HOW SMART THE CITY OF COLOMBO IN SRI LANKA: ANALYSIS USING MODERN BUILDINGS

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Abstract

"Smart" building is a fast-growing concept around the world which has been risen during last few decades. It reduces the life cycle cost of the building with an optimal combination of comfort and energy along with many other benefits. This concept has been largely adapted in developed countries, but yet to achieve many improvements in this field in developing countries. Smartness has many dimensions such as technology, economy, user interaction and adaptability that enable an automated enterprise within a built environment. Since this is still at the adolescent stage in developing countries, the efficiency of buildings by being smart in the built environment are not well achieved.

This paper presents a comprehensive smartness scoring model that designed to measure the level of smartness. Eleven main criteria and 41 variables were considered to model the smartness. Further the model is applied in sixteen modern buildings Sri Lanka.

Results revealed that average smartness is 42%. This indicates that the country needs many improvements to achieve level of the best of the smartness.

Keywords: Smart buildings, Intelligent buildings, building performance, Smartness assessment

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1.0. INTRODUCTION

In early 80s, development of telecommunication industry and personal computer industry in U.S.A laid the first stone, to initiate the concept of "smart buildings" by connecting real estate development and technology (Sinopoli, 2010). At its early stages, the term "intelligent buildings" has been mostly used rather than the word "smart buildings". It is noticed that in more recent literature and industrial reports, the term "smart" has been widely used (Buckman, Mayfield, & Beck, 2014).

Smartness of a facility should be considered in all phases of its life cycle, including design, construction, and operation (Arditi, Mangano, De Marco, &Komurlu, 2013). Thus, a Smart Building (SB) has to be smart from the design where smart architecture has a big role to play (Senagala, 2006). SBs are comfortable and safe for their occupants as well as cost effective for their owners with anticipated low life-cycle costs (Katz &Skopek, 2009). Further SBs are designed for minimum environmental impact, wastage, and maintenance needs (Tsai, Yang, Chang, & Lee, 2014).

The popularity of SBs is becoming high due to increasing awareness of the importance and advantages (Arditi et al., 2015). Further, the smart concept has gone beyond the buildings by expanding into cities (Nam & Pardo, 2011). With mega scale construction projects, Sri Lankan construction industry also now trying to adapt smart building concept to mega projects in Sri Lanka.

With the increased demand for SBs, various smartness assessment models have been introduced to get a self-reflection of their facilities (Kahraman& Kaya, 2012; So & Wong, 2002; Arditi et al., 2015; Kolokotsa, et al., 2007). However, lack of holistic models for smartness assessment has been identified as one of the gaps in this field. Therefore, this research is focused to develop a smartness scoring model which can be easily applied by practitioners or facility managers at the operational phase. Following three objectives were set as follows;

1. Identify different evaluation criteria used to assess the smartness
2. Develop a mathematical model to score the level of smartness
3. Assess the smartness using the proposed model, considering modern buildings in Colombo as a case study

2.0. Literature review

2.1. Features of Smartness

Maximizing return on the investment and efficient and effective use of built environment along with occupant satisfaction can be considered as the primary objectives of IBs or SBs (Darwish, 2016; Azari et al., 2016). Within this context, smartness has many features and assessment parameters. Table 1 shows the development of such features and parameters.

Table.1: Smartness features and parameters

Period	Smartness Features	References	Smartness Parameters
1980s	Maximizing return on investment	(Pennell, 2013)	Financial
	Information communication network	(Kroner, 1997)	Integration
	Automatically controlled system	(Powell, 1990)	Automation
	Productive and cost-effectiveness	(Wigginton & Harris, 2013)	Financial
1990s	Human as the focal point	(Fujie & Mikami, 1991)	Occupant control, Occupant comfort
	Dynamic and responsive	(Everett, 2008)	Adoptability
	The emergence of ICT and automated systems	(Kroner, 1997)	Integration, Automation
	Maximizing the technical performance, investment and operating cost savings, and flexibility	(Derek & Clements-Croome, 1997)	Financial
	Responding to the social and technological changes	(Derek & Clements-Croome, 1997)	Adoptability, Learning ability
	Maximizing the effectiveness of the building's occupants and efficient management of resources	(Wigginton & Harris, 2013)	Financial, Space management
2000–2005	Responding to user expectations and quality of life	(Preiser & Schramm, 2002;Wigginton & Harris, 2013)	Occupant control, Occupant comfort, Adoptability
	The role of user interactions and social changes	(Wong et al., 2005; Wigginton & Harris, 2013)	Occupant control, Adoptability
	Flexibility and adaptability	(Hagras, Callaghan, Colley, & Clarke, 2003)	Adoptability
2005–2010	The efficiency aspect, the cost aspect, the environmental aspect, the health aspect and the security aspect	(Gray, 2006)	Financial, Environment, Safety, Security
	Safer, more productive and more operationally efficient for the owners	(Ehrlich, Capehart, Capehart, Allen, & Green, 2007)	Financial, Safety
	Energy-saving features	(Strumiłło & Łódz, 2014)	Energy efficiency
	Incorporation of smart active features and passive design techniques	(Ochoa & Capeluto, 2008)	Passive intelligence
	Eco-intelligent	(GhaffarianHoseini, 2012)	Sustainability
2010–2015	People, products, and processes	(Alwaer & Clements-Croome, 2010)	Enterprise intelligence

	User involvement in sustainable energy performance of buildings	(Janda, 2011)	Occupant control, Energy efficiency
	Considering the users' interactions and even the social values of users	(Jamaludin, 2011)	Occupant control
	Ecologically sustainable design	(GhaffarianHoseini, 2012)	Sustainability
	Innovation as an enabler and new products such as cloud computing, embedded sensors, and smart materials	(Alwaer, et al., 2013)	Integration, Automation
	Responding to the needs and social well-being of the occupants and of society	(Clements-Croome, 2011)	Occupant comfort, Adoptability
	Suitability for their planned use and success at fulfilling the brief	(Clements-Croome, 2011)	Enterprise intelligence
	Energy-intelligent concept	(Nguyen & Aiello, 2013)	Energy efficiency
	Satisfying occupants' need with high energy efficiency	(Yang, 2013)	Occupant comfort, Energy efficiency
	Sensory design	(Kerr, 2013)	Automation
	Intelligent control strategies, including smart grids, smart metering, demand response control	(Farias et al., 2014;Costanzo et al., 2012)	Integration, Automation
	Adaptability of buildings including to climate change	(Buckman et al., 2014)	Adoptability
	Learning capability, self-adjustability, and the relationship between occupants and environment	(Kaya & Kahraman, 2014)	Adoptability, Learning ability

Adapted from Ghaffarianhoseini et al. (2016)

2.2. Smartness Assessment Criteria and Rating Systems

Different rating systems and methods are developed to assess the level of smartness (Wong et al., 2005) and they can be classified into three groups as follows (Clements-Croome, 2004);

- Rating methods: Relies on a series of factors/indicators related to the design and the performance issues together with their defined scales to rate the smartness
- Simulation methods: Uses artificially settings based on real-world data from the operation of a SB
- Facilities management methods: Use experts' knowledge to achieve goals in design, construction and operation of a SB.

Asian Institute of Intelligent Buildings (AIIB) developed a quantitative assessment model; "intelligent building index (IBI)" that was originated from nine 'Quality Environment Modules' (M1–M9) where; M1: environmental friendliness: health and energy conservation, M2: space utilization and flexibility, M3: human comfort, M4: working efficiency, M5: culture, M6: image of high technology, M7: safety and security measures: fire, earth- quake, disaster and structural damages, etc., M8: construction process and structure, and M9: life cycle costing: operation and maintenance with emphasis on cost effectiveness.Kolokotsa et al. (2007) proposed a Matrix tool in which 5 performance indicators such as built environment, responsiveness, functionality, economic issues, and suitability have been used. Later in 2015, Arditi et al. (2015) developed a simplified Smartness Index that considered only three aspects such as economic, energy and occupant comfort. Further, Nilashi et al. (2015) mentioned that any rating system that is focused on sustainability and environment factors can also be used to assess the smartness of buildings. For instance, green building rating systems like LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), CASBEE (comprehensive assessment system for building environmental efficiency) and Green Star are frequently used methods to assess smart buildings (Chen, et al., 2006). Same criteria can be extended to evaluate cities as the indicators used in above methods can be commonly used to assess urban environments. However, most of above mentioned evaluation criteria have been criticized by researchers for being subjective and being focused on few main attributes (Wong et al., 2005; Chen et al., 2006).

3.0 Research Methodology

This research has been conducted into 3 steps as follows;
First Step: different attributes and variables which can be used to assess the smartness were identified through literature.
Second Step: Attributes and variables identified through literature were validated from 5 industry experts. They were selected from five fields related to smart buildings as shown in Table 2 to ensure the comprehensiveness of data collected. Based on the literature findings and further from expert interviews, 11 independent attributes were established to assess the level of smartness in buildings. They are as follows,

1. Automated control and monitoring
2. Service integration
3. Energy efficiency
4. Intelligent space management
5. Organizational, enterprise intelligence
6. Adoptability and Learning ability
7. Passive intelligent features
8. Occupant control
9. Occupant comfort
10. Safety and security measure
11. Environment and sustainability

Further, a number of sub factors (variables) were identified as shown in Table 3 to assess each attribute.

Table 2: Expert profile

Expert No	Designation/Experience	Description
E1	Senior MEP Engineer/ Managing director 15 years local experience	Actively involved in many large scale building projects. Passionate towards innovative building projects. Managing director of a leading MEP consultancy firm.
E2	Senior Engineer/ Director	Director of a Sri Lanka's leading innovative building

	14 years of experience that includes 8 years of international experience	consultancy firm. Specialized in energy and climate related aspects. Actively involved in innovative building projects in Sri Lanka.
E3	Senior facilities engineer/ Chief operating officer 16 years of local experience	Presently works as the senior facilities engineer at a large scale commercial building that can be considered as a smart building. Previously involved in several innovative energy efficiency projects.
E4	Chief facilities engineer 13 years of local experience	Presently works as the chief engineer of a very recently build high rise five-star hotel. Actively involved in many smart implementation projects.
E5	Manager building automation 10 years of local and international experience	Actively involves in number of building automation projects including most sophisticated projects in Sri Lanka. Presently works as a manager in a leading building automation company.

Table 3: Weightages of attributes (**Wi**) and Variables (**Vi**)

Attributes (*F*)	W_i	No.	Variables (*X*)	V_{ij}
Automated control and monitoring	4.6	1	Integrated building management system (BMS) for overall controlling and monitoring of the building	5.0
		2	HVAC	4.8
		3	Electrical system	4.2
		4	Water distribution and drainage	3.4
		5	Addressable fire detection and alarm system	4.2
		6	Telecommunication (PABX)	1.2
		7	Lighting	4.0
		8	Security monitoring and surveillance (CCTV)	1.6
		9	Access control	3.2
		10	Transportation systems	2.6
		11	Computerized maintenance management system	3.4
Service integration	4.4	1	Level of service integration	4.4
Energy efficiency	4.4	1	HVAC	5.0
		2	Lighting	3.4
		3	Pump system	1.6
Intelligent space management	2.4	1	Capability of the building to respond to rapid changes in the size and structure of organizations and work practices.	2.4
Organizational/enterprise intelligence	4.4	1	Level of integration of organizational functions with the building	4.4
Adoptability and Learning ability	4.6	1	Different people's perceptions of comfort at different times of day and different times of year	3.6
		2	Changes in occupants or building use	4.4

		3	Varying occupancy data characteristics	4.6
		4	Varying yearly average external whether conditions	4.0
Passive intelligent features	2.6	1	Effective Orientation	2.0
		2	Integration of renewable energy technologies	4.2
		3	Efficient building envelope	2.8
		4	Natural ventilation	3.2
		5	Daylighting	3.6
Occupant control	4	1	HVAC	4.6
		2	Lighting	4.6
Occupant comfort	4.2	1	Temperature	4.0
		2	Humidity	4.0
		3	Air quality	4.0
		4	Acoustic comfort	2.2
Safety and security measure	3.6	1	Fire detection	5.0
		2	Fire fighting	5.0
		3	Public address	4.6
		4	Security control	3.8
		5	Structural monitoring	2.4
Environment and sustainability	2.8	1	Water efficiency	4.2
		2	Solid waste management	4.4
		3	Gaseous Effluent management	3.0
		4	Liquid effluent management	4.2

Third Step*:* The second objective of the expert interview is to determine the weightages of each attributes and variables. This is essential because different attributes and variables are not equally important toward measuring the smartness of a building. According to Brace (2008) Likert scale has an advantage of self-completion within short time period. Therefore, experts' views were obtained using a five-point Likert scale where 5 - Extremely important, 4 - Very important, 3 - Averagely important, 2 – Less important and 1 – Rarely important. Mean value of the experts' answers were then used to calculate the weightages of all the attributes (W_i) and relevant variables ($V_{i,j}$).

Further, Delphi survey was used to ensurethe accuracy and accountability of the weightages (Okoli& Pawlowski, 2004). In this survey, after the first round of interviews, the summarized data of all the interviews sent back to all experts to communicate the different views of experts to one another. It also gave an opportunity for experts to review their views on the assessment model. Most importantly experts were able to consider the newly added, rejected and modified variables and attributes during this process. Weightages were adjusted accordingly (refer Table 3) as follows;

$$weightage = \frac{1\times N_1+2\times N_2+3\times N_3+4\times N_4+5\times N_5}{N} \quad (1)$$

Where,

N_n=number of responds per scale

N = Total number of respondents = 5

Smartness Assessment Model

In this model, the smartness is derived as a function of above attributes (*F*). When a certain factor is a characteristic of number of attributes, factorial methodology can be used to quantify if those attributes are linearly connected and independent (Chew & De Silva, 2004). Assuming above attributes and variables are independent and linear, the smartness can be quantified as;

$$Smartness\ (S)\ = f(F_i) \quad (2)$$

Since the importance of each attributes towards the smartness can vary, the smartness was assessed using their weightages and thus, smartness can be modelled as;

$$Smartness\ (S) = \frac{\sum_{i=1}^{n} W_i F_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

Where,

n = Number of attributes

W_i = Weightage of the attribute

Since each attribute (*Fi*) is a function of another set of variables (X) (refer Table 3), *Fi* is then expressed as;

$$(F_i) = f(X_{ij}) \quad (3)$$

F_i = i^{th} attribute

X_{ij} = j^{th} variable of i^{th} attribute

j = variable number

The variables related to each attribute also have different level of importance towards assessing smartness. Thus, equation 3 can express as follows;

$$Attribute\ value\ (F_i) = \frac{\sum_{j=1}^{m} V_{ij} X_{ij}}{\sum_{j=1}^{m} V_{ij}} \quad (4)$$

Where,

V_{ij} = Weightage of the variable

m = Number of related variables of the attribute

Further the grading of each variable is setup according to the particular levels of scores associated with it. Thus, the *k* set of sub-grades denoted by $[X_{ij}]_k$, where ***j*** = 1,2,…….,m and *k*= 1,2,3 (refer Appendix B and C) were used. Therefore, $F_i$is;

$$Attribute\ value\ (F_i) = \frac{\sum_{j=1}^{m} V_{ij} X_{ij,k}}{\sum_{j=1}^{m} V_{ij}} \quad (5)$$

<u>Fourth Step</u>: Multiple case studies were conducted to assess the smartness of modern buildings in Sri Lanka using the developed model. Physical observations of the buildings and interviews

with relative professionals in the buildings were conducted to gather in depth data for variables. Each variable was then assessed using a set of sub-grades. For example, sub grades of the variable "computerized maintenance management system" are as follows;

3 (Advanced) - Computerized maintenance management system is in operation with advanced features like Mobile Access, Purchasing and Technician Management.
2 (Important) - Computerized maintenance management system is in operation with important features like Asset Tracking, Calibration Management, Inventory Control, Key & Lock Management, Service History Tracking and Work Order Management.
1 (Essential) - Computerized maintenance management system is in operation only with basic features like preventive maintenance scheduling.

Since many modern buildings are situated in Colombo suburb area and also due to the convenience in access, the buildings located in Colombo suburb area were selected for multiple case studies. Smart building concept initially came to the practice in Sri Lanka in around year 2000 therefore, older buildings normally do not show smart building features. Hence, buildings which started their operation after 2004 were chosen for the sample framework. Since it is very rare that small building projects adopt smart building concept, only high rise buildings were considered. Therefore, high-rise commercial, hotel and apartment buildings were selected. Then the sample population as all commercial, hotel and apartment buildings in operation situated in the Colombo suburb area which started operation after 2004 and which has eight or more than eight floors.

4.0. Analysis and Results

The validated smartness assessment model was applied to selected sample of sixteen buildings in Colombo suburbs to assess the smartness of Sri Lankan modern buildings. Building sample consisted of commercial, hotel and apartment buildings. Results showed that average smartness of modern buildings in Colombo is 42%. Among the different types of buildings, commercial buildings have obtained the highest smartness rating of 48.35% while hotel buildings and apartment buildings are rated as 45% and 34% respectively (Table 4).

Table 4: Smartness ratings

Building Name	**S**	**S_R**
CB1	1.4223	47.41
CB2	1.2587	41.96
CB3	0.9971	33.24
CB4	1.8401	61.34
CB5	1.7336	57.79
Average of commercial buildings	**1.4504**	**48.35**
HB1	0.9064	30.21
HB2	1.2879	42.93
HB3	1.6352	54.51
HB4	1.6961	56.54
HB5	1.2718	42.39
Average of hotel buildings	**1.3595**	**45.32**
AB1	1.0124	33.75
AB2	0.8944	29.81

AB3	1.5560	51.87
AB4	0.7672	25.57
AB5	1.2718	42.39
AB6	0.6514	21.71
Average of apartment buildings	**1.0255**	**34.18**
Overall average	**1.2627**	**42.09**

Among the commercial buildings, CB4 and CB5 have obtained the high smartness ratings 61.34 and 57.79 respectively. Not only among commercial buildings, these two buildings obtained the highest smart ratings of the entire sample. Highly advanced and sophisticated BMS, advanced technologies used in the HVAC systems, and advanced sensors/controls are the main smart features of these buildings. The lowest rating of 33.24 among commercial building was obtained by CB3. CB3 is a government owned building which was relied on very conventional technologies.

Among hotel buildings, HB4 and HB3 obtained highest smartness ratings of 56.54 and 54.51 respectively. HB4 received this rating mainly by addressing energy efficient features while HB3 by addressing organizational intelligence features.

AB3 has achieved the highest smartness rating of 51.87 for apartment buildings. This is mainly due to advanced BMS system and itsenvironment friendly features.

The average scores for each attribute are calculated using equation 5. Table 5 indicates the findings.

Table 5: Average attribute scores

Building type	Building	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_2
Commercial	CB1	61.1	66.6	56.0	66.6	0.00	0.00	69.6	33.3	89.6	67.6	27.0
	CB2	45.7	66.6	56.0	66.6	0.00	0.00	53.1	66.6	28.1	63.4	35.8
	CB3	35.1	33.3	44.6	66.6	0.00	0.00	40.5	83.3	0.00	46.1	45.1
	CB4	63.1	66.6	67.3	66.6	66.6	0.00	87.3	66.6	94.8	69.5	35.8
	CB5	77.8	66.6	100.	66.6	66.6	9.24	40.5	0.00	84.5	84.9	27.0
Average		**56.6**	**60.0**	**64.8**	**66.6**	**26.6**	**1.85**	**58.2**	**50.0**	**59.4**	**66.4**	**34.2**
Hotel	HB1	56.6	60.0	64.8	66.7	26.7	1.8	58.2	50.0	59.4	66.3	34.2
	HB2	33.6	33.3	83.3	0.00	33.3	0.00	77.2	66.6	37.5	65.7	45.1
	HB3	60.8	66.6	61.3	66.6	100.	0.00	40.5	66.6	32.8	86.2	9.28
	HB4	52.1	66.6	84.0	66.6	66.6	0.00	44.3	66.6	66.6	70.8	36.2
	HB5	24.4	33.3	56.0	33.3	33.3	0.00	67.0	100.	38.5	51.6	45.1
Average		**45.5**	**52.0**	**69.9**	**46.7**	**52.0**	**0.4**	**57.5**	**70.0**	**47.0**	**68.1**	**34.0**
Apartment	AB1	33.6	33.3	50.6	0.00	33.3	0.00	79.7	66.6	0.00	63.4	15.6
	AB2	24.1	66.6	28.0	0.00	0.00	0.00	73.4	66.6	0.00	66.9	9.28
	AB3	57.9	66.6	28.0	0.00	66.6	0.00	12.6	83.3	84.5	84.9	62.4
	AB4	32.4	0.00	38.6	0.00	0.00	0.00	43.0	66.6	10.3	59.6	42.1
	AB5	61.5	66.6	28.0	0.00	66.6	0.00	55.7	66.6	9.39	67.6	33.3
	AB6	24.4	0.00	28.0	0.00	0.00	0.00	73.4	66.6	0.00	40.0	26.5
Average		**39.0**	**38.9**	**33.6**	**0.0**	**27.8**	**0.0**	**56.3**	**69.4**	**17.4**	**63.8**	**31.6**
Overall average		**47.1**	**50.3**	**56.1**	**37.8**	**35.5**	**0.7**	**57.3**	**63.1**	**41.3**	**66.1**	**33.3**

Tenth attribute “safety and security” obtained the highest score followed by “occupant control” and “passive intelligent features”. Safety feature is evaluated mainly based on the fire safety, security controls and structural safety of buildings and their advanced technologies were assessed. In analyzing occupant control, provisions provided for controlling of HVAC and lighting were assessed. Hotels and apartments have provided more occupant control while commercial buildings were using more centralized and automated controlling mechanisms such as scheduling, zoning and sensor based controlling. Integration of renewable energy, efficient building envelop and orientation, effective use of natural ventilation and day lighting were considered under passive intelligent features of buildings. All passive intelligent features used in those buildings could able to reduce the energy cost.

Since the assessment was done using completed buildings, these variables can be assessed during the design stage in order to assess the Smartness of the buildings that it will get after completion. Thus, this can be used as a tool to assess the smart architecture.

5.0 Conclusion

Smart building concept is a very popular concept used by the developed countries to maximize the efficiency and performance while achieving low operational cost. On the other hand, in developing countries like Sri Lanka, smart building concept has not adapted at its full scale due to several limitations such as high initial cost, unavailability of advanced technologies and unavailability of competent professionals.

Smart building concept is not an instantaneously implemented concept. It is a progression of concepts such as automated buildings, sustainable buildings and intelligent over few decades. This progression is mainly influenced by the rapid development in telecommunication technologies, information technology and automation technologies. Findings indicate that there is no absolute definition for smart buildings. Different authors and institutes have defined smart buildings from different viewpoints. Generally, smart building is a building which use advanced technologies to provide an optimum overall performance throughout its lifetime. Smart buildings have many features that may not be specific to smart buildings but should possess by the smart buildings.

It is identified that different institutes and authors have introduced many different building performance evaluation criteria over last few decades. These criteria focus different bases in assessing the performance of the buildings. From these methods, the researcher was able to identify different evaluation criteria that can be used assess the level of smartness in buildings in the literature review. Most of these methods can be criticized for the comprehensiveness as those are focused on several main attributes rather than focusing the total smartness of the building. Thus, a holistic smartness assessment model was developed in this research. 41 variables under 11 attributes are used to model the smartness.

All the attributes in the smartness assessment model were weighted considering importance towards assessing the smartness in a building with the opinions of the experts. If there are more than one variable available under one attribute those variables were also weighted same as the attributes. Each of variable is quantified using subgrades to assess them accordingly. Therefore, this developed smartness assessment model can be used as a tool to assess the level of smartness in buildings.

6.0 Limitations

Several limitations were encountered by the researcher during the research process. Contrast views about smart buildings available in the literature was a main limitation faced in the literature review. Very less number of experienced professionals are available in Sri Lanka, who are actively involved with smart buildings as this concept, since it is still a new concept to the local context. Therefore, an extra effort and time had to be spent in conducting the expert interviews. The researcher had selected only sixteen buildings located in Colombo suburb, for the convivence of easy access. All the buildings selected had started their operation after 2004 and had at least eight floors. Since, generally older buildings do not have smart features and smart building features are mostly implemented in high rise buildings.

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