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Abstract

Awareness of the importance of developing smart buildings is increasing. Many definitions of "smart" are cited in the context of building projects, but a standard definition does not so far exist. Researchers and practitioners usually focus on one or few aspects and there is a lack of comprehensive classification of the most common issues associated with smart buildings. The objective of the research presented in this paper is to capture the perspective of professionals about smart buildings. After the pertinent literature is examined, three domains are identified, namely economic issues, energy consumption, and level of comfort. Construction managers are surveyed for their opinions about the issues associated with these three domains. The results indicate that the three domains are rated almost equally by the respondents, with energy consumption a little ahead of life-cycle costs and occupant comfort. While cost considerations are most important in the planning and design phase of the life cycle of a smart building, the performance of the heating, cooling and lighting systems appear to be of importance in energy performance, and air quality and functionality dominate occupant comfort. This study is of benefit to smart building owners, designers, and constructors since it highlights the most salient issues associated with smart buildings.

Keywords: *Smart Building, Construction Management, Building Performance Measurement*

1. Introduction

Higher competitive pressures are forcing owners and developers to construct buildings that can be considered smart. Smart buildings involve the use of technology and processes to develop buildings that are comfortable and safe for their occupants while at the same time economical for their owners [1]. They achieve smartness by exploiting computer and organizational technologies in order to get a reduction of life-cycle costs and an optimal combination of comfort and energy consumption [2]. Smartness is considered in all the phases of a construction project, including design, construction, and operation.

A standard definition of "smart" does not so far exist. This lack of standard definition can make it difficult to assess what makes a building smart. The objective of the research presented in this paper is to capture the perspective of professionals about the critical issues involved in smart buildings. After the pertinent literature is examined, three domains are identified, namely, economic issues, energy consumption, and level of comfort. A large number of construction managers are surveyed for their opinions about these issues. Based on the results of the survey, the critical issues are identified.

2. Issues in Smart Buildings

Cole and Brown [3] propose a set of key attributes for smart buildings:

- Automated buildings: automated systems that control the building services.
- Informatic buildings: integrated, centrally managed information and communication structures.
- Intelligent space management: capability to respond to rapid changes in the size and in the structures of organizations and work practices.
- Passive intelligence: perceptive design strategies, to positively influence environmental performance and thereby reducing or replacing unnecessary systems.
- Organizational intelligence: strategic plans that integrate organizational needs with building capability and capacity.

Lu et al. [4] argue that the most important aspect associated with smart buildings is the ability to measure and monitor their service systems. Yang and Peng [5] propose measuring the performance of a building by looking into its organizational flexibility, technological adaptability, individual comfort, and environmental performance. Gonzàlez et al. [6] propose an energy efficiency index that is basically the ratio between the performance (in terms of energy consumption or CO_2 emissions) of an actual building and the performance of a reference building. Chen et al. [7] suggest three different assessment methods for measuring building performance, including rating methods based on indicators associated with design, operation, and simulations. Wong et al. [8] propose eight building control systems in a typical smart building:

- Integrated building management system for overall monitoring of the building
- Heating, ventilation, and air-conditioning control system for comfort control and the quality of the indoor air
- Addressable fire detection and alarm system for fire prevention and annunciation
- Telecom and data system for communication network
- Security monitoring and access system for surveillance and access control
- Smart/energy efficient lift system
- Digital addressable lighting control for light design
- Computerized maintenance management system

Chwieduk [9] emphasizes the performance of solar-power systems and heat pumps, waste sorting, the re-utilization of wastes, water treatment, water-saving equipment, use of rain water, and re-use of waste water, whereas Wong and Jan [10] propose performance measures in spatial comfort, indoor air quality, visual comfort, thermal comfort, and acoustic comfort; Morsy [11] states that psychological aspects can influence building users' comfort and that smart buildings' performance in adapting to the psychological needs of the occupants is important.

In summary, the literature suggests that smart buildings improve building performance relative to life-cycle costs in all phases of a project (design, construction, operation), energy consumption, and occupant comfort

2.1. Life-Cycle Costs

Smart buildings are too complex and too large for one organization to design, maintain, and operate. The challenge is to set up a team so that every member's responsibilities align with the same objectives and all these responsibilities collectively appear able to militate for success [12]. At the same time facilities management, construction, and design are equally important [13]. A smart building must be able to respond to individual, organizational and environmental requirements and to cope with changes. It is also believed that a truly smart building should be able to learn and adjust its performance based on the information obtained from its occupancy and the environment [5]. A smart building is a complex system of three inter-related elements: products (structure, equipment, facilities, materials), people (users, owners, occupants), and processes (construction, facility management, maintenance) [14].

2.2. Energy Consumption

Buildings are responsible for a large percentage of energy consumption and in turn pollution and CO_2 emissions in the world. Most of the energy used is for heating, cooling and lighting in both commercial and residential buildings [15]. Impacts of high energy consumption on the environment are gaining importance as society recognizes the seriousness of this issue [16]. Over the last few decades, economic growth has steadily increased the demand for energy. Despite the economic and financial crisis that started in 1981, the global demand for energy is expected to continue increasing in particular because of the high growth rates of China and India.

In the future, the main concern is not how to produce the energy that is needed, but to reduce the energy consumption and to mitigate the effects of high consumption on the environment and health [6]. Building automation systems have become increasingly common in response to these needs. A building automation system usually consists of several subsystems such as HVAC control, security and access control, fire security, building transportation control, etc. The role of these subsystems is crucial, since they contribute to the achievement of higher energy efficiency, higher levels of comfort, and lower costs [17].

2.3. Occupant Comfort

In addition to energy conservation, Kofler et al. [18] propose different domains of interest for smartness, namely resource information, exterior influence, building information, actor information, process information, and comfort information. According to Wang et al. [2], three basic factors – thermal comfort, visual comfort and indoor air quality – measure the quality of living in a building environment. Temperature, illumination level, and CO2 concentration are three main indexes for thermal comfort, visual comfort and air quality, respectively. Eang and Priyarsdasini [19] as well, indicate thermal comfort, illumination, fresh air ventilation, and indoor air quality as environmental parameters that should be taken into account. Wu and Noy [15] propose evaluating comfort indexes that have significant influence on people's well-being in the building by installing sensors to collect data about indoor physical parameters. The reduction of the power consumption requires continuous monitoring of various environmental parameters inside and outside the building. The methodology proposed by Doukas et al. [17] includes both indoor and outdoor sensors (for the measurement of temperature, humidity, air quality, and luminance), controllers (e.g., switches, diaphragms, valves, and actuators) and databases (that record all the information).

3. Applicability of WE Category in Developing Research Method

The research was conducted in four steps.

- First, the different domains and constituent variables associated with the smartness of a building were identified by reviewing the literature. The outcome of this step is discussed in the preceding section.
- Second, based on the domains and their variables, a survey questionnaire was designed to seek the opinions of professionals on these issues. After some general questions about their professional experience, the respondents were asked to rate the importance of the tools that can be used to enhance the smartness of a building, the importance of the different domains and the importance of the variables associated with the domains. For all statements, a scoring system of 1-5 was used to assess the answers, where 1 = Not important, 2 = Moderately important, 3 = Important, 4 = Very important, and 5 = Extremely important.
- Third, the survey was administered to a group of specialists who are members of the Construction Management Association of America (CMAA), an organization formed in 1982 that is dedicated to the interest of professional construction management.
- Fourth, the data collected were studied, the findings were analyzed in the light of the exiting literature, and conclusions were drawn about the current perceptions of the critical issues in smart buildings.

4. Findings and Discussion

The questionnaire was sent to 1,600 professionals that are members of CMAA; 120 responded, yielding a rate of response of 7.5%. Any size of company is represented in the sample evidenced by 41 having fewer than 1,000 employees, 32 with 1,000 to 10,000 employees, and 43 with more than 10,000 employees.

Most of the respondents had 20 to 35 years of experience in construction. This means that the sample is made up of very skilled professionals, and therefore the answers can be considered to be reliable. The majority of the professionals were constructors or designers, with only 19 owners. Construction management services are often provided by constructors and designers. It is not surprising to see only few owners among the respondents because only few owners are members of CMAA.

Table 1 shows the means of the responses for domains and variables. It shows that all domains are rated almost equally by the respondents, with energy consumption being the most important one for a smart building. Buildings consume 30-40% of all primary energy worldwide [20]. They are the single source of carbon emissions which account for 50% of total emissions [21]. According to the U.S. Department of Energy, more than 76 million residential buildings and 5 million commercial buildings will account for 37% of all energy used, 68% of all electricity, and 40% of raw materials used in the U.S., generating 36% of the CO_2 emissions [22] [23]. The International Energy Agency (IEA) predicts that non-OECD countries account for 93% of the increase in global energy demand between 2007-2030, mostly driven by China and India [23] [24].

Energy use in buildings comprises the energy used in the production and transportation of construction materials, energy used for the building's operation, and the energy used for dismantling and demolition [25]. Sustainable building practices can considerably reduce the built environment's role in energy consumption. For example, a survey of 99 green buildings in the U.S. showed that green buildings use an average of 30% less energy than conventional buildings [26].

The systems that consume energy are rated also almost equally by the respondents, with cooling being slightly more important than heating and lighting systems, and water systems being slightly less important than the first three.

Energy efficiency has to be considered from the perspective of life-cycle costs, in the sense that an investment in energy efficiency needs to be economical. The findings indicate that life-cycle costs at the planning and design phase carry slightly higher importance than in other phases. The construction industry is bound to use sustainable practices now and in the future; these practices can be enhanced only by applying life-cycle costing principles [27]. The development of new monitoring and simulation tools is a way to increase energy efficiency [28], but these tools need to be considered in the preliminary analysis carried out during the planning and design phase for them to improve the smartness of a building. In a sense, the objectives relative to smartness and the tools to achieve these objectives are specified in the design phase. Bad decisions in the design phase cause problems not only with economy, functionality and appearance, but also with smartness [29]. For instance, the selection of the devices and how they are integrated into the system are important design parameters [30]. Also, Dussault et al. [31] underline how sustainability considerations that involve smart components are increasingly integrated into building design to improve building performance. It is therefore only natural that the construction phase receives less attention relative to smartness-related decisions.

The comfort of occupants is in general considered less important even though people spend about 80% of their time indoors and even though the indoor environment has important effects on human health [32]. In the comfort domain, temperature and air quality assume relevance for the smartness of a building. A probable explanation is that temperature and air quality are most important in living conditions. For example, Gao [33] believes that indoor air quality is the most important and yet overlooked issue of our time. Psychological aspects were expected to be very important, but the respondents gave it low scores. This could be due to the fact that these issues are usually considered by interior designers rather than construction professionals. Moreover, the assessment of these aspects is often associated with issues related to perceptions that are hard to measure.

Table 1. Results of the survey

Domains and Variables	Mean Scores	Normalized Weights
Life-Cycle Costs	**4.14**	**0.33**
Costs in planning and design phase	4.49	0.28
Costs in Construction phase	3.60	0.22
Costs in operation and maintenance phase	4.23	0.26
Costs associated with sustainability	3.91	0.24
Energy Consumption	**4.39**	**0.35**
Heating system	4.37	0.26
Cooling system	4.48	0.27
Lighting system	4.17	0.25
Water system	3.57	0.21
Occupant Comfort	**3.95**	**0.32**
Temperature	4.26	0.12
Humidity	3.77	0.12
Air quality	4.17	0.14
Acoustic comfort	3.57	0.12
Functionality	3.90	0.14
Psychological aspects	3.33	0.11
Security	3.46	0.11
Fire protection	3.91	0.13

5. Conclusion

A questionnaire aimed at exploring the perceptions of professionals about smart buildings was administered to the members of CMAA. The means of the responses were used to analyze the responses. The results suggest the following:

- Energy consumption is most relevant in evaluating the smartness of a building. In particular heating and cooling systems are seen as the most important factors in reducing energy consumption.
- The planning and design phase is the phase of a project where most smartness-related decisions are made. The biggest impact on the life-cycle cost of smartness-related decisions occurs in the planning and design phase.
- Occupant comfort is considered slightly less important than energy consumption and life-cycle costs. Temperature and humidity stand out in this domain as more important than other categories.

The study is limited by the number of respondents, especially the number of owners. It should also be noted that the results are limited to the construction industry in the U.S. Research is under way to explore professional perspectives and practices in other countries, particularly in Europe.

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