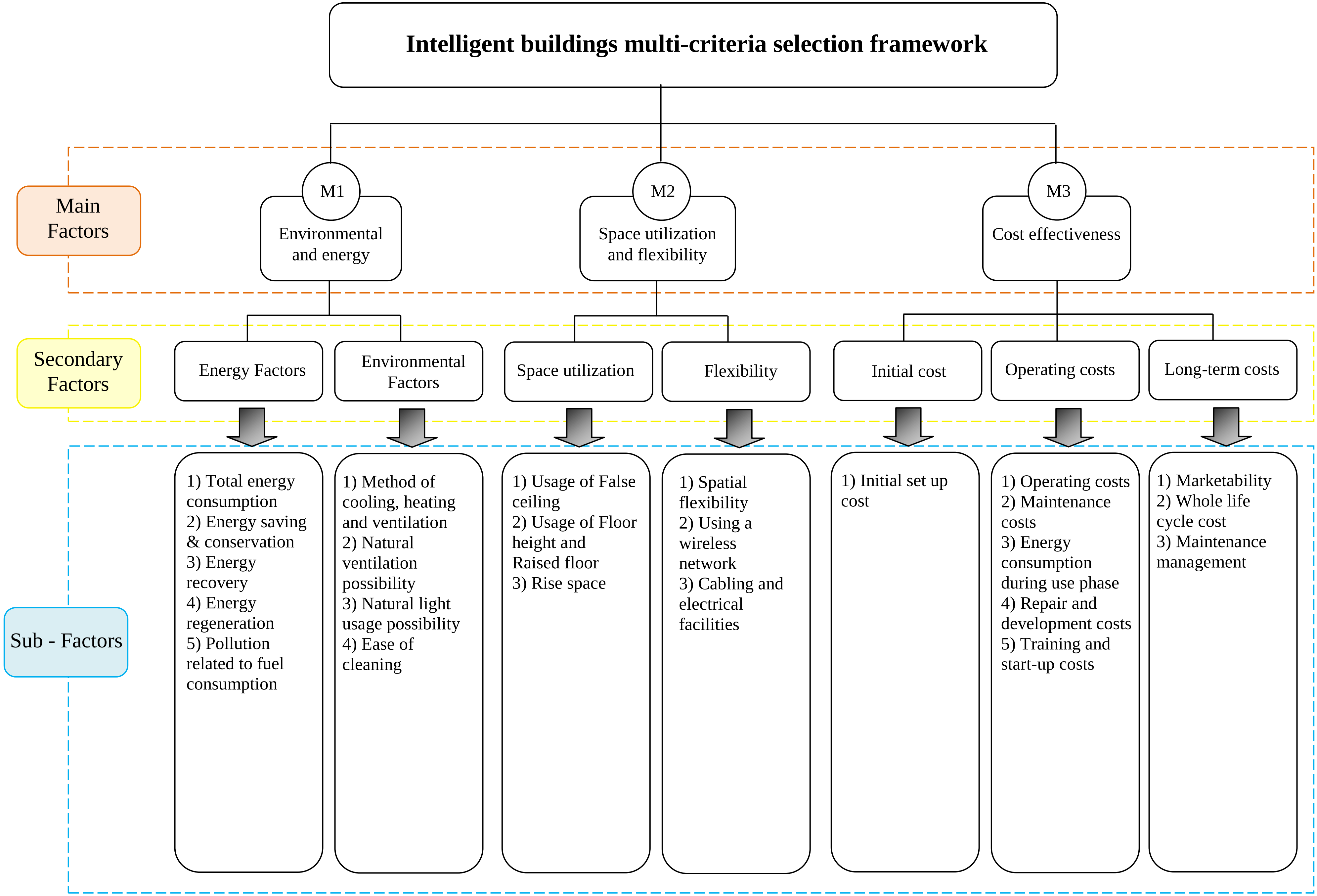
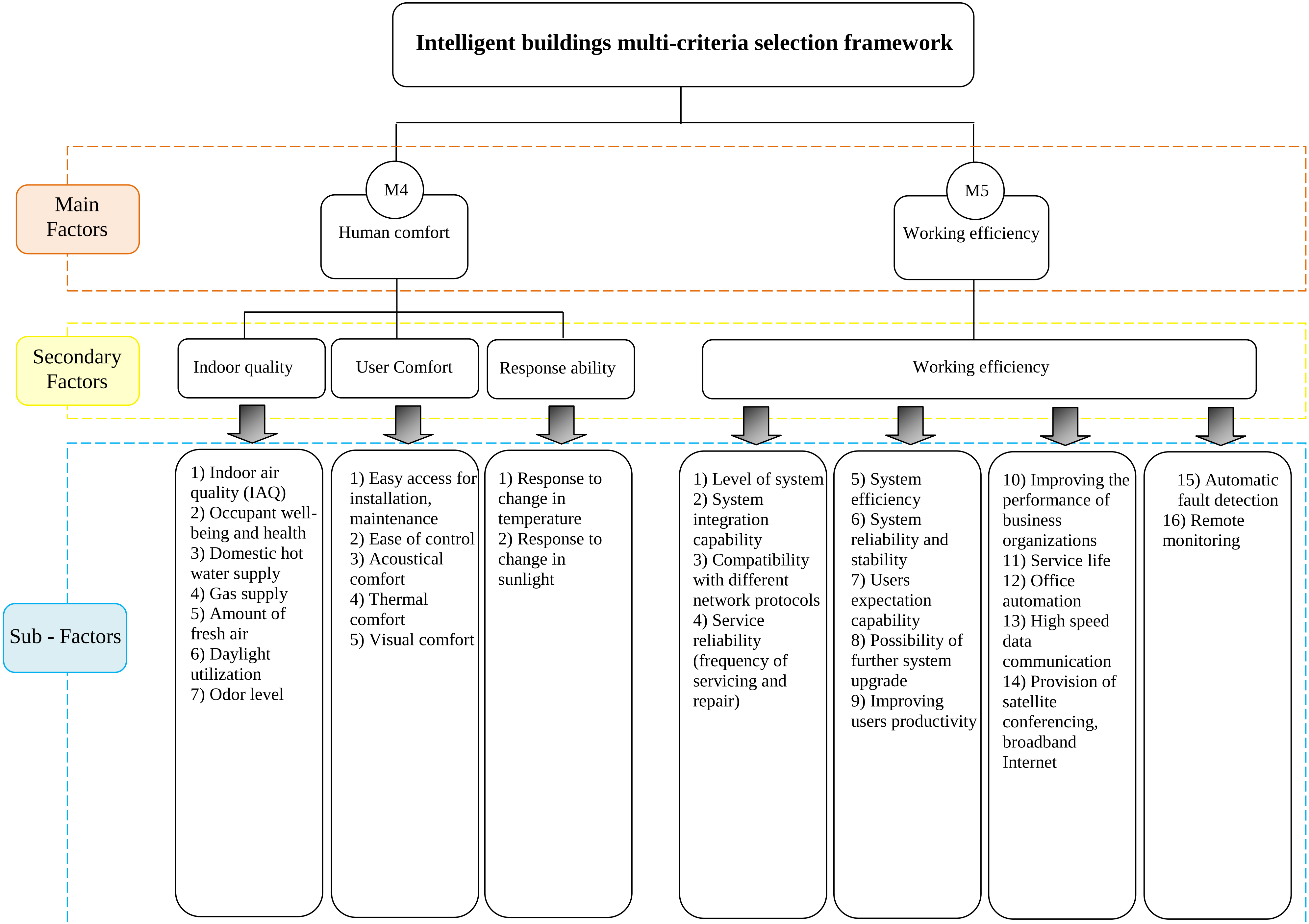

Intelligent buildings multi-criteria selection framework
Main Factors
M1
Environmental and energy
M2
Space utilization and flexibility
M3
Cost effectiveness
Secondary Factors
Energy Factors
Environmental Factors
Space utilization
Flexibility
Initial cost
Operating costs
Long-term costs
Sub - Factors
1) Total energy consumption
2) Energy saving & conservation
3) Energy recovery
4) Energy regeneration
5) Pollution related to fuel consumption
1) Method of cooling, heating and ventilation
2) Natural ventilation possibility
3) Natural light usage possibility
4) Ease of cleaning
1) Usage of False ceiling
2) Usage of Floor height and Raised floor
3) Rise space
1) Spatial flexibility
2) Using a wireless network
3) Cabling and electrical facilities
1) Initial set up cost
1) Operating costs
2) Maintenance costs
3) Energy consumption during use phase
4) Repair and development costs
5) Training and start-up costs
1) Marketability
2) Whole life cycle cost
3) Maintenance management



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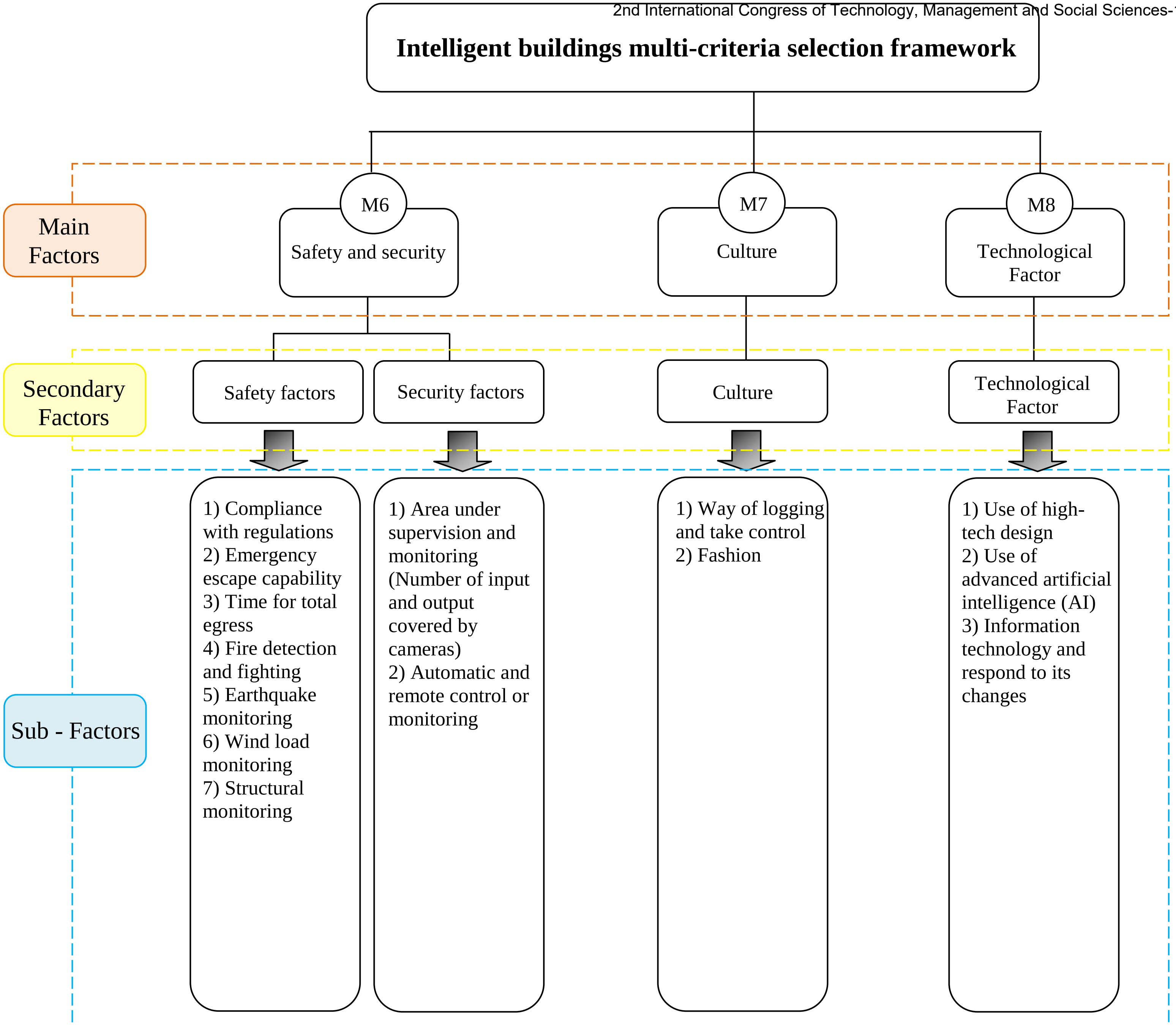

Fig. 6. Intelligent buildings multi-criteria selection framework [6], [7], [8], [14]

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VI. Conclusion

In conclusion, efficient intelligent buildings have become a trend for the future of construction industry. The main challenge of designing such buildings is the multiplicity of the factors influencing the decision making process. In the present study, a comprehensive framework of factors affecting the development of intelligent buildings is gathered. Using 8 quality environment modules the main, secondary and sub-factors were driven including 68 key elements. Analyzing the collected data revealed that three main factors of "Safety and security", "User comfort" and "Environment and energy" are amongst the most important factors regarding IBs. Moreover, the nearly equal weight of cost effectiveness and energy further confirms the direct relation between these two factors. The results of this study can provide a better insight for the design and development of a more sustainable intelligent building.

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