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What is an intelligent building? Analysis of recent interpretations from an international perspective

Amirhosein Ghaffarianhoseini[a], Umberto Berardi[b], Husam AlWaer[c*], Seongju Chang[d], Edward Halawa[e], Ali Ghaffarianhoseini[f] and Derek Clements-Croome[g]

[a]*Department of Geography, Faculty of Arts and Social Sciences, University of Malaya (UM), Kuala Lumpur, Malaysia;* [b]*Department of Architectural Science, Ryerson University, Toronto, Canada;* [c]*School of Social Sciences (Architecture & Planning), University of Dundee, Dundee, UK;* [d]*Department of Civil & Environmental Engineering, KAIST, Daejeon, Korea;* [e]*Centre for Renewable Energy (CRE), Charles Darwin University, Darwin, Australia;* [f] *School of Engineering, AUT University, Auckland, New Zealand;* [g]*School of the Built Environment, University of Reading, Reading, UK*

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In recent years, the notion of intelligent buildings (IBs) has become increasingly popular due to their potentials for deploying design initiatives and emerging technologies towards maximized occupants' comfort and well-being with sustainable design. However, various definitions, interpretations, and implications regarding the essence of IBs exist. Various key performance indicators of IBs have been proposed in different contexts. This study explores the notion of IBs and presents an analysis of their main constituents. Through a comparison of these constituents in different contexts, this study aims to extract the common features of IBs leading to an evolved definition which could be useful as a reference framework for design, evaluation, and development of future IBs. Findings also scrutinize the long run benefits of IBs, while demonstrating the constraints and challenges of the current international interpretations.

Keywords: intelligent buildings; key performance indicators; intelligence; sustainable buildings

1. Introduction

> Over the past 20 years, many different buildings have been labeled as intelligent. However, the application of intelligence in buildings has yet to deliver its true potential.(Clements-Croome 2013)

For the last three decades, the so-called intelligent buildings (IBs) were only a conceptual framework for the representation of future buildings. However, today, IBs are rapidly becoming inherent constituents of influential policies for design and development of future buildings. Undeniably, urbanized areas are expected to be highly influenced by IBs in order to promote smart growth, green development and healthy environments (Hollands 2008; Choon et al. 2011; Berardi 2013a). Various studies have tried to map the evolution of the concept of IBs (e.g. Clements-Croome 1997, 2004; Buckman, Mayfield, and Beck 2014). In essence, the emergence of information and communication technology (ICT), together with the development of automation, embedded sensors, and other high-tech systems are key elements in IBs (Kroner 1997).

The intelligence embedded into IBs are claimed to enable them to be highly responsive to users' needs, the environment, and the society, and to be effective in minimizing the environmental impacts and natural resource wastes (Kua and Lee 2002; GhaffarianHoseini 2012). Reduction of operational costs through efficiency in energy management and the capability of being "user-oriented" encompassing improved safety, health, and well-being are other important goals of IBs (Silva et al. 2012; Cempel and Mikulik 2013).

The attention towards IBs began in early 80s in the USA; at that time, the Intelligent Building Institution described an IB as "one which integrates various systems to effectively manage resources in a coordinated mode to maximize: technical performance; investment and operating cost savings; flexibility". From the appearance of that definition, many new ones have been developed, and will be analysed in this paper (see Section 2 below) in order to extract the common features of IBs. As a result, this paper is an attempt to review the available scholarly studies related to design and developments of IBs towards clarifying the available definitions and identifying their most significant key performance indicators (KPI). The paper is exploratory and boldly aims to provide a re-conceptualization of IB and to develop an analytical framework for more systematic enquiry. In addition, the paper frames a future research agenda and prepares

*Corresponding author. Email: h.alwaer@dundee.ac.uk

the ground for more detailed works in this field. The review also covers the current status of IBs from different parts of the world including Europe and North America, Southeast Asia (Malaysia and Singapore), Far East Asia (Korea, Hong Kong, Japan, and China), Australia and New Zealand.

2. Review of existing definitions of IBs

Back to 1988, an IB was defined as "one which has an information communication network through which two or more of its services systems are automatically controlled, guided by predictions based upon a knowledge of the building and usage, maintained in an integrated data base" (Leifer 1988). In that definition, networks, data processing equipment, automation, telecommunication, and building management systems (BMS) characterize the main constituents of IBs. During 1980s, definitions of IBs were mainly intertwined with the characteristics of automated technology, while later definitions were extended to include other features. An international symposium on IBs in Toronto in 1985 concluded that "an intelligent building combines innovations, technological or not, with skillful management to maximize return on investment" (Pennell 2013).

The Intelligent Building Institute (IBI) Foundation in 1989 defined an IB as "one which provides a productive and cost-effective environment through optimization of its four basic elements including structures, systems, services and management and the interrelationships between them" (Wigginton and Harris 2002). Later, the European Intelligent Buildings Group (EIBG) in 1998 defined an IB as "one that creates an environment which maximizes the effectiveness of the building's occupants, while at the same time enabling efficient management of resources with minimum lifetime costs of hardware and facilities" (Nguyen and Aiello 2013). The IBI and EIBG definitions are derived from performance and operation points of view with focus on comfort, adaptability, reduced lifecycle costs, and enhanced control over available resources (Brad and Murar 2014). IBs are characterized or associated with application of sophisticated operational systems to lifecycle cost efficiency, and ecological performance (Bedos et al. 1990; So and Chan 1999).

During the 1990s, the definitions of IBs expanded to include many aspects related to a cohesive linkage between "users, building systems, and environment" as well as the key dimensions of "quality of life". This can be illustrated by reference to the CIB (1995) Working Group W98 stating that

> an intelligent building is a dynamic and responsive architecture that provides every occupant with productive, cost-effective and environmentally approved conditions through a continuous interaction among its basic elements: places (fabric; structure; facilities); process (automation; control; systems); people (services; users) and management (maintenance; performance) and the interrelation between them. (Clements-Croome 2004)

Meanwhile, definitions developed in Japan by the Mitsubishi Electric Corporation in 1990 (Bystrom 1990) and Shimizu Corporation in 1993 (Yasuyoshi 1993) suggested that the human being is the focal point of IBs.

The work of Clements-Croome (1997) was one of the first attempts to clarify the concept of IBs, their effectiveness, efficiency, and their potentials to respond to the social and technological changes. Early definitions of IB mainly focused on the role of technologies and later gradually moved towards the role of user interactions and social changes demonstrating a significant attention to the quality of life indices (Wigginton and Harris 2002; Wong, Li, and Wang 2005). In this line, many similar definitions support that future IBs should respond to user expectations and quality of life (Preiser and Schramm 2002; Wigginton and Harris 2002). This is reflected in the following definition: "one in which the building fabric, space, service and information systems can respond in an efficient manner to the initial and changing demands of the owner, the occupier and the environment" (Arup 2003). Another contends that, "intelligent buildings are not just about technology, it is more about their suitability for their planned use and success at fulfilling the brief" (Clements-Croome 2013b).

It can be argued that one of the challenges towards transforming knowledge into action is the priority given to the technical dimension of IBs, often resulting in neglecting the social and economic perspectives (Cooper and Symes 2008). Current definitions of IBs have gradually considered the users' interactions and even the social values of users (Jamaludin 2011; Ghaffarianhoseini 2012) and this transition can be observed in the evolution of the fundamentals of smart homes including Matilda Smart House (developed at University of Florida), MIT Smart House, and The Aware Home (developed at Georgia Institute of Technology) which raise the idea that intelligent living environments must be aware of and responsive to their occupants' demands and activities. In the same scenario, the main focus of IBs has shifted to the concept of learning capability and the relationship between occupants and environment (Kaya and Kahraman 2014). Additionally, Jiri Skopek describes the benefits of IBs: "In terms of several different issues – the efficiency aspect, the cost aspect, the environmental aspect, the health aspect and the security aspect" (Gray 2006). Today IBs are enabling the connectivity between people, their environment produced by the systems, and the building to become much more real and effective.

In contrast, there has been criticism directed towards IBs which, due to the utilization of integrated automated systems, consumes more energy than necessary (Jin 2012). This has led to reconsidering the role of energy-saving features (Cook and Das 2007) such as Building as Power Plant initiative by Hartkopf (2004) which has been selected by the US Congress as the national test-bed for advanced technology in buildings. IBs should be eco-intelligent (Goleman 2009) and include ecologically sustainable design principles (Ghaffarianhoseini 2012; Ghaffarianhoseini et al. 2013). The essence of existing smart houses in developed countries seems to be the embodiment of intelligent environment which is highly linked to sustainability principles (Ghaffarianhoseini et al. 2013a). The incorporation of passive design techniques with smart active features was seen as a necessity for improving the sustainable performance of IBs exemplified by the role of intelligent facades that offer evidence (Ochoa and Capeluto 2008) in achieving effective IB responses to their environment. Other studies also ascertain that energy-saving strategies are the inherent components of IB technologies (Strumiłło and Łódź 2014) while recommending integrating user involvement in sustainable energy performance of buildings (Janda 2011). In the same way it is articulated that "the main objective in intelligent building design is to satisfy occupants' need with high energy efficiency" (Yang 2013b), while proposing the concept of energy-IB (Nguyen and Aiello 2013) and highlighting the adaptability of buildings to climate change (Thompson, Cooper, and Gething 2014).

From the economic point of view, it is essential to debate about the initial high costs and reliability of the application of intelligent technologies such as advanced sensors/actuators and energy management systems in IBs as well as the related operational and monitoring costs. Nevertheless, the ultimate added value of IBs is claimed to influence the economic feasibility of their production. Hence, achieving the following benefits can significantly affect the economic conditions, specifically in intelligent offices: lower healthcare costs, higher levels of work productivity, higher rental values, higher staff retention rates due to increased employee satisfaction, as well as minimization of the energy consumption and its operating costs (Clements-Croome 2015). Integrated design that offers flexibility and adaptability is essential for IBs to be economically viable (Hagras et al. 2003). Supporting the claimed benefits of IBs, the EU study by Clements-Croome (2014) refers to several promising and innovative design initiatives; the world's first full-scale bio-reactive façade in Germany towards providing shade and renewable fuel source based on a collaboration between Colt International, SSC Ltd and Arup (Arup 2013); application of intelligent skins in building envelope with kinetic louvres by El Sheikh (2011) towards responding to dynamic daylighting and users' presence; the new offices of Apple company located in Cupertino in San Francisco Bay (to be completed in 2016) with 70% use of natural ventilation and an overall maximum resource efficiency as described by; design and development of the robotic façade as a mass-customizable constituent of building envelope for context-aware dynamic lighting as proposed by the MIT media lab (Lonergan et al. 2015); development of a climate control technology (local warning concept) for dynamically controlling localized heating in buildings by MIT Senseable City Lab, application of biomimetics in architectural design initiatives towards reducing the environmental threats to society such as climate change impacts as pointed out by Zari (2010), Vincent (2014), and Clements-Croome (2014); and consolidating design to fabrication as an innovative process towards automation in design and construction. Emerging technologies that could be applied to building sector might pose new possibility for enhanced performance levels of IBs but the actual effectiveness and efficiency to prove the benefits would need scrutinized monitoring and analysis.

The aforesaid perceptions, representing the overlapping notion of IBs and energy-oriented features of green buildings, are clearly demonstrated in the environmentally friendly and sustainable strategies applied in several energy efficient IBs including the Jean-Marie Tjibaou Cultural Center by Renzo Piano in Noumea, New Caledonia based on the incorporation of the ancient and the modern representing the socio-cultural dimension of sustainability and passive design techniques using local materials and natural ventilation (Clements-Croome 2013b; RPBW 2015), the award winning ST Diamond building in Putrajaya, Malaysia, the Sarawak Energy Berhad building in Sarawak, Malaysia, the Twelve West building in Portland, USA with integrated wind turbines mounted on the roof for electricity generation, the Manitoba Hydro Place in Canada with 70% energy savings compared to typical large office towers, and the Capital Tower as a mega-structure in Singapore's financial district plus many other prominent examples. The Edge in Amsterdam as the world's most sustainable office building, Al Bahr Towers in Abu Dhabi, and One Angel Square in Manchester as one of the most sustainable and innovative buildings in the Europe are among these exemplary IBs.

Several interpretations of IBs draw attention to the meaning of intelligence in the IB context. The three essential components of intelligence are technology, function, and economy (Huang 2014). The intelligence of IBs can be classified according to the following characteristics (So, Wong, and Wong 2011):

(1) Environmental friendliness – sustainable design for energy and water conservation; effective waste disposal; zero pollution.
(2) Space utilization and flexibility.
(3) Value-giving quality for economic whole lifetime costs.
(4) Human health and well-being.
(5) Working efficiency and effectiveness.
(6) Safety and security measures – fire, earthquake, disaster, and structural damages.
(7) Culture; meeting client expectations.
(8) Effective innovative technology.

(9) Construction and management processes.
(10) Health and sanitation.

Likewise, IBs should be "safer and more productive for the occupants and more operationally efficient for the owners" (Ehrlich 2007) as supported by proposed dimensions for productive workplaces (Clements-Croome 2006) to be taken into account including pleasure and joy, safety, consciousness and senses, indoor environmental quality, emotion, and the economic impacts. For instance, in the UK, approximately 90% of the entire operating costs of any business entity belong to the staff salaries and their benefits. Thereby, if IBs can provide healthy working environments, which can lead to higher productivity and healthy status of staff while avoiding staff absenteeism, more and more private and public sectors would be encouraged to invest in IBs.

According to Gnerre, Cmar, and Fuller (2007) "Intelligent buildings must talk. The business value is only achieved when they share what they know, communicating between building systems and with their owners." Furthermore, the significance of sensory design for IBs is referred to by Kerr (2013) "buildings that do not fulfil the (sensory design) brief leave occupants intellectually, physiologically, emotionally, behaviourally and spiritually unstimulated".

IBs should respond to the needs of their occupants and society, be functional and sustainable, and promote well-being of the people (Clements-Croome 2013). This could be the response to the claim of the mismatch between the expectations of users and the real products in current IBs (Naticchia and Giretti 2014). In this regard, the study refers back to a basic definition of IB originated from CIB in the 90's

> a sustainable intelligent building can be understood to be a complex system of inter-related three basic issues People (owners; occupants, users, etc.); Products (materials; fabric; structure; facilities; equipment; automation and controls; services); and Processes (maintenance; performance evaluation; facilities management) and the inter-relationships between these issues. (AlWaer and Clements-Croome 2010)

Furthermore, IBs require an intelligent process indicating the importance of collaborative process in design, implementation, and management (Clements-Croome 2013a). In this line, the study refers to the application of building information modelling (BIM) as recommended by Kensek (2014) due to its highly inclusive and collaborative notion with great potentials to involve various stakeholders.

In a recent study, the importance of buildings management systems BMS was raised (Johnstone 2013), whereas another study implied the application of intelligent control strategies, including smart grids, smart metering, demand response control, and load shifting/shaving, as a fundamental component of IBs (Worall 2013). Likewise, highlighting the important influence of ergonomic aspects in IBs, five intelligent criteria for IBs are identified: *input system that receives information by means of information receiver; processing and information analysis; output system that reacts to the input in form of a response; time consideration that makes the response happen within the needed time; learning ability* (Strumiłło and Łódź 2014). Considering the multi-complex and interdisciplinary essence of IBs, they should be the product of an integrated team including clients, consultants, architects, engineers, contractors, and facilities managers in which all team members play a key role towards meeting the social, environmental and economic targets.

It is crucial to stress the important role of innovation as an enabler and new products in IBs such as cloud computing (for virtual and thin computers), embedded sensors (for personalization and real-time feedback), smart materials, self-healing and low embodied (for energy efficiency), biomimetics (for economical use of materials and energy), robotics (for maintenance and internal surveys), using chaos, and complex theory and network science (AlWaer et al. 2013). Definitions of IBs are hence expanding to include learning ability as well as self-adjustability (Yang and Peng 2001; Wigginton and Harris 2002; Wong, Li, and Wang 2005; Kaya and Kahraman 2014).

From the above review, it can be concluded that IB existing definitions can be categorized into three clusters, namely: performance-based, system-based, and service-based definitions as previously pointed out by Wang (2009). The performance-based definitions (such as the definitions by IBI and EIBG) predominantly concentrate on the building performance and the expectations and increasing demands of users (and of society) while considerably less attention is given to the integrated technologies and intelligent systems. The service-based definitions mainly characterize the IBs based on their quality of services. On the other hand, the system-based definitions generally refer to the technological systems and integrated intelligence used in the buildings but linked to the occupants responses. Likewise, the Chinese IB Design Standard (GB/T50314-2000) describes IBs as those buildings which "provide building automation, office automation and communication network systems, and an optimal composition integrates the structure, system, service and management, providing the building with high efficiency, comfort, convenience and safety to users".

Summarizing the analysed definitions, this review shows how definitions of IBs have changed over time. By analysing the drivers that affect the evolutionary progression of IBs and the role of interdisciplinary collaboration between professionals, developers, clients, and policy-makers pathways can be defined that lead to the exploration of the true potentials for IBs (Figure 1). Table 1 summarizes the key features and components of IBs derived from the available definitions.

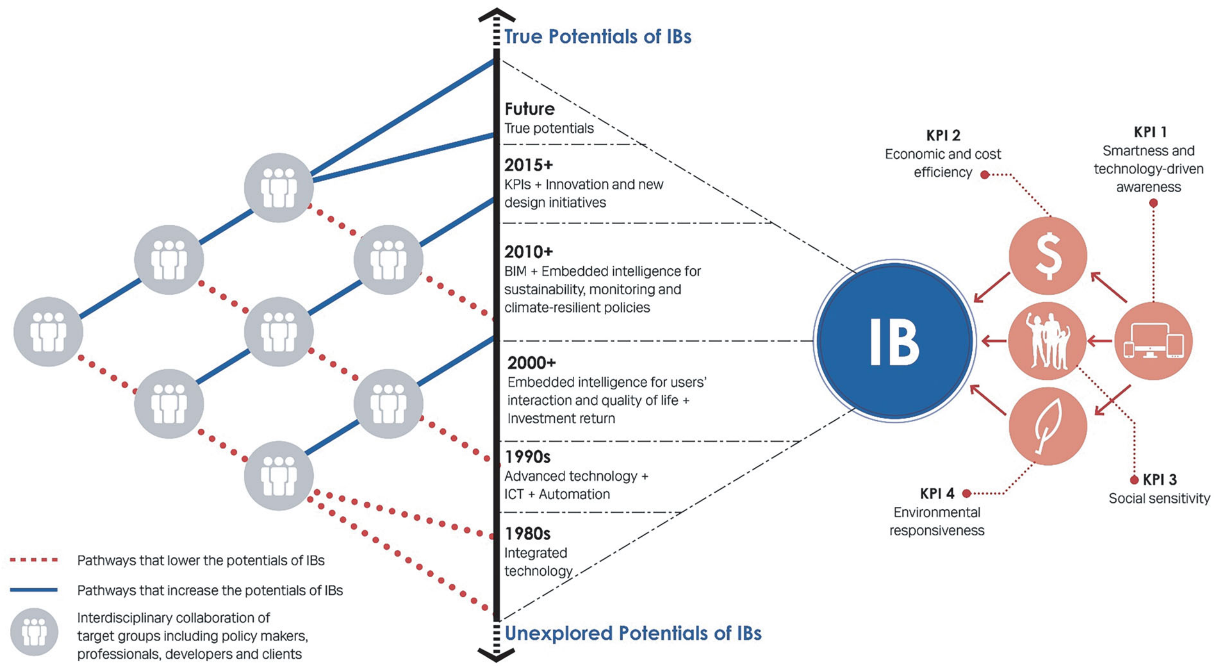

Figure 1. Evolutionary progression of IBs.

3. Embedded smartness or intelligence in IBs

3.1. An overview of smart technologies

Should we say intelligent or smart buildings? From collected viewpoints, smart can be described by various capacities such as reasoning, problem-solving, acquiring knowledge, memory, speed of operation, creativity, general knowledge, and motivation. A challenge for IBs is to see how far these aspects of human intelligence are achievable in the design and operation (Clements-Croome 2013).

Beyond the comparison between smart and intelligent terms, the concept of "sentient" buildings is proposed, as the embodiment of highly responsive environments, equipped with sensor networks (Mahdavi 2006). Similarly, the concept of "hybrid" buildings is introduced towards achieving net zero energy/zero carbon status (Newton and Tucker 2010). The "domotic" buildings idea is developed towards the automation of domestic services while discussing the challenges of building regulations towards implementing advanced technologies (Millán Anglés et al. 2014). It is indicated that the concepts of digital and cyber designs, plus automation strategies, and advanced technologies are the main constituents of IBs, while the social and environmental dimensions are essential for a complete representation of them (Figure 2).

The embedded smartness in buildings results in an environment which

> integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at its core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction. (Buckman, Mayfield, and Beck 2014, p. 104)

Smart technologies as part of IBs have evolved towards a strong integration of *human*, *collective*, and *artificial intelligence*.

IBs require smart users if they are to be truly inclusive, innovative, and sustainable. The collective intelligence of building's users is based on the interpretation of IBs as facilitators in knowledge access. The artificial intelligence embedded into the physical environment of the building and available to the building's users becomes the digital spaces for online problem-solving tools. In this line, the study refers to the project Gardens by the Bay in Singapore (completed in 2012) and its conservatories, designed by Wilkinson Eyre Architects showcasing the application of smart technologies and building automation systems (BAS) for energy efficiency and optimized performances (Clements-Croome 2013a).

Considering the important role of BAS, term "intelligent" is defined to "be classified as a productive system designed for the execution of processes intended to meet the functional specifications that characterize the facility as intelligent" (Silva et al. 2012).

Developing an intelligently monitored building environment is becoming an essential standard consideration. This is leveraged while focusing on building energy efficiency under the influence of heating, ventilating, and air conditioning (HVAC), lighting, air quality (Shih 2014). Contemporarily, IBs employ networked sensors to monitor the indoor air quality (IAQ). This includes monitoring various parameters including temperature, humidity, emissions, dangerous contaminants, etc. These monitored

Table 1. Key features and components of IBs based on available definitions.

Period	Key features and components	Key references
1980s	Maximizing return on investment	Symposium on IBs in Toronto (1985)
	Information communication network and automatically controlled system	Leifer (1988)
	Productive and cost-effective	
1990s	Application of sophisticated operational systems to lifecycle cost efficiency, and ecological performance	Bedos et al. (1990)
	Human as the focal point	Bystrom (1990) and Yasuyoshi (1993)
	Dynamic and responsive	
	The emergence of information and communication technology (ICT) and automated systems	Kroner (1997)
	Maximizing the technical performance, investment and operating cost savings, and flexibility	Clements-Croome (1997)
	Responding to the social and technological changes	Clements-Croome (1997)
	Maximizing the effectiveness of the building's occupants and efficient management of resources	
2000–2005	Responding to user expectations and quality of life	Wigginton and Harris (2002) and Preiser and Schramm (2002)
	The role of user interactions and social changes	Wigginton and Harris (2002) and Wong, Li, and Wang (2005)
	Responding to the changing demands of the owner, the occupier and the environment	Arup (2003)
	Flexibility and adaptability	Hagras et al. (2003)
2005–2010	The efficiency aspect, the cost aspect, the environmental aspect, the health aspect and the security aspect	Gray (2006)
	Safer, more productive and more operationally efficient for the owners	Ehrlich (2007)
	Communicating between building systems and with their owners	Gnerre, Cmar, and Fuller (2007)
	Energy-saving features	Cook and Das (2007)
	Incorporation of smart active features and passive design techniques	Ochoa and Capeluto (2008)
	Eco-intelligent	Goleman (2009)
2010–2015	People, products, and processes	AlWaer and Clements-Croome (2010)
	User involvement in sustainable energy performance of buildings	Janda (2011)
	Considering the users' interactions and even the social values of users	Jamaludin (2011) and Ghaffarianhoseini et al., (2011)
	Ecologically sustainable design	Ghaffarianhoseini (2012)
	Embedded sensors, automation	Chen (2013)
	Innovation as an enabler and new products such as cloud computing, embedded sensors, and smart materials	AlWaer et al. (2013)
	Responding to the needs and social well-being of the occupants and of society	Clements-Croome (2013)
	Suitability for their planned use and success at fulfilling the brief	Clements-Croome (2013b)
	Energy-intelligent concept	Nguyen and Aiello (2013)
	Satisfying occupants' need with high energy efficiency	Yang (2013b)
	Sensory design	Kerr (2013)
	Buildings management systems (BMS)	Johnstone (2013)
	Intelligent control strategies, including smart grids, smart metering, demand response control	Worall (2013)
	Adaptability of buildings to climate change	Thompson, Cooper, and Gething (2014)
	Added values based on technology, function, and economy	Huang (2014)
	Learning capability, self-adjustability, and the relationship between occupants and environment	Kaya and Kahraman (2014)
	Energy-saving strategies	Strumiłło and Łódź (2014)

parameters provide information for better controlling of building's mechanical–electrical systems. This approach aims to facilitate a healthy and comfortable living environment while rationalizing the energy consumption (Eliades et al. 2013). Appropriate monitoring of IBs allows optimization of building's energy performance. This is achieved through identification of ineffective energy usage and promotion of energy-efficient operations (Gökçe and Gökçe 2013). Thus, application of BMS is a critical factor towards the success of these intelligent environments. BMSs have been evolved following the "manual controlling, timer scheduling, sensor controlling, visual recognition, and vision-based dynamic commissioning" (Shih 2014) order. Among these, advanced vision-based and dynamic vision-based approached are of the most effectiveness. Continuous track and detection of building occupants

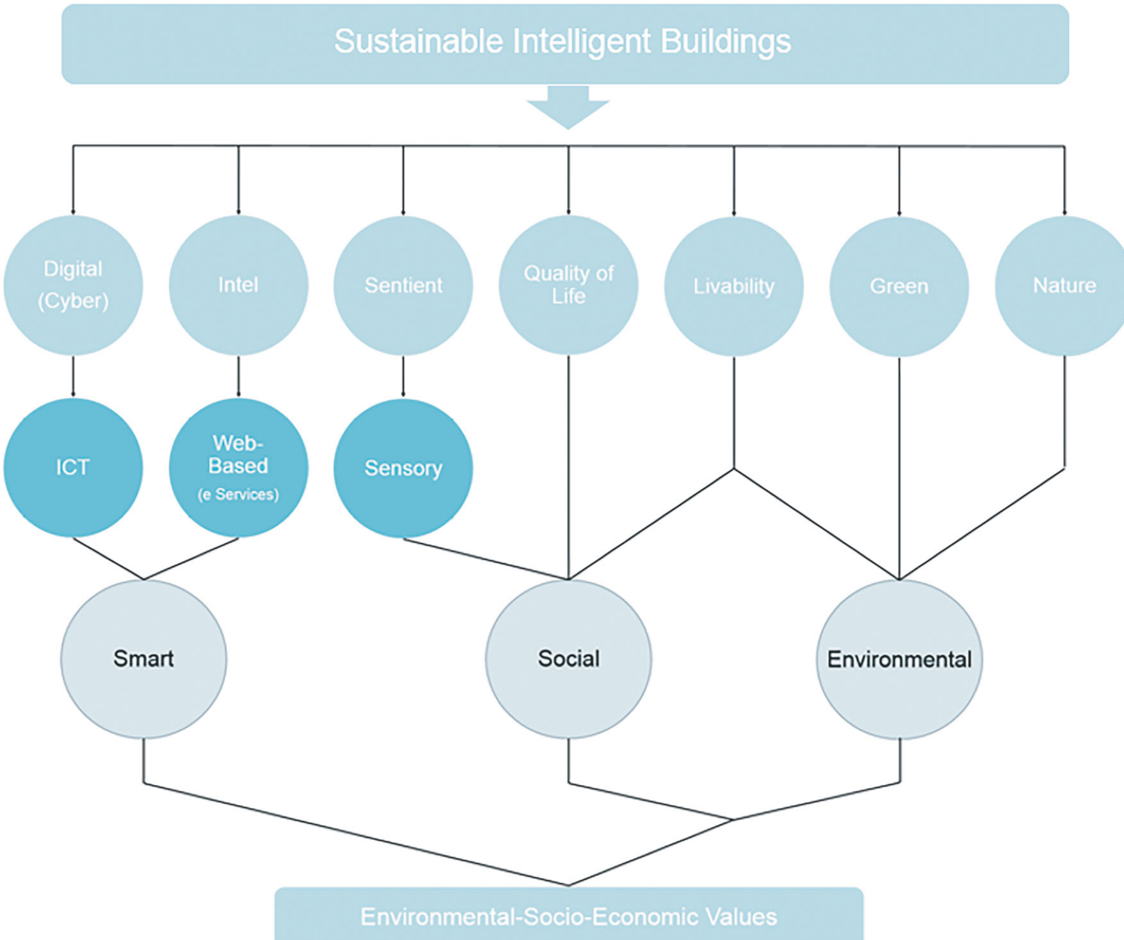

Figure 2. Key constituents of IBs (Source, Clements-Croome 2013, p. 289).

is also an essential factor in IBs' monitoring/management systems (Shih 2014). In these regards, incorporation of BIM-based systems and IBs for monitoring and cost estimations has become more tangible. Optimal building scheduling for construction/maintenance/lifecycle Assessment is achievable using these approaches (Lu et al. 2015). Eventually, in addition to various role-playing factors, advancements of intelligent devices coupled with their widespread utilization, governmental supports and social awareness is critical towards cost-effective and affordable IBs.

IBs is nowadays fostered by the attention to the concept of smart cities (Lee, Phaal, and Lee 2013), and has become an emerging target for many policy-makers (Neirotti et al. 2014; Albino, Berardi, and Dangelico 2015). From macro to micro level viewpoints, these targets include enhancing the life quality of inhabitants, and optimizing the use of resources (Yamagata and Seya 2013). Going forward, it is recommended that the interchangeably used terms such as sustainable, green, healthy, digital, and smart which at least belong to one of the four areas of environmental, socio-cultural, economic, and innovative dimensions should all fall under a larger cluster called IB (Figure 3).

3.2. Role of advanced sensors in recent definitions of IBs

> An intelligent building requires real-time information about its occupants so that it can continually adapt and respond.(Keeling et al. 2013)

In the design of IBs, a focus on sensing is expected. Incorporation of more intelligence in IBs highly relies on deploying embedded advanced sensors, which can lead to the identification and collection of physical information while transferring the captured information to control systems (Kwon, Lee, and Bahn 2014). There are various body sensors for integration in IB ambient including accelerometers, heat flux monitors, galvanic skin response monitors, and skin temperature monitors (Clements-Croome 2013a). Meanwhile, IBs have started to be fully integrated with sensor networks for the sake of enhancing the IAQ (Eliades et al. 2013). Wireless sensors and networks are nowadays considered primarily related to the progress of radio sensitivity, ultra-low power consumption, micro-electromechanical system-based sensors, and energy harvesting (ON World 2013). Through the advancement of self-functional advanced sensors, IBs benefit from self-adjustability via learning from the environment and

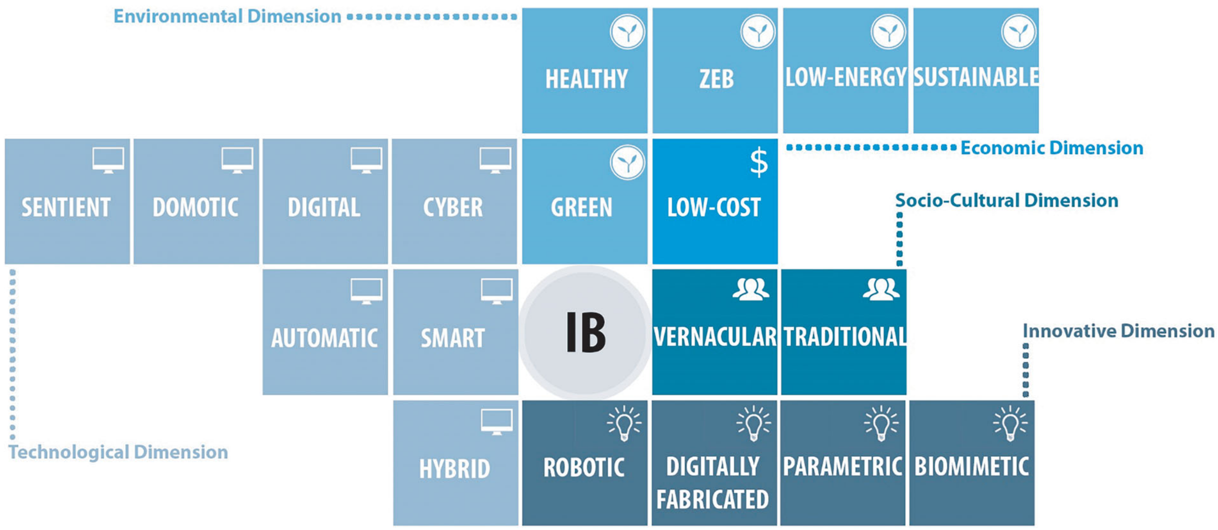

Figure 3. Key clusters of IBs and the interchangeably used terms.

user behavioural patterns (Wong, Li, and Wang 2005; Kaya and Kahraman 2014).

Attention to the heterogeneous systems of IBs encompassing "high capacity communication infrastructures" and "high performance sensor technologies" has been raised recently (Perumal, Sulaiman, and Leong 2013). Meanwhile, various studies demonstrate the groundbreaking impact of multi-agent systems (Yang and Wang 2013). These are utilized to direct, organize, and control the building integrated facilities and carry out multifaceted tasks collaboratively based on autonomous decision-making, automatic actions, and interactions among the agents, while being characterized by the key attributes of pro-activity, reactivity, and social ability (Yang and Wang 2013).

New systems provide building occupants with an increased control; among these, there are smart energy meters that communicate with the energy supplier, allowing remote reading, accurate feedback to the occupants on energy use, and connection to the grids.

4. KPIs of IBS in different regions

4.1. Fundamental features in Europe and North America

The concept of IBs as part of smart city has been quite fashionable in the European policy arena in recent years. Its focus seems to be on the role of ICT infrastructure, although much research has also been carried out on the role of human capital/education, and environmental implications. The European countries stress the role of innovation in ICT sectors and provide a toolkit to identify consistent indicators, thus shaping a framework of analysis for smartness (Caragliu, Del Bo, and Nijkamp 2011).

In this context, ambitious targets have been set for 2020 aiming to foster European economy to highly sustainable energy paths. This policy is a first resolute step towards the achievement of the low-carbon economy goal, whilst making at the same time the consumed energy more secure, competitive, and sustainable. In fact, the Directive 2010/31/EU promotes with the ultimate goal of ensure that all new buildings are nearly zero energy by 2020.

Over the last 20 years, it has been increasingly important to understand the building sustainability assessment tools that play significant roles to promote and guide the sustainable development at buildings level. In Europe, over time the tools became a roadmap for projects that wanted to provide higher performance whether for market differentiation, perceived benefits for occupants, organizational mission, or long-term cost savings. These tools share much in common but also evidence differences of scope, approach, and reporting. They make use of measurable criteria which align with the sustainable development model providing indicators as the basis for measurement of performance against the standards (Du Plessis 1999; Finco and Nijkamp 2001). In North America, the emergence of the concept of IB goes back to 1980s. Looking at the Continental Automated Buildings Association (CABA), founded in 1988 in North America, the development of industry standards and indices, and cross-disciplinary initiatives towards developing IBs has been continuously observed. North America especially USA emphasizes the importance of performance and cost-effectiveness, therefore, various technologies have been developed to support this. The other characteristic feature of IBs in North America is the buildings' tight coupling with advanced and innovative information technology. For instance, according to CABA integrated and intelligent building council (IIBC) which promotes larger building automation, a web-based building automation intelligence rating programme (BiQ)

Table 2. Summary of the key features and performance indicators of IBs from European perspective.

Key features	Key components	Performance indicators
Building for sustainability	Energy and climate change	Substantially intertwined with smart cities index and sustainability rating systems (BREEAM, DGNBSeal, HQE, ITACA, etc)
	Indoor environmental quality	
	Transport and accessibility	
	Site selection and ecology	
	Material, recycling, and waste	
	Water conservation and efficiency	
	Management (i.e. sustainable procurement)	
	Innovation in other low-carbon technologies	
Social, behavioural, and perceptual aspects	Health and Well-being (i.e. Thermal Comfort, Productivity)	Health and well-being
	Multi-functionality	Socially and culturally responsive
	Privacy, safety and security	User-oriented design
	Flexibility and adaptability	
	Dynamism and usability	
	Ease of indoor spaces reconfiguration and adjustability	
Cost and whole life value	Lifecycle cost and service life planning	Whole life value
	Return on investment (ROI) and whole life value	Service life planning
	Building operation, controllability, and management	Facilities management
	Building maintenance	Skills and knowledge
	Skills and knowledge of operating staff	
ICT Integration and automation	Quality of digital communication	Optimized automated systems and digital communication
	Data, information, and communication	
	Building User Information	
	User's personal control	Highly integrated BAS for automatic monitoring and control
	Integrated building automation and control systems	
	Responsive and adjustable indoor environment based on users' behaviours and preferences	Enhanced level of communication between building and users
	Intelligent control strategies (i.e. smart meteringand smart grid) and monitoring building performance	

is developed that illustrates the convergence of information technology to all building systems while rating the intelligence of building automations towards identifying sufficient information for guiding future decision-making and operations and enhancing the intelligence in the architecture, engineering and construction industry (Katz and Skopek 2009). The rate of adoption of building intelligence and automation systems is dramatically increasing in North America, resulting in increasing numbers of buildings with advanced integrated building systems and controls.

The key learning point here is that the choice of indicators will determine the characteristics of assessment and consequently the types of alternatives considered and selected in decision-making. This can lose sight of the bigger picture and building stakeholders would need to take a step back from time to time to reflect on the relevance of the indicators (Berardi 2013b; Bond and Morrison-Saunders 2013). Overall, the identified key features, components, and performance indicators relevant to IBs are reported in Table 2 (AlWaer, Sibley, and Lewis 2008a, 2008b; AlWaer and Clements-Croome 2010; Brandon and Lombardi 2011; Deakin and Al Waer 2011; AlWaer and Kirk 2012; AlWaer and Clements-Croome 2013; AlWaer, Bickerton, and Kirk 2014).

4.2. *Fundamental features in Southeast Asia (Malaysia and Singapore)*

Cities and urban areas in Southeast Asia, particularly Malaysia and Singapore, are rapidly evolving as a result of globalization, emerging intelligent systems, and penetration of ICT. In recent years, considerable attempts towards integrating the intelligent and sustainable design concepts in the future planning of cities are observed in Malaysia and Singapore. Nonetheless, it is still ambiguous and controversial on how the respective concepts and policies would be implemented.

The implication of IBs in Malaysia and Singapore is fundamentally intertwined with the concept of green design and sustainable developments. Intelligent design in these contexts is characterized as a multi-dimensional metaphor for creation of buildings that would be labelled as green, and environmentally responsive rather than being exclusively bound with ICT and digital technologies. In Singapore, IBs are mainly recognized based on the key components of "automation" and "high-tech systems"; in Malaysia, IBs are more influenced by the sustainable indicators.

Back to 1999, it was theorized to transform Singapore into an intelligent island through the incorporation of ICT to develop a smart city (Mahizhnan 1999). From the other side, the inclusion of ICT and advanced technologies plus creation of smart infrastructures for development of mega-intelligent cities was observed in Malaysia while targeting to ensure an enhanced level of sustainable developments (Siong Ho et al. 2013).

Referring to National Physical Plan 2025 and National Urbanization Plan 2006, policies and planning strategies for development of intelligent and sustainable communities and cities are established with eight fundamental modules including

> Shaping national spatial framework, Improvement of national economic competitiveness, Modernization of agricultural sector, Strengthen of tourism development, Management of human settlement, Conservation of wildlife and natural resources, Integration of all national transportation network and Installation of appropriate infrastructure. (FDTCP 2006, 2010)

Looking holistically into the essence of IBs in Malaysia and Singapore, it is inferred that the environmental implications, social dimensions, and economic repercussions can become an ideally conceptual basis as a general framework. To support this thought, recent studies in Malaysia claim that IBs, besides being harmonized with advanced technologies, must be culturally and environmentally responsive in order to ensure a high level of users' satisfaction (Ghaffarianhoseini et al. 2011). Thus, the application of IBs in these contexts is beyond the level of technological integrations, and encompasses any sort of building that is responsive to the context, environment, and society.

Purpose and expansion of IBs are not limited to a certain functionality, but instead, three key fundamentals are set for IBs as sufficient telecommunication systems, advanced networking infrastructure, and emerging automatic control systems (CABA 2006).

For the context of Malaysia and Singapore, sustainable building assessment organizations and the developed tools include Green Building Index (GBI) and Green Mark Scheme (BCA). GBI; encompasses six main constituents of criteria for evaluation of green buildings (GBI 2013) which are partially associated with the KPIs of IBs in Malaysia.

On the other hand, Green Mark Scheme (Singapore) embraces five main components as the assessment criteria for green building rating including energy efficient, water efficiency, environmental protection, indoor environmental quality, and other green features and innovation, hence, similarly, these components are directly linked to the KPIs of IBs in Singapore (BCA 2013). According to Building and Construction Authority in Singapore, analysing the KPIs, it is postulated that IBs could be characterized by interrelated key features including "highly automated", "high level of control", "effective in reducing operational costs", "effective in reducing energy consumption", "world-class working environment", and "automatic control of HVAC, IAQ, energy and lighting systems and life safety detections" (BCA 2013). Likewise, in Singapore, IBs are essentially required to be entirely designed based on two major components of "ICT infrastructure" and "intelligent facility management" (BCA 2013).

The discussed initiatives and developed strategies towards a more sustainable and greener future are tremendously promising in Malaysia and Singapore. In accordance with the elaborated thoughts, the design and development of IBs are not only limited to portray the buildings as energy efficient, automatically responsive, and well integrated with ICT, but are targeted to ensure functional flexibility, improved maintenance, optimized productivity, and comfortable living environments. Overall, the identified key features, components, and performance indicators of IBs are reported in Table 3.

4.3. Fundamental features in far East Asia (Korea, Hong Kong, Japan, and China)

IBs in Asian region represent a manifestation of built-in technological advances reflecting a highly sophisticated integration of materials, components, and systems into a building. Recent tendency over the spread of IB system in far eastern Asia is the coexistence of "smartness" and "sustainability" embedded in the concept of IB. This means that energy conservation or environmental soundness become a crucial integral part of IB system in addition to the traditional domains of building automation, and telecommunication. Nevertheless, it is noted that sustainability is beyond the one-dimensional focus on energy-oriented aspects related to the environmental performance and impact of buildings, and the recent studies show more and more attention to the user-oriented issues of quality of life and users' well-being.

In China, the concept of IBs has attracted the attention of the governmental sectors and professional bodies in 1990s and has become highly widespread in the following years (Wang et al. 2004). Beijing Development Building could be considered as the first IB project developed in China followed by Shanghai Jinmao Building (88F), Shenzhen Diwang Building (81F), Guangzhou Zhongxin Building (80F), Nanjing Jinying International Commercial Building (58F) as described by Wang et al. (2004). Today,

Table 3. Summary of the key features and performance indicators of IBs from Malaysian and Singapore perspectives.

Key features	Key components	Performance indicators
Building sustainability	Energy efficiency Indoor environmental quality sustainable site planning and management Material and resources Water efficiency Environmental protection Innovation in other green features	Substantially intertwined with sustainability indicators and sustainability rating systems (GBI and GMS)
Social and Behavioural dimensions	Privacy Flexibility Multi-functionality Dynamism Well-being	Socially and culturally responsive User-oriented design
Renewable energy, efficiency, and conservation	Energy efficiency Highly equipped with on-site and off-site renewable energy sources (specially solar energy) Self-energy-harvesting systems and techniques Optimized energy-saving operations and conservation	Greater attention to the renewable energy-harvesting and energy-saving and conservation systems
Economic repercussions	Investment evaluation	Higher level of economic benefits based on lifecycle analysis and long-term benefits
ICT Integration and automation	Highly automated and responsive	Optimized automated systems and digital communication
	Self-adjustable based on new behavioural patterns	Highly integrated with advanced BAS for automatic monitoring and control
	Fully integrated with WSN	Enhanced level of communication between building and user for optimization of safety, security, and well-being
Effective management and environmental services		Improved level of building services
Security and safety	Personal safety and security, data, information, and communication.	Greater level of security compared to "standard" buildings.

the spectrum of the application of IBs has become widened to be applied in several public buildings such as Shenzhen Library and Art Center (Wang et al. 2004).

Unlike USA and UK emphasizing the performance aspects of IBs, China is said to be focusing on system aspects while Japanese IB are more service oriented. Especially, in China, three automatic systems ("3A")-communication automation, office automation (OA), and building management automation systems-could be extended to "5A" by adding fire automation and comprehensive maintenance automation systems (Wang 2010).

As a part of system oriented perspective of IBS, Chinese government has been actively pursuing the integration of IT and IBS in the form of Information Systems, Intelligent Systems, and Infrastructure Systems. Typical IB systems in China include Equipment Scheduling System, Optimum control System, Monitor Systems, Alarm Reporting Systems along with some modern advanced systems such as Fingerprint Identification Systems, Automatic Water Supply and Drainage Systems, Premise Distribution Systems, and Building Integrated Management Systems (Jiang, Gao, and Wang 2013).

Korea is one of the countries with the best communication infrastructure on the globe. Especially fourth generation wireless communication network is covering entire boundary of the nation providing high bandwidth bidirectional multimedia services. The level of general awareness on the energy conservation and environmental sustainability might not be up to that of Japanese society, Koreans are also emphasizing energy sensitivity, ecological sustainability, and management efficiency in addition to the enhanced productivity and comfort of the occupants in an IB. Among traditionally raised features of an IB, BAS becomes dominant sector of focus in Korea since highly performing OA equipment and facilities are spread all over and ITC is mostly covered by wired and wireless communication networks. In 2006, the Ministry of Ocean, Construction, and Transportation in Korea launched the "Intelligent Building Certification Program (IBCP)" for enforcement to promote the installation and operation of IBs (KMCT 2006).

In Korea, this integrates architecture, electricity and electronics, information and communication, mechanical equipment, energy, and environmental systems to provide a comfortable, safe, and environmentally sustainable built environment. Currently, MOLIT (Ministry of Land, Infrastructure and Transportation in Korea administers IBCP for residential buildings, cultural and meeting facilities, retail and shops, education and research facilities, commercial buildings, accommodation, and broadcasting and communication facilities. For residential sector, required items, rating items, and additional items are defined in various domains such as architectural and environmental, mechanical facility, electrical facility, ICT, system integration, and facility management. Residential sector certification is performed for architectural and mechanical, electrical and ICT, system integration, and facility management domains.

The actual rating schemes for certification items are targeted to very detailed equipment or facilities using both performance-based or prescription-based criteria. Separate from IBCP, previous housing performance indication system and green building certification criteria have recently been integrated into G-SEED (Green Standard for Energy and Environmental Design) system. G-SEED has seven domains for evaluation such as land use and transportation, energy and environmental pollution, material and resources, water circulation management, ecological environment, and indoor environment. One of the distinct features of IBs in Korea is the fact that there is government initiated separate standard or certification system for assessing each of smart and/or sustainable aspects of a building even if there are some inevitable overlaps especially in energy or environment related domains.

Japanese land price and the cost of electrical power are high therefore making and operating highly integrated energy conservative building became important issue in the pertinent industry. Furthermore, Japanese citizens have high awareness on the environmental and ecological sustainability, which drives typical IB to serve for the occupants' comfort and health based on the requirements extracted from bottom-up fashion. The major aspects of Japanese IBs are related to provide information communication infrastructure, maximizing workers' satisfaction and comfort, efficient and effective operation and management of the building and resilience, and flexibility to adapt to the changing environments (So, Wong, and Wong 1999). Obviously, the automation of the things and processes in a building is an essential feature of Japanese IBs considering the nation's technological advances including robotics. The primary strategies and apparatus to deliver this ideation on the IBs in Japan includes high speed Local Area Network, centralized monitoring and control system, task and activity adaptive conditioning, glare-free lighting system, raised floor system, and the provision of semi-public or public spaces. Some literature also points out entertainment systems and services are uniquely associated with Japanese IBs.

Hong Kong has a monsoon-influenced humid subtropical climate and the low temperature in winter hardly drops below zero. Typically, hot and humid weather in this region might has influenced the buildings to cope with especially cooling and dehumidification loads. Population density in Hong Kong is as high as 62,000 persons/km^2. A strong cultural factor that influences the design of a building in Hong Kong is Feng Shui, which proposes to "achieve a harmonisation amongst heaven, earth and human by providing an equilibrium amongst nature, building and people. It interprets the environment so that people can live in a more harmonious space" (Mak and Thomas Ng 2005). Its impact has been demonstrated in some famous buildings, such as the Hong Kong Shanghai Bank Headquarters, the Bank of China Tower, the Repulse Bay Hotel, and the Hopewell Centre.

Asian Institute of Intelligent Buildings (AIIB) of Hong Kong as an independent certification authority for IBs developed an intelligent buildings index (IBI). IBI is composed of 378 elements. Main categories of assessment include comfort, health and sanitation, space, high-tech image, safety and structure, working efficiency, green, cost efficiency, practice and security, and cultural codes. Different modules of evaluation criteria are prioritized depending on the type of a building (AIIB 2005).

By briefly reviewing the primary features and evaluation systems of an IB in three far eastern regions such as Korea, Japan, and Hong Kong, the following observations are reached. Firstly, conventional definition of IB emphasizing BAS and ICT has been extended to include energy and carbon emission sensitivity and ecological sustainability of a building commonly observable in all three regions. Japan and Hong Kong have more integrated criteria or performance ranking system to include both smart and green building features, whereas Korea has quite distinctively separated certification system for each of smart building and green building sectors. Secondly, even though all three regions are interested in developing a building for maximizing human comfort with minimized energy, environmental load and cost, the detailed assessment criteria or set of performance indicators are not identical due to the difference of each region's geographical, economic, social, and cultural background. For instance, Japanese inclusion of entertainment performance indicator and Hong Kong's high-tech image as one of the IB Index are the examples of the cultural propensity of those two regions. Lastly, the IB rating schemes to quantify objectively the score of each performance indicator category are different among these three regions. Hong Kong seems to be mostly rigorous in pursuing methodologically objective assessment algorithm whereas Korea has very extensive set of enabling equipment and facilities to judge either inclusion or exclusion of such items as the indicator of associated IB performance. Japan especially shows a comprehensive way of evaluating energy load by including both internal and external loads to evaluate a building's energy performance (Kim, Cho, and Yee 2011). Overall, the identified key features, components and performance indicators of IBs are reported in Table 4.

Table 4. Summary of the key features and performance indicators of IBs from Korean, Japanese, and Hong Kong perspectives.

Key features	Key components	Performance indicators
Building sustainability	Energy conservation Material and resources Water peration and management	External/internal energy load, insulation, energy efficiency of facilities, energy efficient operation, adoption rate of renewable energy sources, embodied energy, material recycling rate, water recycling rate, building operation efficiency
Service performance	Spatial flexibility Durability and responsiveness Integration with ICT	Ease of spatial reconfiguration, level of functional support of a space, durability of building components and systems, level of network connection, and effectiveness in sensing and control
Human dimension	Occupants comfort Technical symbolism	PMV, PPD, noise criteria, illuminance, glare index, Air Change per Hour, productivity measurement
Safety andsecurity	Fire safety Earthquake and disaster protection Facility and data security	Fire protection measures Structure and facility integrity Security protection level
Community Awareness	Environmental pollution Ecological conservation Regional characteristics Global warming reduction	Soil, water and air pollution indices, on-site conservation scope, context-aware site and building design, CO_2 emission rate

4.4. Fundamental features in Australia and New Zealand

Unlike many other countries, Australia and New Zealand do not seem to have any institution dealing directly with the IB. The operation of buildings built with green features as listed in the Green Building checklist could have not be realized without embedded smartness or intelligence (GBCA 2010). Although not as "complete" and "complex" as the IB features in commercial buildings, green villages such as Lochiel Park in Adelaide, South Australia, are fitted with "smart" devices that provide the occupants with the ability to check and control interactively the energy consumption of various energy appliances, watch the energy consumed by each appliance and consequential greenhouse gas emitted in real time (Saman et al. 2011).

This status is a mixed blessing for Australia and New Zealand. On the one hand, they have much to learn about how to deliver and operate these types of buildings successfully (Healey 2011). On the other hand, this very status enables them to experiment "naturally" with the introduction of buildings with IB features without being restricted by associated guidelines, standards and acceptable definition that still needs to be developed rigorously as discussed in this paper.

Thus, discussion on key features and performance indicators in this section is a preliminary attempt to pave the way for a more comprehensive formulation of requirements of IBs in the Australian context. How "smart systems" address the objectives of IBs through key intelligent attributes or level of service system integration have been discussed elsewhere (Bien et al. 2002; Wong, Li, and Lai 2008).

The proliferation of buildings with intelligent features in Australia and New Zealand is expected to increase due to the following factors: (1) their commitment to increase performances of various aspects such as environmental, economic, operation, and safety of new and existing buildings, (2) continued improvement of performance and reliability of various technologies in communications, control, automation, etc. that have already found their deployment in buildings. These two factors are interrelated; adherence to stringent performance of various features set by various guidelines or standards could only be attained largely through the introduction of these technologies in buildings.

Australia and New Zealand are two of the developed countries with highest greenhouse gas emissions per capita in the world (UNFCC 2013) and this has influenced people's attitude towards living sustainable life. In Australia, governments have set a number of initiatives dealing with these issues. NABERS is an Australia rating system for assessing environmental performance of buildings, which includes energy efficiency, water, waste management, and IAQ (NABERS 2013). In the state of New South Wales, BASIX (BASIX 2013) was introduced to assess the energy and water efficiencies of residential buildings. Similar environmental or energy performance assessment schemes exist in other states. New Zealand has just introduced NABERS NZ, and has also developed its own environmental rating scheme called "Green Star" (NZGBC 2013).

Building sustainability should be one of key features of an IB from Australian and New Zealand perspectives. Based on Green Building checklist (GBCA 2010), the term "green" seems to have covered not only environmental but to some extent economic and social dimensions of sustainability. Compared to sustainability indicators identified/proposed by AlWaer and Clements-Croome (2010), the indicators listed in the Green Building checklist (GBCA 2010) are more comprehensive and measurable. It covers broad range of sustainability elements such as energy and water efficiency, thermal comfort, IAQ, waste management, and transport.

One of the main and justified concerns with the IB concept is that, relying too heavily on the smartness embedded into building may make people more "passive and disconnected from reality" (Soebarto, V. 2013. Personal Communication, September). While IB concept overall impacts positively on the building occupants, one should carefully consider the unintended consequences of such "emerging intelligence" of buildings on human, an aspect that has not been properly considered yet.

The human dimensions that need to be properly considered in the Australian context perhaps could be best summarized by the following statement:

> buildings that help the occupants realize and be thankful that they are humans who can move around, use their hands, feet, and brain ... buildings that help the occupants realize what being alive actually entails – and that includes to feel happy and sad, to feel warm, cool, cold, hot, sweaty, freezing, to feel tired and relaxed. (Soebarto, V. 2013. Personal Communication, September)

Thus, whilst automation has been "de facto" standard for modern IBs should always allow for flexibility in relation to the way occupants want "to live their life" in the building. Table 5 outlines key features and performance indicators of IB in the Australian and New Zealand context. Those features are often common to buildings normally called or known as "green" or "sustainable". However, the intelligence of IB should make easier the task of realizing the key features.

5. Discussion

Several key characteristics and potential benefits of IBs are presented above and the accelerated growth rate of IB development in today's urban areas observed. The study has portrayed several promising technological initiatives and innovative strategies for application in the design, construction, management, and operation phases of future buildings including the so-called IBs. Despite the increasing interest in development of IBs, findings draws attention to certain barriers including insufficient economic resources for promotion of IBs and the potential risks of the integration of untested intelligent technologies, ineffective, and inadequate incentivized programmes and support for utilization of IB systems, lack of public awareness about the positive impacts of IBs and their long-term benefits, and insufficient technical potentials and capacity to apply and implement the intelligent technologies. Moreover, the study demonstrates a lack of empirical evidence that IBs actually deliver the benefits claimed for them. IBs of today, being significantly affected by the "tech push and market pull" scenario, are highly unaffordable due to the high cost of available intelligent systems and the lack of widespread expertise for monitoring their operations, specifically in the context of small-scale commercial, educational and residential buildings. The economic feasibility for developing IBs can be partially resolved by the possible long-term payback of the initial investment, as discussed in previous sections, which has not been thoroughly studied in recent years. Furthermore, the economic feasibility of IBs should not be beyond a simple payback calculation (such as energy-saving benefits) and in this regard, more studies should look into the lifecycle costing of IBs as an essential approach for understanding their promising benefits. Nonetheless, the massive proliferation of IBs, once fully embedded in future governmental plans, can result in promoting the "tech push and market push" scenario where considerably less costs would be needed for embedding intelligence in buildings. Likewise, professional bodies, stakeholders, and researchers require a universally acknowledged framework for design and development of future IBs. This framework has to extend to include the monitoring and evaluation of IBs performance over time.

In practice, researchers and institutions are still grappling with multiple definitions and interpretations of the essence of IBs and associated implications. This study has evaluated most of the existing definitions of an IB based on its evolutionary progress with viewpoints to the social, environmental, economic, technological, and organizational dimensions and according to the status of IBs in different contexts. Having shown the status of IBs in different contexts, findings provide new insights for defining the intelligence embodied in built environments and clarify the future direction of intelligent environments as part of future

Table 5. Summary of the key features and performance indicators of IBs from Australian and New Zealand perspectives.

Key features	Key components	Performance indicators
Building sustainability	Energy efficiency, water efficiency, waste management, thermal comfort, visual comfort, IAQ, sustainable building materials, lighting, planting, transportation, land use, and ecology	Adherence to existing "sustainability" rating schemes such as NABERSand NABERS NZ.
Security	Personal safety and security, data, information, and communication	Greater level of security compared to "standard" buildings. Quantitative indicators need to be developed.
Human dimensions	Dynamism, casualness, privacy, flexibility, creativity, etc.	IBs degree of flexibility to accommodate "human dimensions".

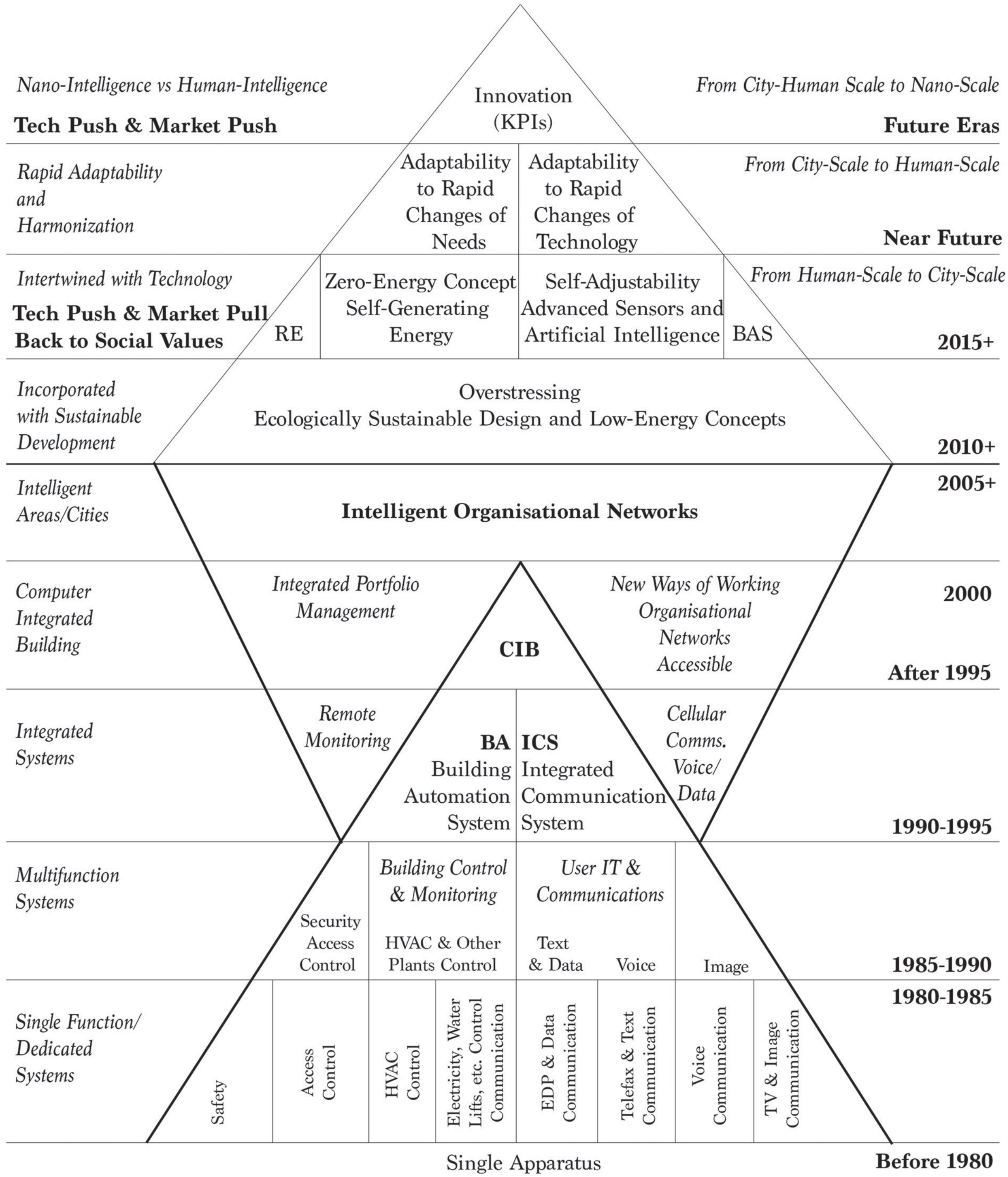

Figure 4. Updated IB pyramid (after Harrison, 1999 in Clements-Croome, 2004, p. 26).

intelligent cities. In this line, the study proposes in Figure 4 an updated version of the IB Pyramid originally defined and developed by Harrison (1999) and Clements-Croome (2004).

Findings point out that there is not yet a standard definition for IBs, demonstrating a research gap, and therefore, diversified interpretations and inferences regarding this field are observed. Analysing the essence of IBs and current agendas of governmental and private sectors in different regional contexts with viewpoint to the application of ICT and emerging advanced technologies in buildings, findings represent the identified KPIs of IBs according to the respective regions. In our opinion, IB is an evolutionary entity that seeks to harness available cutting edge technologies at the time and location to fulfil chosen set of multi-dimensional performance criteria, cost effectively.

Finally, an IB should respond to all three key components of systems, performances, and services and has to have following components:

KPI-1) Smartness and Technology Awareness

- Utilization of advanced embedded systems for building components.
- Incorporation of intelligent technologies and economic principles.
- Intertwined with advanced sensors and artificial intelligence.
- Application of building systems and technological integrations.
- Application of up-to-date adaptable and interoperable building control systems.
- In line with innovative future technologies and upgrades.

KPI-2) Economic and Cost Efficiency

- Consideration of economic repercussions, lifecycle analysis, and cost effectiveness.
- Consideration of enhanced productivity and effectiveness of environments.
- Application of efficient management of resources.
- Application of integrated facility management.
- Consideration of cost/time saving strategies.

KPI-3) Personal and Social Sensitivity

- Consideration of the requirements and expectations of occupants and/or users.
- Consideration of comfort, convenience, safety and security.
- Adaptable to ever-expanding and changing human needs.
- Responsive to social and technological changes.
- Responsive to the needs for communication and globalization.
- Consideration of well-being, emotional satisfaction, and enhanced creativity of users.
- Use of self-support of user activity.

KPI-4) Environmental Responsiveness

- Application of ecologically sustainable design.
- Utilization of renewable energy sources, energy efficient strategies, and conservation techniques.
- Application of energy management systems.

6. Conclusions

This study demonstrates, with clear research and empirical evidence, references, quotations, and exploration of practical implementations, why we should consider IBs as a significant component of future built environments. These findings show that IBs are expected to play a fundamental role in shaping future cities. The prominent potential of IBs is expressed in a host of values like the automation and digitalization of living environments and the integrated technological facilities; enhanced security ; health and well-being; optimized resource performance; reduced environmental impacts; investment returns and reduced level of operational costs; improved networking potentials; higher productivity; better well-being for the users. Clarifying the currently available definitions of IBs allows us to develop new platforms for developments of globally acknowledged IB indices.

We would like to stress the point that IBs are evolving and will change. This paper sets out the main factors which will combine in various ways dictated by societal and technological change. For instance, OA once considered to be one of the essential components of IBs is no longer getting so much attention whilst energy saving with green building features together with the human values are becoming more critical for both current and future IB design and operation practices. IBs should be treated as a dynamic and evolutionary entity rather than a static and fixed one. Nevertheless, the commonalities of IBs across all different regions and times clearly exist and that has been described in this paper.

The IB offers a new building design paradigm through embedded intelligence leading towards attainment of optimized functions of a building in real time. As a result, the rate of adoption of building automation, embedded intelligence, and advanced sophisticated systems is increasing in some parts of the world, resulting in increasing numbers of buildings labelled intelligent, smart, and green although as has been indicated these terms are sometimes mixed up and their distinctions blurred.

Concerning the discussed aspirations, built environment professionals confront challenges on how to become more responsible for intelligent buildings and the value of their outcomes. Any search for such 'new professionalism' must therefore span all the built environment and design professions, as they have interconnected and collective responsibilities (Cooper and Symes 2008; Hill and Lorenz 2011; Hill et al. 2013; Bordass and Leaman 2013). Professionals, it would seem, are being asked to confront the consequences of their actions, learn from them and share results. They are being asked to construct new roles in proactive market shaping, assessing future needs, demands and risks, at all appropriate levels of scale, taking longer-term responsibilities for learning through the realization of IBs' objectives in use (Cooper and Symes 2008; Hill and Lorenz 2011; Hill et al. 2013; Bordass and Leaman 2013).

Overall, the findings in this paper indicate that a fundamental agenda for the twenty-first century is to develop highly responsive buildings with substantive potentials of automatic control and monitoring towards optimizing ambient intelligent environments while balancing this approach with the human values, well-being, health, and quality of life. In this line, IBs should successfully respond to the ever-increasing demands of society while reducing the environmental impacts and this requires effective design initiatives to be put in place.

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ORCID

Umberto Berardi http://orcid.org/0000-0002-0508-6195

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