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Development of a conceptual model for the selection of intelligent building systems

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Abstract

With the availability of a myriad of intelligent building components or products in the market, the decision to choose between them becomes significant and crucial in the configuration of building alternative. This results in placing the decision makers in the selection 'dilemma'. This paper presents the development of a conceptual model for the selection of intelligent building systems which aims at assisting the decision makers to select the most appropriate combination of intelligent building components. The paper commences by reviewing the literature on intelligent building research. A survey is conducted to examine the criticality of selection attributes. Findings of this survey enrich the field of intelligent building research in at least two ways. Firstly, it widens the understanding of the factors, as well as their degree of importance, in affecting the selection of intelligent building systems and components. Second, the identified selection attributes form a conceptual framework which can be used to guide the selection of intelligent building components.

Keywords: Intelligent building systems; Selection attributes; Building performance

1. Introduction

For the past two decades, the rapid evolving information technologies and a growing awareness of building constraints stimulated a stream of intelligent technology development, and raised abruptly the demand for 'intelligent' building. However, the development of intelligent building has higher complexity than a non-intelligent (traditional) building project. Such complexity arises from a number of concerns. First, intelligent buildings often incorporate state-of-the-art technologies to enhance workplace automation, energy management, safety, security, and telecommunications system [1]. These requirements are capital-intensive and entail a higher initial capital investment [2,3]. Second, the risk of obsolescence of technology distinguishes the intelligent buildings from other buildings. If technologies embedded in an intelligent building becomes obsolete, it would lose tenants very quickly as they may turn to other buildings which are able to meet their requirements or offer more sophisticated services [1]. Finally, the lack of experience and knowledge of intelligent building design and construction can be risky to both developers and designers [4]. These concerns indicate that selecting appropriate combination of building systems and components for a particular intelligent building project is one of the most fundamental and significant issues in the design stage.

While there are a plethora of intelligent building components or products available on the market, decision makers are confronted with the task of forming a particular combination of components and products to suit the need of a specific intelligent building project (for example: building automation system, HVAC, lighting, electrical installation, lift, fire protection, safety and security system), and simultaneously resolving any conflicts between the performance criteria. This process

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is essential, as the selected components should be matched as much as possible with the perceived user requirement or performance specification. If a particular component fails to meet the demand then under-performance arises. Any erroneous selection of systems can seriously affect the durability, service life, sustainability, and cost of repair and refurbishment of the building, and in turn, additional liabilities would be incurred to the building owners. Therefore, an analytical model is deemed conducive to selecting the most satisfactory components and systems as the 'trial and error' approaches are inefficient and impossible [5].

Despite that there is an abundance of literature on intelligent building research, no previous study has been found on the development of a systematic and analytical approach for the selection of the most satisfactory systems for intelligent buildings. Only a few closely related studies in performance attributes and assessment methods have been identified. Examples are the studies reported by Arkin and Pacuik [6] and Smith [7], and several useful performance indexes have been complied by well-known intelligent building research institutes [e.g. Intelligent Building Research Group (IBRG), the Asian Institute of Intelligent Buildings (AIIB)]. Examples of performance scoring models include: 'intelligent building score' (IBS) by Arkin and Pacuik [6]; 'quality facilities strategic design' (QFSD) and 'reframing' technique by Smith [7]; 'intelligent building index' (IBI) by AIIB [8]. Despite these developments, the explicit application of these models for intelligent building performance evaluation, has been generally minimal. Many of these models are perceived to be either incomprehensive or difficult to manipulate [9]. In addition, these studies have not sought to develop a systematic approach towards the selection of appropriate combination of building systems and components for intelligent building project [9,10]. This inspired the authors to develop a conceptual model for the selection of the most appropriate combination of intelligent building components. To achieve this tour study has been conducted to:

- determine the key attributes affecting the selection of the building systems and components,
- test criticality of these selection attributes,
- develop a conceptual model for the selection of the appropriate combination of building systems and components for intelligent building project.

2. Determination of the selection attributes

An extensive survey of literature enabled us to identify the attributes that can be used for the selection of intelligent building systems. (for example: [9,11–26]). Specifically, AIIB [8] identified several factors concerning the evaluation of the 'intelligent level' of intelligent building, and these factors were classified into nine criteria groups (for example: green, space, comfort, work efficiency, culture, high-tech image, safety and security, construction process and structure, and cost effectiveness). A summary of selection attributes is listed in Table 1, based on our literature search of existing studies in relevant areas. Although these identified attributes are important, it is certain that relative importance varies. A questionnaire survey was conducted to obtain professional judgments on the relative importance of these attributes.

3. Questionnaire survey

A structured questionnaire was adopted in this study instead of using rating or weighting determination methods as the former can provide less biased results [27–29]. This survey requires the respondents to rate the influence of pre-determined attributes based on their judgment and experience. They are also invited to add new attributes if necessary.

The questionnaire comprised three parts. Part 1 was intended to ask the respondents to rate the importance of numerous building systems according to their roles, responsibilities and functions in the intelligent building. In Part 2, the respondents were requested to select and verify the most important attributes when they selected the appropriate intelligent building systems and components. Part 3 of the questionnaire sought respondents' details to obtain their profile. All survey data accumulated were examined and analyzed using a standard version of SPSS® 12.0 software.

3.1. Sampling and data collection

A pilot study was conducted prior to the main survey, in order to test the suitability and comprehensibility of the questionnaire [30]. A minor group of construction professionals with knowledge of intelligent building were asked to comment and review on the clarity and relevance of the questionnaire. At the end of this pilot study, all comments received were positive and the unadulterated questionnaire remained for use in the main survey study.

In the main survey, six groups of professionals comprising academics, architects and design consultants, engineers, quantity surveyors, developers and construction practitioners were invited to complete the questionnaire. Using the official lists of professionals (for example: from the Association of Consulting Engineers of Hong Kong, and the Hong Kong Institute

Table 1
A summary of potential factors affecting the selection of intelligent building systems and components

Selection attributes	Reference
Building automation system (BAS)	
Work efficiency	
Grade and level of BAS	AIIB (2001)
Ability of integration	Myers (1997), Piper (2002), Dwyer (2003), Finch (1998)
Complied with standard	Myers (1997), Piper (2002), Dwyer (2003), Finch (1998), Bushby (1997)
Use of internet protocol	Best and de Valence (2002), Finch (2001)
Reliability	Piper (2002)
Efficiency (speed)	Piper (2002)
Allow for further upgrade	Piper (2002)
Maintenance factors	Piper (2002)
Remote control and monitoring	Dwyer (2003), Finch (1998)
Life span	Clements-Croome (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997), Piper (2002)
Life cycle cost	Clements-Croome (2001), Finch (2001), Myers (1997), Piper (2002)
Information and communication network system	
Work efficiency	
Transmission rate/speed	AIIB (2001), Armstrong et al. (2002)
Reliability	AIIB (2001), Armstrong et al. (2002)
Electromagnetic compatibility	AIIB (2001)
Mobile phone coverage	AIIB (2001)
Office automation (level)	AIIB (2001)
Public address system	AIIB (2001)
Clean earth	AIIB (2001)
FDDI	AIIB (2001)
Number of telephone line	AIIB (2001)
Satellite conferencing or high speed video conference	AIIB (2001)
Intranet management system	AIIB (2001), Best & de Valence (2002), Wang (2002)
Broadband internet connection	AIIB (2001), Best & de Valence (2002), Wang (2002), Dwyer (2003)
GOS & exchange lines	AIIB (2001)
IP address per staff	AIIB (2001)
Allow for further upgrade	Best and de Valence (2002)
Life span (year)	Clements-Croome (2001)
Technological related	
Advanced IT system	AIIB (2001), Best and de Valence (2002), Finch (2001)
Existence of artificial intelligent (AI)	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997), Armstrong et al. (2002)
Life cycle cost	Clements-Croome (2001), Myers (1997)
Fire protection system	
Work efficiency	
Compliance with fire protection & fighting code	Chow and Chow (2005)
Compliance with fire resistance code	Chow and Chow (2005)
Automatic sensoring and detection system for flame, smoke and gas	AIIB (2001), Luo et al. (2002), Shanghai (2001), Trankler & Kanoun (2001)
Remote control	AIIB (2001), Best and de Valence (2002), Finch (1998)
Signal transmission rate	AIIB (2001)
Maintainality of installation	AIIB (2001)
Comprehensive scheme of preventive maintenance	AIIB (2001)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Chow and Chow (2005)
Compatibility with other building systems	Myers (1997)
Integrated with BAS	Myers (1997), Shanghai (2001)
Technological related	
Existence of AI based supervisory control	AIIB (2001)
Modernization of system	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997)
Life cycle cost	Clements-Croome (2001), Myers (1997)

Table 1 (*continued*)

Selection attributes	Reference
HVAC system	
Environmental related	
Pollution related to fuel consumption	AIIB (2001)
Energy recycling	AIIB (2001)
Total energy consumption (kWh/year/m^2)	AIIB (2001), Wang (2000), Pan et al. (2003), Myers (1997)
Method of cooling	AIIB (2001), Wang (2000)
Condition of pipe insulation	AIIB (2001)
Contamination	AIIB (2001)
User comfort	
Thermal comfort: Predict mean vote (PMV)	AIIB (2001), Alcalá et al. (2004), Armstrong et al. (2002)
Thermal comfort: Indoor air quality	AIIB (2001),Clements-Croome (2001), Alcalá et al. (2004), Pan et al. (2003), Armstrong et al. (2002), Reffat and Harkness (2001)
Thermal comfort: OTTV (W/m^2)	AIIB (2001)
Amount of fresh air changes per second (litres/s/occupant)	AIIB (2001), Reffat and Harkness (2001)
Coefficient of performance of the whole building	AIIB (2001)
Cool air distribution	AIIB (2001), Reffat and Harkness (2001)
Noise level (NC)	AIIB (2001), Reffat and Harkness (2001)
Special ventilation for kitchen and toilet measured in are changes per hour (AC/h)	AIIB (2001)
Odour & freshness of indoor air	AIIB (2001), Alcalá et al. (2004), Reffat and Harkness (2001)
Appearance	AIIB (2001)
Cleanliness	AIIB (2001)
Work efficiency	
Heat pump & heat wheel	AIIB (2001)
Frequency of breakdown	AIIB (2001)
Refrigerant leakage detection	AIIB (2001)
Access for erection & maintenance	AIIB (2001)
Condensate drain water leakage	AIIB (2001)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Myers (1997)
Compatibility with other building systems	Myers (1997)
Integrated with BAS	Myers (1997), Shanghai (2001)
Technological related	
Existence of artificial intelligent (AI) based supervisory control	AIIB (2001), Myers (1997), Shanghai (2001)
Modernization of system	Best and de Valence (2002)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997), Klaassen (2001)
Life cycle cost	Clements-Croome (2001), Klaassen (2001), Myers (1997)
Electrical installation system	
Environmental related	
Electricity demand provision (VA/m^2)	AIIB (2001), Shanghai (2001)
Electric power quality	AIIB (2001), Shanghai (2001)
Work efficiency	
Electric power outlet	AIIB (2001), Shanghai (2001)
Electric power supply (A/m^2)	AIIB (2001), Shanghai (2001)
Frequency of major breakdown	AIIB (2001)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Myers (1997)
Compatibility with other building systems	Myers (1997)
Integrated with BAS	Myers (1997)
Technological related	
Extensive use of artificial intelligence for monitoring	AIIB (2001)
Safety related	
Compliance with regulations (i.e. electrical wiring regulation)	AIIB (2001)
Comprehensive scheme of preventive maintenance	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997)
Life cycle cost	Clements-Croome (2001), Myers (1997)
Lighting system	
Environmental related	
Permanent artificial lighting average glare index	AIIB (2001)
Permanent artificial lighting average lux level (lux)	Best and de Valence (2002)
Average efficacy of all lamps (lm/W)	AIIB (2001), Reffat and Harkness (2001)

Table 1 (*continued*)

Selection attributes	Reference
User comfort	
Adequate daylighting measured in average daylight factors (%)	AIIB (2001), Reffat and Harkness (2001), Earp et al. (2004)
Ventilation for excessive heat from lighting	AIIB (2001)
Noise from luminaries	AIIB (2001)
Ease of control	AIIB (2001)
Cleanliness	AIIB (2001)
Average colour temperature (nm)	AIIB (2001), Reffat and Harkness (2001)
Colour rendering	AIIB (2001), Reffat and Harkness (2001)
Glare (glare index)	AIIB (2001), Reffat and Harkness (2001)
Suitability for the task	AIIB (2001)
Colour matching of the finishes	AIIB (2001)
Appearance of finishes of lighting	AIIB (2001)
Work efficiency	
Permanent artificial lighting average power density (W/m^2)	Best and de Valence (2002), AIIB (2001)
Uniformity of lux level	AIIB (2001)
Automatic control/adjustment of lux level	AIIB (2001)
Maintenance factors (total lumen output in aging/total lumen output in new)	AIIB (2001), Atif and Galasiu (2003)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Myers (1997)
Compatibility with other building systems	Myers (1997)
Integrated with BAS	Myers (1997)
Technological related	
Architectural design (image)	AIIB (2001)
Extensive use of artificial intelligence for control and monitoring	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997)
Life cycle cost	Clements-Croome (2001), Myers (1997)
Hydraulic and drainage system	
User comfort	
Cleanliness	AIIB (2004)
Automatic flushing water control system (refilling speed, flow rate)	AIIB (2001), Shanghai (2001)
Automatic fresh water control system (flow rate)	AIIB (2001), Shanghai (2001)
Work efficiency	
Automatic flushing water control system	AIIB (2001), Shanghai (2001)
Automatic fresh water control system	AIIB (2001), Shanghai (2001)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Myers (1997)
Compatibility with other building systems	Myers (1997)
Integrated with BAS	Myers (1997)
Technological related	
Existence of artificial intelligent (AI) based supervisory control	AIIB (2001)
Architectural design (modernization of system)	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997)
Life cycle cost	Clements-Croome (2001), Myers (1997)
Safety and security system	
Work efficiency	
Time needed for public announcement of disasters (second/minute)	AIIB (2001), Chebrolu et al. (2004)
Time needed to report a disastrous event to the building management (second/minute)	AIIB (2001), Chebrolu et al. (2004)
Time for total egress (minute)	AIIB (2001), Chebrolu et al. (2004)
Connectivity of CCTV system to security control system	AIIB (2001), Chebrolu et al. (2004), Hetherington. (1999), Shanghai (2001)
Number (or %) of monitored exits and entrances	AIIB (2001)
Earthquake monitoring devices	AIIB (2001)
Wind load monitoring devices	AIIB (2001)
Structural monitoring devices	AIIB (2001)
Maintainality of installation	AIIB (2001)
Comprehensive scheme of preventive maintenance	AIIB (2001), Chebrolu et al. (2004)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Myers (1997)

Table 1 (*continued*)

Selection attributes	Reference
Compatibility with other building systems	Myers (1997), Dwyer (2003), Hetherington. (1999)
Integrated with BAS	Myers (1997)
Technological related	
Existence of artificial intelligent (AI) based supervisory control	AIIB (2001)
Modernization of system	AIIB (2001), Best and de Valence (2002)
Area monitored by CCTV	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997)
Life cycle cost	Clements-Croome (2001), Myers (1997)
Vertical transportation system	
Environmental related	
Energy consumption (kJ/passenger/minute)	AIIB (2001), Hetherington. (1999)
In-car and lobby noise (dBA)	AIIB (2001)
Machine room noise (dBA)	AIIB (2001)
Maximum allowable electrical power (kW)	AIIB (2001)
Total harmonics distortion (THD) of motor drive systems	AIIB (2001)
Regeneration into supply system (energy conservation)	AIIB (2001)
User comfort	
Acceleration and deceleration (m/s^2)	AIIB (2001)
Average illumination (lux)	AIIB (2001)
Air change (AC/hr)	AIIB (2001)
Noise (dBA)	AIIB (2001)
Vibration (m/s^2)	AIIB (2001)
Work efficiency	
Maximum interval time (second)	AIIB (2001), Siikonen (1997), Chu et al. (2003), Yost & Rothenfluh (1996)
Handling capacity in % of total population (%)	AIIB (2001), Chu et al (2003)
Journey time (second)	AIIB (2001), Siikonen (1997), Chu et al. (2003), Yost and Rothenfluh (1996)
Waiting time (second)	AIIB (2001), Siikonen (1997), Chu et al. (2003), Yost and Rothenfluh (1996)
Servicing and repair (times per month)	AIIB (2001)
Efficiency of drive and control system	AIIB (2001)
Automatic and remote monitoring	AIIB (2001)
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	Myers (1997)
Compatibility with other building systems	Armstrong et al. (2002), Myers (1997)
Integrated with BAS	Myers (1997)
Technological related	
Existence of artificial intelligent (AI) based supervisory control	AIIB (2001), Tanaka et al. (2004), Schofield et al. (1997)
Provision of indoor information display system	AIIB (2001)
Architectural design	AIIB (2001)
Modernization of system	AIIB (2001)
Safety related	
Time to identify trapped passengers without a mobile phone (minute)	AIIB (2001)
Installation of sensoring and detecting system	AIIB (2001)
Reliability (mean time between failure (MTBF)/month)	AIIB (2001)
Comprehensive scheme of preventive maintenance	AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Myers (1997)
Life cycle cost	Clements-Croome (2001), Myers (1997)
Building facade system	
Environmental related	
Sunlight pollution to others	AIIB (2001)
Allow for natural ventilation	Wigginton and Harris (2002)
Use of pollution-free product	AIIB (2001)
Prevention of noise pollution from outside	Armstrong et al. (2002)
User comfort	
Automatic response to change in temperature	Clements-Croome (2001), Wigginton and Harris (2002)
Automatic response to sunlight	Clements-Croome (2001), Wigginton and Harris (2002)

Table 1 (*continued*)

Selection attributes	Reference
Work efficiency	
Ability to filter excess and harmful sunlight	Armstrong et al. (2002), Wigginton and Harris (2002)
Automatic control and monitoring	Armstrong et al. (2002)
Remote control and monitoring	Wigginton and Harris (2002)
Life span (year)	Clements-Croome (2001) Wigginton and Harris (2002)
Allow for further upgrade	Armstrong et al. (2002), Wigginton and Harris (2002)
Compatibility with other building systems	Wigginton and Harris (2002)
Integrated with BAS	Wigginton and Harris (2002)
Technological related	
Existence of artificial intelligent (AI) based supervisory control	Wigginton and Harris (2002)
Architectural design (image of modernization)	Wigginton and Harris (2002), AIIB (2001)
Cost effectiveness	
First cost	Clements-Croome (2001), Armstrong et al. (2002), Wigginton and Harris (2002)
Life cycle cost	Clements-Croome (2001), Armstrong et al. (2002), Wigginton and Harris (2002)
Building interior layout	
Environmental related	
Pollution-free product	AIIB (2001)
Acoustics: Indoor ambient noise level (dBA)	AIIB (2001), Reffat and Harkness (2001)
Acoustics: Reverberation time	AIIB (2001), Reffat and Harkness (2001)
Spatial management	
Flexibility for installing new false ceilings and floor utilities for a totally different use	AIIB (2001), Myers (1997)
Flexibility for re-partitioning	AIIB (2001), Myers (1997)
Flexibility of internal re-arrangement of personnel	AIIB (2001), Myers (1997)
Work efficiency	
Life span (year)	Clements-Croome (2001)
Allow for further upgrade	
Compatibility with other building systems	
Integrated with BAS	Myers (1997)
Colour matching of finishes	AIIB (2001)
Technological related	
Architectural design (image of modernization)	
Cost effectiveness	
First cost	Clements-Croome (2001)
Life cycle cost	Clements-Croome (2001)

of Architects) as a basis, their companies profile and job history were reviewed via website so as to elicit those who had experience in intelligent building projects. With their assorted background and knowledge in the field, their views provided a good reflection of the selection attributes and their relative importance. A total of 136 copies of the questionnaire were distributed, and 65 valid responses were received. As there was no amendment required in the pilot questionnaires, these results also were added to the sample of main survey, which resulted in 71 usable responses, representing a response rate of 55%.

3.2. Statistical measures and analysis methods

In order to elicit the 'most important' factors, various techniques were considered. The Likert five-point scale was selected as it gives unambiguous results and is easy to interpret [28]. In this survey, all items in Part 1 and 2 of this questionnaire were measured on an ordinal basis. The respondent's perceptions are measured on the interval basis using a five-point scale, and they were asked to rank the attributes in descending order, where 1 represented 'not important at all', and 5 represented 'extremely importance'. All factors are first calculated and ranked according to their mean score ratings. The mean score rating was calculated using the following formula [28,31]:

$$\text{Mean} = \frac{1(n_1) + 2(n_2) + 3(n_3) + 4(n_4) + 5(n_5)}{(n_1 + n_2 + n_3 + n_4 + n_5)}, \qquad (1)$$

where n_1, n_2, n_3, n_4, n_5 represent the total number of responses for attributes as 1 to 5, respectively.

On the other hand, the t-test analysis was employed to identify the 'important' and 'most important' attributes among them [28]. The rule of t-test set out as follows:

The null hypothesis (H_0), $\mu_1 < \mu_0$, against the alternative hypothesis (H_1), $\mu_1 > \mu_0$, were tested, where μ_1 represents the population mean, and μ_0 represents the critical rating above which the attribute considered is most important. The value of μ_0 was fixed at '4' because it represents 'importance' and 'extremely importance' attribute according to the scale in the questionnaire. The decision rule was to reject null hypothesis (H_0) when the calculation of the observed t-values (t_O) (Eq. (2)) was greater than the critical t-value (t_C) (Eq. (3)) as shown in Eq. (4).

$$t_O = \frac{\overline{\chi} - \mu_0}{\widehat{s}_D/\sqrt{n}} \tag{2}$$

$$t_C = t_{(n-1,\alpha)} \tag{3}$$

$$t_O > t_C \tag{4}$$

where $\bar{\chi}$ is the sample mean, $\widehat{s}_D/\sqrt{n}$ is the estimated standard error of the mean of different score (i.e. $\widehat{s}_D$ is the sampled standard deviation of difference score in the population, n is the sample size which was 71 in this study), $n-1$ represents degree of freedom, and α represents the significant level which was set at 5% (0.05).

In this study, the importance of attributes to the selection of intelligent building systems was tested using Eq. (3). If the observed t-value is larger than the critical t-value ($t_O > t_C$), $t_{(70,0.05)} = 1.6669$ at 95% confidence interval, then null hypothesis (H_0) where the attributes were 'neutral', 'unimportant' and 'not important at all' was rejected and only the alternative hypothesis (H_1) was accepted. If the observed t-value of the mean ratings weighted by the respondents was less than the critical t-values ($t_O < t_C$), the null hypothesis that was 'neutral', 'unimportant', and 'not important at all' only was accepted.

In addition, the non-parametric Kruskal–Wallis one-way ANOVA test was undertaken to test whether there were statistically significant differences or divergences between each group of professionals regarding the relative importance of building systems and attributes. The matched parametric testing method was not employed in this study since the parametric assumptions were not fulfilled and the variables were measured by ordinal scale of measurement [30,32]. The results of the Kruskal–Wallis test are interpreted by the Chi-square (χ^2) and degree of freedom (df), and if the p-value is <0.05 which means there is a significant difference between the groups.

4. Findings and discussion

4.1. Demographic information

Fig. 1 provides a breakdown of the valid respondent responses by professional groups. Of the 71 respondents, the majority of them worked in quantity surveying (30%), engineering (28%), or architectural and building services design (17%), and the remainder had backgrounds in construction (15%), property development (6%) and research & development (4%). Sixty-one percent of the respondents have worked in construction industry for more than 10 years. All respondents had knowledge and experience in intelligent buildings, and 30% of them had direct experience of intelligent building design and construction.

4.2. Relative importance of intelligent building systems

Respondents were asked to rank the importance of 11 building systems. They were invited to add new building systems if necessary but no additional system was suggested. The results are shown in Table 2. The t-test of the means indicated that five building systems were considered 'more important' in intelligent building. Namely they are *building automation system; information and communication network system; fire protection system; HVAC system; and safety and security system*. These systems were classified as the 'primary building systems'. Conversely, the remaining building systems were ranked as less important, and were named as 'secondary building systems'. These systems included *electrical installation system; lighting system; hydraulic and drainage system; vertical transportation system; building façade system; and building interior layout system*. In order to investigate whether there were significant differences in rating the importance of building systems across the six professional groups, Kruskal–Wallis one-way ANOVA test was conducted. The results in Table 2 revealed that there was no significant difference between various professional groups for any of the listed building systems.

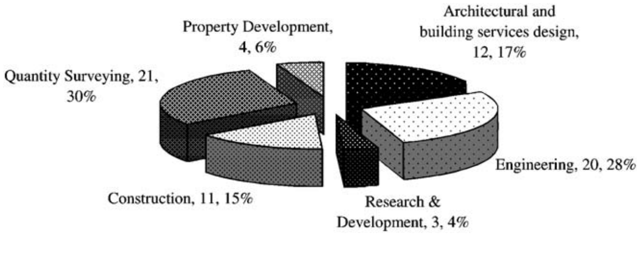

Fig. 1. Respondents by professional type.

Table 2
Survey results on relative importance of intelligent building systems

Intelligent building systems	Scale details		Mean		Mean rank						Kruskal–Wallis statistics	*p*-value
	Mean	SD	Rank	*t*-value	G.1	G.2	G.3	G.4	G.5	G.6		
A. Building automation system (BAS)	4.49	0.51	1	8.25	27.38	39.80	30.33	41.09	37.10	27.38	5.90	0.316
B. Information and communication network system	4.27	0.66	2	3.45	39.54	36.65	36.83	33.82	37.33	20.50	3.62	0.605
C. Fire protection system	4.27	0.88	3	2.57	40.67	31.45	34.33	39.36	34.00	47.25	3.94	0.557
D. HVAC system	4.23	0.66	4	2.88	31.92	31.15	59.00	39.27	38.00	35.75	7.10	0.213
E. Electrical installation system	3.97	0.79	7	−0.30[a]	36.17	32.55	44.50	38.50	36.76	35.50	1.49	0.914
F. Lighting system	3.94	0.83	8	−0.58[a]	29.46	34.28	36.67	33.50	40.07	49.25	4.64	0.461
G. Hydraulic and drainage system	3.76	0.80	9	−2.52[a]	36.50	33.48	50.17	37.64	31.81	54.00	6.63	0.250
H. Safety and security system	4.20	0.77	5	2.17	40.08	34.60	31.33	37.91	35.67	30.75	1.23	0.941
I. Vertical transportation system	4.01	0.91	6	0.13[a]	34.38	31.15	41.83	38.73	37.33	46.25	3.03	0.695
J. Building façade system	3.21	0.79	11	−8.40[a]	33.58	29.83	30.50	37.18	40.55	51.13	6.35	0.273
K.Building interior layout	3.25	0.87	10	−7.20[a]	35.00	36.63	37.17	42.41	30.05	48.63	4.98	0.418

df for Kruskal–Wallis test = 5.

G.1—architect; G.2—engineer; G.3—research & development; G.4—construction; G.5—quantity surveyor; and G.6—developer.

[a] Represents the *t*-value that is less than cutoff *t*-value (1.6669).

4.3. Relative importance of attributes for the selection of building systems

4.3.1. Important building systems ('primary building systems')

Table 3 summarized the descriptive and inferential statistics for the attributes of those 'more' important building systems. First, a total of 12 sub-criteria for the building automation system (BAS) selection were examined in the survey, and the *t*-test of the means showed that four of them were more significant to the selection of BAS. These were: "reliability" (A1.5), "life cycle cost" (A2.2), "ability of integration" (A1.2), and "efficiency" (A1.6) (as shown in Table 3). The sub-criterion, "reliability" (A1.5) was accorded the highest mean importance rating (4.32) by respondents, followed by "life cycle cost" (A2.2). Surprisingly, a number of attributes including the "grade and level of BAS" (A1.1), "complied with standard" (A1.3), "life span" (A1.10) were adjudged as insignificant. The *t*-test of the means also showed that "life cycle cost" (A2.2) was more significant than "first cost" (A2.1), which suggested that the decision makers concern more on the running and maintenance cost than the initial expense in the purchase of BAS.

"Reliability" (B1.2), "allow for further upgrade" (B1.15), "life cycle cost" (B3.2), "life span" (A1.10), and "transmission rate and speed (in and out)" (B1.1) were five more significant attributes to the information and communication network system. The remaining 15 sub-criteria were adjudged as insignificant contributors. On the other hand, Table 3 also shown that 7 factors were considered as important to the selection of fire protection system. These factors were "compliance with fire protection and fighting codes" (C1.1), "compliance with fire resistance code" (C1.2), "transmission rate of signal" (C1.7), "allow for further upgrade" (C1.11), "automatic sensoring and detection system for smoke" (C1.4), "life span" (C1.10), and "life cycle cost" (C3.2). The Kruskal–Wallis one-way ANOVA test showed that there were significant differences between various professional groups for the attribute: "allow for further upgrade" (C1.11) ($\chi^2 = 11.20$, $p<0.04$). This measure was less important to construction and quantity surveyors than to developers. The rest had very low level of significance.

Regarding the HVAC system, Table 3 suggested that many respondents viewed the sub-criterion "total energy consumption" (D1.4) as of 'importance' or 'extremely importance'. The *t*-test of the means also suggested other significant sub-criteria including "predict mean vote" (D2.1), "indoor air quality" (D2.2), "amount of fresh air changes per second" (D2.4), "noise level for ventilation and A/C" (D2.7), "frequency of breakdown" (D3.2), "life span" (D3.6), "compatibility with other building systems" (D3.8), "integrated with BAS" (D3.9), "first cost" (D5.1), and "life cycle cost" (D5.2). The rest had low levels of significance. The results of the Kruskal–Wallis one-way ANOVA test indicated that that there was no major difference between various professional groups for rating the attributes of HAVC system, except for the "life cycle cost" (D5.2) ($\chi^2 = 12.39$, $p<0.03$). This measure was less important to developers than to architects.

"Time needed for public announcement of disasters" (H1.1) was considered as the most 'significant' attributes in the selection of the safety and security system. Other sub-criteria including "time needed to report a disastrous event to the building management" (H1.2), "time for total egress" (H1.3), "life span" (H1.11), "allow for

Table 3
Selection attributes for the 'most' significant intelligent building systems

Intelligent building systems and their crucial selection attributes		Mean	Rank[a]	*t*-value[b]	Criteria group	Mean rank						Kruskal – Wallis statistics	*p*-value
						G.1	G.2	G.3	G.4	G.5	G.6		
BAS (Rank 1)													
A1.5	Reliability	4.32	1	3.384	Work efficiency (A1)	37.63	35.20	53.00	36.82	32.50	38.50	3.40	0.63
A2.2	Life cycle cost	4.30	2	3.535	Cost effectiveness (A2)	35.75	34.70	35.67	34.77	38.62	33.13	0.64	0.98
A1.2	Ability of integration	4.23	3	2.633	Work efficiency (A1)	36.04	37.65	57.50	28.23	36.93	28.00	6.56	0.25
A1.6	Efficiency (speed)	4.2	4	2.488	Work efficiency (A1)	44.67	36.05	48.33	32.32	31.24	35.63	5.61	0.34
Information and communication network system (Rank 2)													
B1.2	Reliability (frequency of major breakdown)	4.35	1	4.016	Work efficiency (B1)	28.58	36.75	43.67	35.50	38.21	38.50	2.78	0.73
B1.15	Allow for further upgrade	4.28	2	3.206	Work efficiency (B1)	42.42	35.38	55.50	31.36	36.33	16.25	9.51	0.09
B3.2	Life cycle cost	4.24	3	2.778	Cost effectiveness (B3)	38.75	33.00	57.50	38.09	33.38	34.63	5.21	0.39
B1.16	Life span (year)	4.23	4	2.791	Work efficiency (B1)	38.83	27.75	38.17	36.32	44.36	22.38	10.43	0.06
B1.1	Transmission rate and speed (in and out)	4.20	5	2.411	Work efficiency (B1)	37.08	33.40	41.33	38.45	38.24	23.25	2.97	0.70
Fire protection system (Rank 3)													
C1.1	Compliance with fire protection and fighting code	4.25	1	2.846	Work efficiency (C1)	32.33	32.00	46.50	43.77	35.29	41.50	4.46	0.48
C.1.2	Compliance with fire resistance code	4.24	2	2.576	Work efficiency (C1)	28.25	34.85	46.50	42.86	33.95	49.00	6.53	0.25
C3.2	Life cycle cost	4.24	2	2.576	Cost effectiveness (C3)	38.25	31.45	39.67	36.68	39.38	29.63	2.51	0.77
C1.7	Transmission rate of signal	4.23	3	2.709	Work efficiency (C1)	34.33	35.60	30.67	38.91	35.24	43.00	1.18	0.94
C1.11	Allow for further upgrade	4.23	4	2.440	Work efficiency (C1)	40.54	40.90	46.83	22.86	31.55	49.25	11.20	0.04[c]
C1.4	Automatic sensoring and detection system for smoke	4.21	5	2.561	Work efficiency (C1)	32.88	34.13	58.50	32.59	37.79	37.88	5.36	0.37
C1.10	Life span (year)	4.17	6	1.797	Work efficiency (C1)	40.00	30.75	38.67	35.00	36.05	50.75	4.50	0.48

Table 3 (*continued*)

Intelligent building systems and their crucial selection attributes		Mean	Rank[a]	t-value[b]	Criteria group	Mean rank						Kruskal – Wallis statistics	p-value
						G.1	G.2	G.3	G.4	G.5	G.6		
HVAC (Rank 4)													
D3.6	Life span (year)	4.24	1	2.856	Work efficiency (D3)	43.21	36.70	37.50	29.05	36.26	27.50	4.07	0.53
D2.1	Thermal comfort: Predict mean vote (PMV)	4.24	1	2.856	User comfort(D2)	39.63	33.70	47.50	41.14	34.43	22.13	4.93	0.42
D5.2	Life cycle cost	4.23	2	2.440	Cost effectiveness (D5)	42.96	27.30	56.50	42.32	36.64	22.50	12.39	0.03[c]
D2.2	Thermal comfort: Indoor air quality	4.21	3	2.422	User comfort(D2)	43.63	31.83	40.67	37.09	35.81	28.50	3.68	0.59
D1.3	Total energy consumption (kWh/year/m2)	4.21	4	2.303	Environmental (D1)	41.42	37.28	56.50	35.64	31.36	23.38	7.41	0.19
D3.9	Integrated with BAS	4.21	5	2.250	Work efficiency (D3)	41.21	35.50	46.83	31.23	35.52	30.38	2.88	0.71
D3.2	Frequency of breakdown	4.21	6	2.154	Work efficiency (D3)	42.46	37.95	46.33	34.55	30.86	30.13	4.37	0.49
D2.7	Reduced noise from ventilation and A/C	4.20	7	2.219	User comfort(D2)	45.79	32.85	48.33	41.86	30.69	24.88	9.25	0.09
D3.8	Compatibility with other building systems	4.20	8	2.114	Work efficiency (D3)	43.92	34.88	31.33	26.55	37.86	37.63	5.15	0.39
D5.1	First cost	4.18	9	2.260	Cost effectiveness (D5)	42.54	32.30	29.50	44.32	33.60	29.50	5.57	0.35
D2.4	Amount of fresh air changes per second (litres/s/occupant)	4.17	10	1.885	User comfort(D2)	40.83	35.10	32.00	40.73	34.38	24.50	3.17	0.67
Safety and security system (Rank 5)													
H1.1	Time needed for public announcement of disasters (second/minute)	4.42	1	5.919	Work efficiency (H1)	43.33	33.48	43.33	33.18	35.90	29.38	3.55	0.61
H3.2	Life cycle cost	4.41	2	4.857	Cost effectiveness (H3)	40.63	32.15	52.50	31.27	38.43	29.25	5.59	0.34
H1.2	Time needed to report a disastrous event to the building management (second/minute)	4.27	3	2.986	Work efficiency (H1)	44.21	31.30	39.33	37.05	38.43	16.75	7.98	0.15
H1.13	Compatibility with other building systems	4.25	4	2.846	Work efficiency (H1)	44.00	34.50	36.50	40.14	32.90	24.00	4.93	0.42
H1.14	Integrated with BAS	4.24	5	2.638	Work efficiency (H1)	44.83	26.63	37.00	41.23	39.17	24.63	10.16	0.07
H1.11	Life span (year)	4.20	6	2.165	Work efficiency (H1)	47.83	31.95	38.17	4.68	33.24	18.00	10.48	0.06
H1.12	Allow for further upgrade	4.20	6	2.165	Work efficiency (H1)	45.42	30.90	47.83	46.95	31.48	18.00	13.80	0.01[c]
H3.1	First cost	4.18	7	2.077	Cost effectiveness (H3)	37.13	34.35	38.67	35.59	38.19	28.50	1.19	0.94
H1.3	Time for total egress (minute)	4.18	8	1.932	Work efficiency (H1)	49.75	34.15	40.67	33.14	32.64	26.00	8.42	0.13

G.1—architect; G.2—engineer; G.3—research & development; G.4—construction; G.5—quantity surveyor; and G.6—developer

[a] Shows ranking within each building system.

[b] Represents the t-value that is larger than cutoff t-value (1.6669).

[c] Represents the p-value that is less than 0.05; df for Kruskal–Wallis test = 5.

further upgrade" (H1.12), and "compatibility with other building systems" (H1.13), "first cost" (H3.1), and "life cycle cost" (H3.2) were also considered as significant. The results of Kruskal–Wallis one-way ANOVA test showed that there was no significant difference between various professional groups for any of the listed sub-criteria in safety and security system except for the sub-criterion, "allow for further upgrade" (H1.12) ($\chi^2 = 13.80$, $p < 0.01$). This measure was less important to developers than to people engaged in research and development.

4.3.2. Less important building systems ('secondary building systems')

Table 4 encapsulated the statistic analysis of the attributes of the 'less important' intelligent building systems. First, the *t*-test results suggested 14 attributes were significant to the selection of vertical transportation system. They were: "energy consumption" (I1.1), "acceleration and deceleration" (I2.1), "air change" (I2.3), "noise" (I2.4), and "vibration" (I2.5), "maximum interval time" (I3.1), "journey time" (I3.3), "waiting time" (I3.4), "automatic and remote monitoring" (I3.7), "life span" (I3.8), "compatibility with other systems" (I3.10), and "integrated with BAS" (I3.11), "reliability" (I5.3), and "life cycle costing" (I6.2). The rest had low levels of significance. Also, Table 4 shows that four attributes were considered as important in the selection of electrical installation system: "life cycle cost" (E5.2), "compliance with regulations" (E4.1), "compatibility with other building systems" (E2.6), and "integrated with BAS" (E2.7).

Regarding the lighting system, nine attributes including "life cycle cost" (F5.2), "compatibility with other systems" (F3.9), "integrated with BAS" (F3.10), "permanent artificial lighting average power density" (F3.1), "life span" (F3.7), "allow for further upgrade" (F3.8), "average efficacy of all lamps" (F1.4), "ease of control" (F2.4), and "automatic control/adjustment of lux level" (F3.4) were considered by respondents as important attributes as shown in Table 4. "Life cycle cost" (F5.2) was accorded the highest mean importance rating (4.32) by respondents. However, the Kruskal–Wallis one-way ANOVA test revealed that there were significant differences between various professional groups for "life cycle costing" (F5.2) ($\chi^2 = 12.43$, $p < 0.02$). This measure was less important to engineers than to quantity surveyors and architects. On the other hand, only two sub-criteria, "life span" (G2.3) and "life cycle cost" (G4.2), were considered as 'importance' under the hydraulic and drainage system. The rest had a low level of significance.

The importance of attributes for the building façade and interior layout system selection were also calculated in Table 4. The *t*-test of the means suggested that the significant attributes for building façade system included: "automatic response to change in temperature" (J2.1), "automatic response to change in sunlight" (J2.2), "automatic control and monitoring" (J3.2), "life span" (J3.4), "compatibility with other building systems" (J3.6), "integrated with BAS" (J3.7), and "life cycle costing" (J5.2). The *t*-test of the means also identified three attributes which were more significant in the determination of the building interior layout. They were: "life span" (K3.1), "first cost" (K5.1), and "life cycle cost" (K5.2). The rest were considered as unimportance. The Kruskal–Wallis one-way ANOVA test results suggested significant differences between various professional groups in the "first cost" (K5.1) ($\chi^2 = 11.10$, $p < 0.04$) of the building interior layout system. This measure was less important in research and development group than in quantity surveyors.

4.4. Discussions

4.4.1. Intelligent building systems

The survey results specified that, while all building systems are considered as importance in literature, five building systems including the building automation system, information and communication network system, fire protection system, HVAC system, and, safety and security system were considered as marginally more important than the remaining building systems by the respondents. The difference in the importance of each system between professional groups was tested using the Kruskal–Wallis one-way ANOVA and no significant differences were found. The highest ranking of the BAS system (Rank 1) in the survey as the most important systems is not surprising. This finding supported the literature view that the BAS is the 'heart' of 'intelligent building' [33]. Gann [34] noted that the BAS acts as a network linking sensing, monitoring and control devices to a computerized management system which may include energy management, temperature and humidity control, fire protection, lighting, maintenance management, security and access control. Carlson [35] considered BAS as a tool to provide more effective and efficient control over all building systems. This supports why the BAS was ranked by the majority of respondents as the most important intelligent building system.

On the other hand, a sophisticated information and communication network system is considered as the fundamental to the success of the intelligent building in literature [9,23]. The importance was supported by respondents (Rank 2), and there were no significant differences were found between various professional groups (p-value = 0.605) which indicated that the importance of this system in intelligent building is not affected by different professionals. The system is capable of providing efficient and wide area communication through the use of modern communication technologies (for example: the integrated service digital network

Table 4
Selection attributes for the 'less' significant intelligent building systems

Intelligent building systems and their crucial selection attributes		Mean	Rank[a]	*t*-value[b]	Criteria group	Mean rank						Kruskal – Wallis statistics	*p*-value
						G.1	G.2	G.3	G.4	G.5	G.6		
Vertical transportation system (Rank 6)													
I5.3	Reliability (mean time between failure (MTBF)/month)	4.42	1	4.750	Safety and security (I5)	42.25	33.75	41.00	33.27	37.43	24.75	3.81	0.57
I3.8	Life span (year)	4.34	2	3.872	Work efficiency (I3)	46.50	33.60	44.00	33.27	34.29	27.00	5.91	0.31
I3.4	Waiting time (second)	4.34	2	3.872	Work efficiency (I3)	46.50	31.50	34.00	36.00	37.14	22.50	7.03	0.21
I3.1	Maximum interval time (second)	4.30	3	3.188	Work efficiency (I3)	43.00	32.92	44.50	35.18	35.64	28.13	3.48	0.62
I1.1	Energy consumption (kJ/passenger/minute)	4.28	4	3.293	Environmental (I1)	40.17	35.00	36.00	40.55	32.67	33.50	1.98	0.85
I2.1	Acceleration and deceleration (m/s^2)	4.27	5	3.064	User comfort (I2)	40.38	32.83	29.67	35.41	39.10	28.88	2.64	0.75
I3.3	Journey time (second)	4.25	6	2.846	Work efficiency (I3)	42.25	31.60	36.67	38.36	37.52	24.25	4.16	0.52
I3.11	Integrated with BAS	4.24	7	2.576	Work efficiency (I3)	42.21	34.25	30.33	36.68	34.45	36.63	1.84	0.87
I3.10	Compatibility with other building systems	4.24	8	2.518	Work efficiency (I3)	44.42	31.40	30.17	36.50	36.05	36.50	3.77	0.58
I6.2	Life cycle cost	4.24	8	2.518	Cost effectiveness (I6)	40.46	32.70	55.50	33.91	35.26	34.13	4.56	0.47
I2.4	Noise (dBA)	4.23	9	2.791	User comfort (I2)	43.92	30.40	28.00	32.23	40.00	35.63	5.84	0.32
I2.3	Air change (AC/h)	4.23	10	2.440	User comfort (I2)	43.33	31.20	30.67	33.82	39.43	30.00	4.42	0.48
I2.5	Vibration (m/s^2)	4.23	10	2.440	User comfort (I2)	45.17	30.65	27.50	31.18	39.83	34.75	6.47	0.26
I3.7	Automatic and remote monitoring	4.17	11	1.839	Work efficiency (I3)	44.25	35.92	22.83	36.09	34.05	31.50	4.03	0.54
Electrical system (Rank 7)													
E5.2	Life cycle cost	4.25	1	3.002	Cost effectiveness (E5)	37.50	35.85	47.00	33.27	36.86	27.00	2.25	0.81
E2.7	Integrated with BAS	4.24	2	2.778	Work efficiency (E2)	38.75	33.00	37.33	31.73	40.55	29.63	2.95	0.70
E4.1	Compliance with regulations (i.e. electrical wiring regulation)	4.24	2	2.638	Safety and security (E4)	45.00	28.60	46.67	38.59	36.29	29.38	7.32	0.19
E2.6	Compatibility with other building systems	4.20	4	2.571	Work efficiency (E2)	42.50	37.10	31.33	32.45	34.76	30.75	2.57	0.76
Lighting system (Rank 8)													
F5.2	Life cycle cost	4.32	1	3.943	Cost effectiveness (F5)	40.96	28.93	55.50	29.41	42.76	24.50	12.43	0.02[c]
F3.7	Compatibility with other building systems	4.25	2	2.712	Work efficiency (F3)	40.25	32.08	45.83	30.95	37.60	41.00	3.42	0.63
F3.8	Integrated with BAS	4.24	3	2.638	Work efficiency (F3)	38.42	33.33	37.00	29.82	39.17	41.75	2.67	0.75
F3.1	Permanent artificial lighting average power density (W/m^2)	4.20	4	2.342	Work efficiency (F3)	35.67	37.42	31.33	30.27	38.10	38.13	1.60	0.90
F3.6	Allow for further upgrade	4.18	5	2.077	Work efficiency (F3)	46.67	31.78	39.00	28.68	37.21	36.63	6.45	0.26
F3.5	Life span (year)	4.18	6	2.025	Work efficiency (F3)	36.33	32.85	38.83	31.27	41.81	31.13	3.44	0.63
F2.4	Ease of control	4.17	7	2.044	User comfort (F2)	33.96	38.58	39.83	31.09	39.00	24.13	3.49	0.62
F1.3	Average efficacy of all lamps (lm/W)	4.17	8	1.987	Environmental (F1)	40.17	37.00	14.67	29.00	40.24	31.50	7.15	0.20
F3.3	Automatic control/adjustment of lux level	4.17	9	1.839	Work efficiency (F3)	46.54	31.03	32.00	33.59	36.38	36.88	5.23	0.38
Hydraulic and drainage (Rank 9)													
G2.3	Life span (year)	4.28	1	3.491	Work efficiency (G2)	35.42	36.80	36.33	35.36	37.29	28.50	0.79	0.97
G4.2	Life cycle cost	4.28	2	3.126	Cost effectiveness (G4)	31.67	36.15	55.50	37.41	35.38	33.00	3.98	0.55
Interior layout (Rank 10)													
K5.2	Life cycle cost	4.31	1	3.683	Cost effectiveness (K5)	45.33	38.85	38.83	29.77	32.38	27.75	6.18	0.28
K3.1	Life span (year)	4.18	2	2.194	Work efficiency (K3)	44.79	38.50	39.33	28.00	32.14	36.88	5.87	0.31
K5.1	First cost	4.14	3	1.688	Cost effectiveness (K5)	37.08	37.55	15.00	27.9	43.67	25.00	11.10	0.04[c]
Façade system (Ran 11)													
J5.2	Life cycle cost	4.52	1	8.273	Cost effectiveness (J5)	43.75	35.92	29.17	33.41	34.17	35.00	3.13	0.67

J3.7	Integrated with BAS	4.42	2	4.876	Work efficiency (J3)	45.13	33.92	26.00	36.23	32.57	43.88	5.57	0.35
J2.1	Automatic response to change in temperature	4.39	3	4.702	User comfort (J2)	43.83	33.40	16.33	28.64	40.38	37.50	8.77	0.11
J3.4	Life span (year)	4.38	4	4.308	Work efficiency (J3)	45.25	36.25	32.33	31.77	32.93	37.50	4.24	0.51
J2.2	Automatic response to sunlight	4.37	5	4.058	User comfort (J2)	43.75	32.80	17.50	30.73	39.69	37.75	7.35	0.19
J3.6	Compatibility with other building systems	4.35	6	3.652	Work efficiency (J3)	45.88	34.30	32.67	32.14	32.81	44.75	5.63	0.34
J3.2	Automatic control and monitoring	4.30	7	3.048	Work efficiency (J3)	46.38	32.95	25.00	32.27	35.88	39.25	5.70	0.33

G.1—architect; G.2—engineer; G.3—research & development; G.4—construction; G.5—quantity surveyor; and G.6—developer.

[a] Shows ranking within each building system.

[b] Represents the t-value that is larger than cutoff t-value (1.6669).

[c] Represents the p-value that is less than 0.05; df for Kruskal–Wallis test = 5.

(ISDN), satellite systems, fiber optic system, bandwidth internet system). In addition, the implication of this system for the buildings is that they can improve the systems integration. For example: the recent development of web-enabled devices for the BAS allows remote monitoring of the building by interaction of the central BAS workstation with the remote dial-up system via modem [36]. This helps provide a low cost mechanism for reporting building performance remotely without the need for on-site computers. These critical functions may probably support the reason why the information and communication network system is considered as one of the most important systems in intelligent building.

Fire protection in good time is critical as it can contribute significantly to the success of rescue operations and to limiting the degree of damage [37]. The immediate reaction and the reliability of fire protection system are very important to maintain the safety of the occupants in the intelligent buildings. The importance of fire protection system (Rank 3) was confirmed by many respondents in the survey. This finding was also consistent with the viewpoint of previous literature [38–42]. Consistent with the literature, the HVAC system is also an important system ranked highly (Rank 4) by the respondents. So and Chan [33] pointed out that HVAC system consumes up to 50% of the total electricity consumption, and plays a dominant role to fine control indoor environment to arrive at a comfortable level for people to work and live. Trankler and Kanoun [37] emphasized the importance of HVAC system to avoid serious problems, such as sick building syndrome, building-related illnesses and mildew.

It was expected that the lighting system (Rank 8) would receive higher importance amongst intelligent building systems. This expectation was based on two points. First, the importance of the quality and quantity of lighting related to reflected and indirect glare. The illuminance and contrast values have a direct impact on the well-being, motivation, and productivity of persons in the building [33]. Second, the effective use of lighting can produce significant energy saving in buildings [43–46]. The reason for less importance of lighting system in the survey is probably due to the fact that the respondents consider the maximization of daylight resource has the potential to improve the quality of indoor lighting, substantially reducing the consumption of artificial lighting as well as energy costs [13].

Perhaps the most surprising feature of the results was the relative less importance of building façade system (Rank 11). There were no significant differences found between various professional groups (p-value = 0.273). The façade system is not only considered as a system providing protection from the weather, but also acting as climate modifiers controlling the amount of noise, sunlight and airs that enters the buildings and sustaining a healthy environment [1]. The lowest ranking of façade system in this survey was surprising. The possible reason to explain why the importance of the façade system was not supported was the respondents recognized the internal building systems were more significant in determining the success of the intelligent building, and thus received a higher importance.

4.4.2. Selection attributes

The survey results indicated that four building systems (HVAC, safety and security, vertical transportation, and lighting system) had more than eight important attributes in their component selection process. This implied that these systems cannot be simply determined by a few factors, more attributes with different variety is required to justify their selection decision. For instance, the survey results indicated 14 different criteria in determining the vertical transportation system. The survey findings further indicated that four attributes were repeatedly ranked highest in various building systems. These attributes included: 'life span', 'life cycle cost', 'reliability', and 'allow for further upgrade'. The importance of these attributes in the selection of the appropriate combination of building systems and components was supported by the literature [2].

Further analysis of the survey indicated most of the important attributes were in the 'work efficiency' and 'cost effectiveness' criteria. Work efficiency has been a top priority in intelligent building design in the literature [1,9] and its importance was further confirmed in this survey. The fundamental requirement in the selection of appropriate system was assuring the component function according to the specification and with acceptable durability, service life and sustainability. Also, evidence of the importance of cost-related factors is provided by the high ranking of 'life cycle cost' in all building systems (except for the vertical transportation system). The survey results support the view of Sobchak [47] that the primary concern of the developers, architects and property managers in intelligent building project was the cost savings can be produced in long run. Despite that the initial capital cost ('first cost') was traditionally considered as a decisive factor for the adoption of intelligent building technologies in the literature (for example: [47]), the survey findings indicated that the 'first cost' was declined from being the most important criterion in most of the systems, and was only considered as importance in HVAC system (rank 9), safety and security system (rank 7), and interior layout system (rank 3). This may suggest that the decision makers tend to be concerned with the costs of running, maintenance and refurbishment than the initial capital costs in the building components selection.

Moreover, the 'user comfort' was judged particularly important in the selection of HVAC system. Four attributes including 'predict mean vote'; 'indoor air quality'; 'reduced noise from ventilation and A/C'; and 'amount of fresh air changes per second' were ranked as highly important in the selection of HVAC system. This was consistent with the literature view that, although work efficiency and cost effectiveness of HVAC system were important, the need to provide the occupants with a comfortable and productive working environment which satisfies their physiological needs is also critical in the component selection [14]. These attributes in HVAC system was equally considered as important in AIIB's index model [8].

The importance of attributes in the selection of the appropriate combination of building systems and components was confirmed. However, it is surprising that a number of attributes that are quoted in the literature as crucial were not rated especially important by respondents in this survey. These attributes included: "complied with standard" (A1.4) and "use of internet protocol" (A1.5) in BAS systems [8,20,36,48]; "OTTV" (D2.3), "co-efficient of performance of the whole building" (D2.5), and "odor and freshness of indoor air" (D2.9) in HVAC system [8,21]; "in-car and lobby noise" (I1.2), and "servicing and repair" (I3.5) in vertical transportation system [8]; "sunlighting pollution" (J1.1), and "prevention of noise pollution" (J1.4) in building façade systems [49]; and "indoor ambient noise level" (K1.2), and "flexibility for installation" (K2.1) in interior layout system [8,21]. Here, these attributes were statistically considered as less important and relevant by the respondents, and therefore their importances were declined.

To summarize the findings and results of this survey, a five-level hierarchical conceptual model for the selection of intelligent building systems was proposed in Fig. 2. The top level is the selection goal, and following this is the two groups of building systems ('primary' and 'secondary'). The forth and fifth level comprise the attributes (criteria and sub-criteria) expanding from the building systems.

5. Future directions for research

The contributions of this survey are in at least two ways. First, the survey collected professional views to identify the perceived critical attributes and their degrees of significance. Second, the identified selection attributes form a conceptual framework which can be used to guide the selection of intelligent building components. This survey also attempted to select those professionals befitting to enter into the future research or analysis by asking a question on how the respondent was involved in intelligent building project in the survey. Those who indicated that they have/had practical application of intelligent building were invited to participate in the further research.

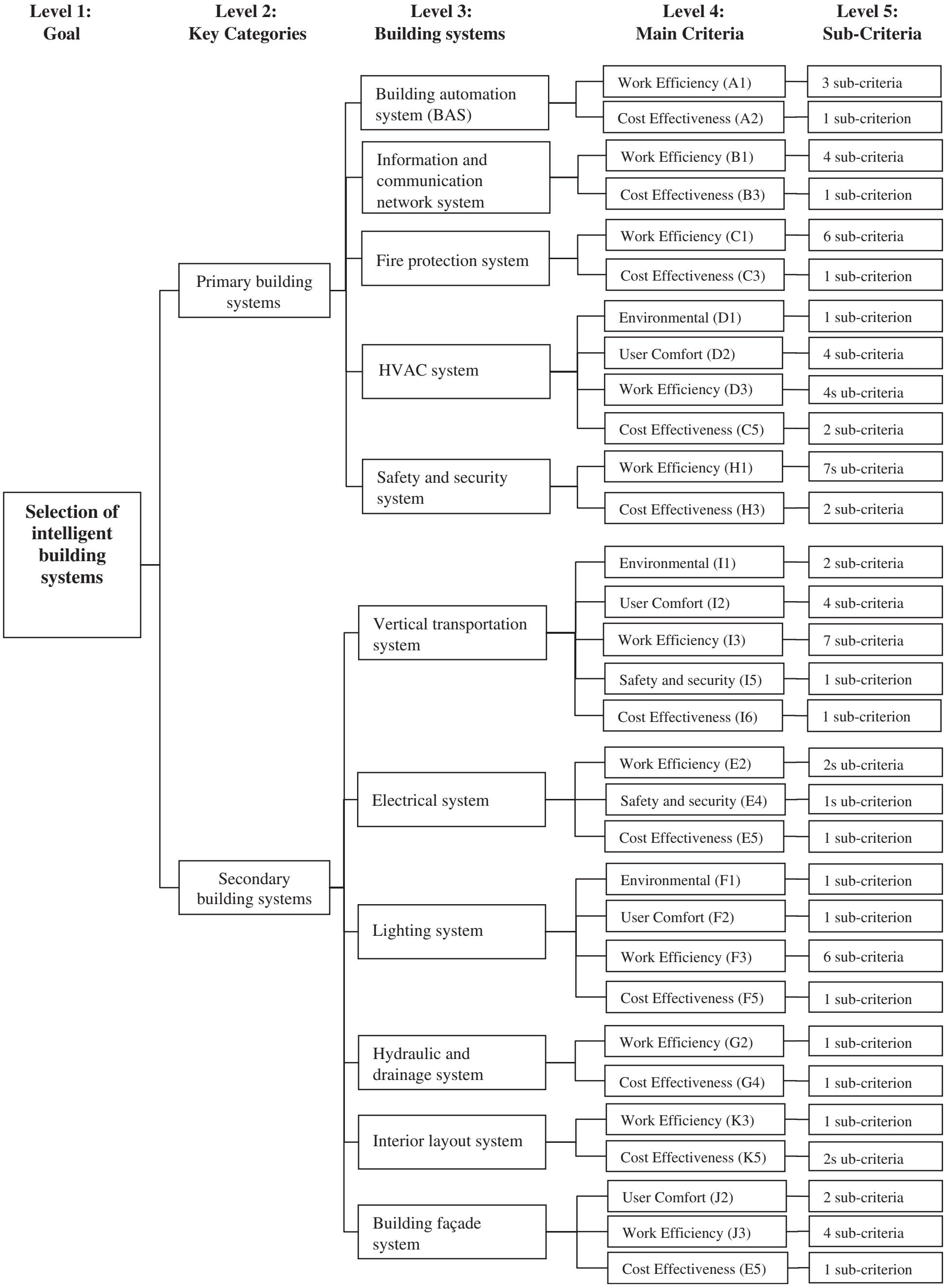

Fig. 2. A conceptual model for the selection of appropriate combination of building systems and components for a particular intelligent building project.

However, this research was not conducted without limitations. First, the current framework is not complete as it does not indicate how it can be used to aggregate all scores of each intelligent building components/systems to produce an integrated result for evaluating the combination of components in an intelligent building. Further work is needed to extend this model by evaluating the comparability of the attributes and specifying numerical weights representing the relative importance of the building systems and their attributes with respect to the goal (select the most appropriate combination of intelligent building systems). To achieve this, the analytical hierarchy process (AHP) is proposed as it helps prioritize or rank the attributes and distinguish in general the more important factors from the less important factors [50–52]. In addition, a computer program [i.e. decision support system (DSS)] is also established to assist decision makers systematically evaluating attributes and alternatives by using the AHP. Upon completion, a DSS is established allowing decision makers add or reduce the elements of a problem hierarchy regarding an individual intelligent building project. The aforementioned studies will be undertaken in the next stage of our work.

6. Conclusion

This paper presents the development of a conceptual model for the selection of intelligent building systems which aims at assisting the decision makers to select the most appropriate combination of intelligent building components. The survey study has been undertaken to investigate the importance of intelligent building systems and to determine the criticality of the selection attributes. In general, five building systems were identified as highly important. Also, a number of 'more important' attributes were identified. Future research is needed to develop the conceptual framework to a fully useful model to support the selection of intelligent building components and systems.

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