Can Intelligent Buildings Lead Us to a Sustainable Future?

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Abstract

There is a serious need for developing an optimized solution of sustainability and intelligence in buildings that will help the agenda of living in a healthy, comfortable, technologically advanced world. A review of the aspects of intelligent buildings and sustainability is presented followed by the study of certain existing projects over the world that incorporates intelligent techniques to achieve sustainability. These concepts were examined through an exploration of the existing literature on impacts of intelligent technologies including scientific literature; government and private organisation reports; and statements from various stakeholders. The research adopts an approach of strategic and critical evaluation of literature to grasp the fundamentals of the current state of knowledge.

Outputs from the study highlight the various benefits of intelligent buildings, which include decrease in energy costs, increase in productivity, and investments. Moreover, the comparison of the attributes of intelligent buildings and sustainable practices illustrates the fact that there is a considerable overlap and intelligence can aid greenness. Thus the research concludes that architectural design; green technologies and intelligence in combination may be a pragmatic approach towards the sustainability aspect. Implications from the study also suggest that though intelligent buildings have been a positive impact there is still a wide scope for enhancement.

Keywords: green buildings, innovative architecture, intelligent buildings, smart buildings, sustainability

Introduction

The Information Age also commonly known as the Digital Age has brought about fast evolution of technology in daily life and allowed rapid global communications and networking to shape modern society. As the world steps into the twenty first century this phenomenon has spurred progress in all fields including the built environment (Kluver, 2000). Intelligent buildings that originated in the early 1980's in the United States, are fast-spreading its tendrils as the elements of the digital information revolution (Harrison et al., 1998 and Mazza, 2008). Although there is no standard recognised definition available, the most expressive definition of intelligent buildings is the one proposed by Bennett et al. (1987) (in Atkin, 1988), which comprehensively highlights the three attributes that an intelligent building should possess:

- *"Buildings should 'know' what is happening inside and is immediately outside.*
- *Buildings should 'decide' the most efficient way of providing a convenient, comfortable and productive environment for the occupants.*
- *Buildings should 'respond quickly to occupants' requests".*

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There has been quite a dramatic shift in the building industry with the advent of computer integrated systems and controls. A plethora of intelligent components and products, which have been introduced and made available in the building markets over the last 20 years, are a testimony to the same (Harrison et al., 1998). Siemens Building Technologies, estimates on the basis of current technological progress and market sales, an additional market potential for intelligent building systems of some 20 billion euros over the coming ten years (Clarke, 2008). International Data Corporation (IDC): Energy Insights estimates that the global smart building market will grow from $3.1 billion in 2010 to $10.2 billion by 2015 (Kolodny, 2011). More recently, within the past 25 years or so, the notion of building intelligence has evolved owing to technological maturity; introduction of web-enabled integration platforms and IP-enabled devices; solid industry standards; substantial cost reduction; and increased market demand (Ehrlich, 2007). This has enabled intelligent buildings to be mainstream, practical and economical than before. Atkin (1988) asserts, *"Intelligent buildings are not a fad, but simply progress".* The study of current technological progress and speculation of future advances in the fields of artificial intelligence, robotics, automation, and architecture, confirm that intelligence in buildings is a sign of technological sophistication which will improve in leaps and bounds as time progresses (Nikolaou et.al., 2004 and Kurzweil, 2005). With all the ingredients for the high-tech option falling into place Futureagenda (2011) foresees, by 2020, *"that the majority of new buildings being constructed around the world, and many that are being refurbished, will be increasingly intelligent".*

Sustainable development is one of the rising issues of concern that has peaked with the advent of the twenty first century. Global warming, resource depletion, deforestation, irresponsible urbanization, etc. are some of the problems plaguing the planet (Garner, 1996; Harris, 2004a and Pitts, 2004). It has been observed that *"the total annual emissions of CO2 have increased from 1.5 million tonnes in the 1950s to almost 6 billion tonnes in the 1990s, and it is further predicted that CO2 concentrations will double by the year 2050 unless action is taken"* (Simpson, 1990; Pickering and Owen, 1994; in Garner, 1996).

Buildings are responsible for at least 40% of energy consumption in most countries (Frost and Sullivan, 2009). They are resource intensive in construction and operation; they also produce enormous quantities of emissions and waste during the construction process, during their period of use and occupation, and also at the point of their eventual demolition (Nikolaou et al., 2004 and Pitts, 2004). A recent report from the SMART 2020 programme forecasts that, with increasing urbanisation, worldwide energy consumption for buildings over the next twenty years will grow by around 45% (Futureagenda, 2011). These projections identify buildings as a sector with the most potential for improvement to meet the targets for reducing the threat of climate change (Nikolaou et al., 2004 and Pitts, 2004).

As energy prices climb and the focus on environmental performance intensifies, buildings will have to make extra efforts to steer towards the sustainable way. Since intelligent buildings are the current trend, and the future foresees a huge growth potential, it is necessary to determine if they provide a pragmatic approach towards a sustainable future?

Motivation

An intelligent building is in essence one that integrates disparate building systems such as lighting, HVAC, safety, security, power management, shared network, voice and data communication, etc. to effectively manage resources in a coordinated mode and provide significant high performance benefits. An ideal intelligent building should provide a dynamic and responsive infrastructure using technology so as to optimise processes, comfort, flexibility, effectiveness, energy efficiency, costs and environmental benefits.

(Caffrey, 1985; Clements-Croome, 1997; Harrison et al., 1998; Sharples et al., 1999; Wacks, 2002; Damodaran, 2006; Clarke, 2008; and Madsen, 2008b).

Gore (2006) claims that the scientific and technological revolution though has brought us tremendous improvements in various fields, has transformed our relationship to the Earth with its unanticipated side effects. Implying, new technology (in this case intelligent buildings) if not coupled with sustainable practices can lead to disastrous effects.

"Old habits + Old technology = Predictable consequences
Old habits + New technology = Dramatically altered consequences"

Intelligent buildings being sustainable, stand to make a huge positive difference on the environment, though there is quite a dilemma as to whether intelligent architecture promotes sustainability or not? Common perception in the intelligent building industry reveals that intelligence can aid sustainability but there is still doubt among stakeholders who view its use as an overtly luxurious lifestyle negating the purpose of sustainable living (Frost and Sullivan, 2009). There have been two prominent schools of thought; one that believe that a 'sustainable building' can be achieved using intelligent building systems while the other which argues that more energy and money can be saved by using natural energy-saving design solutions (Clarke, 2008 and Moore, 2009b). This study explores the concepts of intelligence and sustainability in the built environment to determine if intelligent buildings are sustainable.

Methodology Employed

Relevant literature and case studies were examined through an exploration of scientific literature; government and private organisation reports; and statements from various stakeholders. The literature was reviewed across specific topics and themes, which aim to provide a holistic understanding of intelligent buildings and sustainability in the built environment. A strategic and critical evaluation approach was used to grasp the fundamentals of the current state of knowledge.

An appropriate definition of sustainable development in the built environment context was chosen. This definition was then used as a theoretical framework to judge if intelligent buildings were environmentally, socially and economically sustainable. Case studies from around the world were used to exemplify the application of innovative technologies to achieve sustainable gains. The emphasis of this paper lies in the analysis of intelligent buildings against the principles of total sustainability to reveal its benefits and limitations.

Defining Sustainability in the Built Environment Context

In 1987, the most widely quoted definition of sustainability was coined by the United Nations in the report of the World Commission on Environment and Development (WCED): Our Common Future (also known as The Brundtland Report).

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

John Elkington laid down the *'three pillars'* of sustainability or the *'triple bottom line'* in 1994, which required the reconciliation of environmental, social and economic demands (Elkington, 2004). There are a wide range of definitions available, which goes on to show that sustainable development can be interpreted to have economic, social, political or environmental dimensions, depending on the values and the goals of the individual (Mitchell, 1998). A universally accepted definition of sustainability remains elusive, till date. Many people, including professionals such as architects, engineers, town planners, etc. have hitherto considered sustainability to be a synonym for energy-efficiency (Harris, 2004a). Scott (1998) asserts that sustainability is not only about energy efficiency but also about people's comfort, well-being and cost savings. Alnakib (2004) reiterates that the three dimensions of sustainability are mutually reinforcing to translate sustainability in an architectural setting.

The definition of sustainable development by the World Commission on Environment and Development (WCED) (1987) encompasses the three dimensions of sustainability and also adds to it another dimension of technological development that holds very critical to this study involving intelligent buildings. This study adopts the WCED (1987) definition of sustainable development owing to the multiplicity of issues embraced within it.

"Sustainable development is a process in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony, and enhance both current and future potential to meet human needs and aspirations".

Using the Definition of Sustainability to Evaluate Intelligent Buildings

The introduction of novel practices such, as the use of intelligence in architecture is questionable and needs to be scrutinized under the critique microscope until its benefits as well as limitations are analysed. The advantages shall help in validating the role of intelligent buildings and the disadvantages are gaps, which provide scope for further study.

The definition of sustainable development has been used as a theoretical framework to study intelligent architecture. The three dimensions of sustainability i.e. environmental, social and economic are explored in the intelligent buildings context. The premise being explored is the increasing awareness of the impact of intelligent buildings on the environmental, social and economic front.

Environmental Issues

We are facing new challenges over global warming and long-term supply of fossil fuels. This, combined with the pressure of an aging electrical generation infrastructure, is putting the onus on new programs for high efficiency and even zero-energy buildings. Mitchell (1998), (Gray, 2006), Ehrlich (2007), Rios-Moreno et al. (2007), Moore (2009a), and Liu et.al. (2010) observe programs promoting energy efficiency need to have an intelligent system design as one of their core elements. They account their hypothesis to the varied functions of intelligent control systems such as stop and start equipment when needed; monitoring space conditions and occupancies; and implementing sophisticated strategies to reduce overall energy use. Intelligent buildings also improve indoor air quality through continual ventilation adjustments and air-quality monitoring; and maximise day lighting by automating shading systems.

A building that knows when and where it is occupied can limit its own energy use by confining the operation of power-hungry HVAC and lighting systems to the hours and areas of the building they are needed (Wu and Noy, 2010). In order to achieve this, occupancy sensors are used that provide enhanced presence detection and accurate localised occupancy information to provide solutions that are energy-efficient without compromising on occupant comfort and productivity (Dounis et al., 2011 and Pandharipande and Caicedo, 2011). Although the cost of occupancy sensors varies by the type of sensor used, it is observed that they can usually pay for themselves through energy savings within a few years. Thus, in most cases, occupancy sensors offer greater energy savings and more flexibility than other forms of control and have proved to work effectively in a variety of applications. (Barnes et al., 1998 and Wu and Noy, 2010)

The SMART 2020 programme, informs that intelligent buildings and accompanying smart grids will save around 4 gigatonnes of CO2 equivalent emissions in 2020

(Futureagenda, 2011). IBM estimates intelligent buildings can reduce energy consumption and CO_2 emissions by 50% to 70% and save 30% to 50% in water usage (Moore, 2009b). Johnson Controls, leading producer of energy-saving equipment, says companies can cut energy bills by 20% to 25% by using efficiently programmed and monitored building management systems (BMS) and other intelligent controls (Mazza, 2008). Peter Ferguson, Director from Johnson Controls, explains that the biggest savings come through management of heating and cooling. *"One degree Centigrade down in heating temperature will provide around 7% savings on the energy necessary to heat the building."* (Clarke, 2008)

Despite all the potential energy saving benefits that have been highlighted Matsunawa and Nohara (1994) claim that intelligent buildings use a lot of energy. Sunil Shah, head of sustainability at engineering and construction company, Jacobs, asserts that incorporating methods such as better building design and passive or natural energy-saving solutions can save more energy (Damodaran, 2006). Bob Hayes, director at architecture firm, Architype, argues passive solutions are more sustainable because they don't need to be updated or refreshed during their lifetime and continue doing their job as long as the building lasts (Elkadi, 2000). Newsham et al. (2009) also highlights a contrary view through a questionnaire based study that personal environment control resulted in an average energy reduction of around 10% as compared to the typical intelligent fixed system.

Case Studies

Matthew et al. (2009) conducted a survey of intelligent and non-intelligent buildings that provides insights on the comparative energy efficiency of the buildings, in the Indian context. Three office buildings were chosen with varying levels of intelligence such that Intelligent Building 2 (IB2) was the most intelligent among the three; Intelligent Building (IB1) was lower in intelligence than IB2; and the third building (non-IB) was conventional with no inclusion of intelligent technologies. It was evident that IB2 has the least 'Annual energy expense per sq.m.' while the non-IB has the maximum. Also between the two intelligent buildings compared, IB2 has better energy savings than IB1. This goes on to highlight that intelligent buildings reduce energy usage as compared to conventional ones and also the higher the level of intelligence of a building the greater are the energy savings.

Frost and Sullivan (2009) also studied certain buildings that were prominent examples of intelligent buildings in the US and Canada to determine the effect intelligent technologies (such as asset management system, building information management system, building automation system, energy management system, etc.) has on energy savings, green house gases and CO_2 emissions. The State of Missouri, USA reported 17% annual energy savings and eliminated 205 million pounds of CO_2 equivalent emissions. Kwantlen University's Trade and Technology Centre in Cloverdale, USA observed 30% annual energy savings. 76% savings on lighting energy costs and reduced CO_2 emissions of 2797 tons annually were accounted for at the Rogers Centre in Toronto, Canada. Providence Newberg Medical Centre in Oregan, USA informed 26% annual energy savings and reduced CO_2 emissions by 731 tons annually. The Verve: high-rise condominiums in Ontario, Canada reported 35% annual energy savings and annual green house gas reductions measuring 887 tons.

IBM's Intelligent Building Management solution also tries to address rampant power consumption by the use of technology and comprehensive rule sets that are the general best practices (also gives the customers an opportunity to add their own rules). It has saved IBM's Rochester campus 8% on energy used, year over year, and is also being used to control energy consumption and costs at the Cloisters museum in New York City, at Boston University, and Tulane's campus in New Orleans. (Kolodny, 2011)

Social Issues

Social sustainability is the idea that *"future generations should have the same or greater access to social resources as the current generation (inter-generational equity), while there should also be equal access to social resources within the current generation (intra-generational equity)".* It focuses on individuals' behaviours, actions and reactions. (Sen, 2000) The definitions of comfort and productivity have changed over the centuries owing to the expectations fuelled by advances in technology. At times people perceive intelligent space as an alien entity trying to dominate. (Wacks, 2002) The social implication of intelligent technologies on our lifestyles needs delicate attention so as to ensure an enriching environment to make life meaningful amidst all the technological progress.

Chappells (2010), Chen et.al. (2010), Karjalainen (2010) and Liu et al. (2010) encourage the shift from a technology-centred view to socio-technical interactions of the occupants and pervasive spaces. They promote the need to learn and predict human behaviour so as to inform the production of intelligent and sustainable habitable environments. In conclusion, the benefits of focusing on comfort and wellbeing are considered important in promoting an intelligent and sustainable design. Clements-Croome (2004) to highlight the social responsibility of intelligent buildings proposes, *"Intelligent buildings are required to facilitate social ambience, convenience, security, safety, sensory stimulation, freshness and a pleasant climate"*. Cole and Brown (2009) believe that there is a necessity to accommodate human intelligence in context of automation so as to achieve higher efficiency in sustainable practices. Wu and Noy (2010) add *"comfort for all occupants is a worthy objective, but because of various comfort requirements and clothing levels among occupants, a more practical goal is assuring that at least a proportion, say, 80%, of each individual occupant's preferences are satisfied".*

Recent advancements in pervasive computing allow embedded systems to collect information for context awareness and apply it in ways that result in new advanced services and applications. This technology has resulted in the assessment of a completely different set of issues pertaining to privacy in intelligent spaces (Liu, et al., 2010; Karjalainen, 2010 and Moran and Nakata, 2010). They analyse a series of factors pertaining to monitoring and surveillance, which are believed to influence occupant behaviour, from both physical and social perspectives. The problem areas identified are device obtrusion, coverage and control; number of devices; frequency of data collection; and user awareness. In order to combat issues like these and many more, Kua and Lee (2002) have exposed new concepts that could be used to encourage acceptance of intelligent technologies in an unintimidating way by the general public by introducing the 'Intelligent Building Initiatives'. The intelligent centre, intelligent laboratory, volunteers try-out program, industry co-opting program and technology adaptations and collaborations are some of the initiatives suggested to increase social acceptability.

Riewoldt (1997) and Mazza (2008) assert intelligent spaces should use technology to humanise living environments and help reunite people with their socio-cultural and natural environment in aesthetic, ergonomic and ecological terms. Maximising occupant comfort, acceptability, performance, safety and efficiency are the recipe for social sustenance of the intelligent buildings concept.

Case Studies

Some of the most frequently asked questions to evaluate the role of human intervention in an intelligent environment are, Whether people prefer to be in charge of their surroundings or are perfectly satisfied by the independent job done by the intelligent building systems? Do monitoring and surveillance influence occupant behaviour from social perspectives? How much level of technological intrusion is to be considered healthy in a person's life?

Baird and Lechat (2009) conducted a survey to determine the amount of personal control building users had and whether they considered it to be important. Responses were sought concerning the following five aspects of the working environment: heating; cooling; ventilation; lighting and noise. For the set of buildings studied it was found that the users' perceived the amount of personal control they had of lighting to be reasonable, but that for heating, cooling, ventilation and noise was relatively low. Around 30% of respondents saw it as important to have this control. It was suggested that reaching an optimum solution with user control and automation helps people have a choice and feel comfortable in the environment.

Matthew et al. (2009) analysed the effect of intelligent security systems on employee efficiency in India. This study highlighted that the entry control devices inconvenienced majority of the people (around 70-80%) but at the same time they felt secure at their workplace. The entry control devices did not affect around 10-15% of the people. 60-70% people reported feeling secure in the presence of closed circuit cameras. While 20-30% people felt that their efficiency had improved as they felt their superiors were monitoring them continuously.

There have been several documented cases of promotion of social sustainability in the built environment and Clements-Croome (1997) highlights the Helicon building in London and the Atrium in the Kajima Corporation in Tokyo as intelligent buildings that respect the iterative cycle of human mental needs for freshness, concentration and relaxation in order to work effectively.

Economic Issues

Economic sustainability is the term used to identify various strategies that make it possible to utilize available resources to best advantage and encourages its responsible use. It is a tool to make sure the business is making a profit while addressing environmental concerns and contributing to the financial welfare of the owners, the employees, and the community where the business is located.

"A probable stereotype of an intelligent building is that it is a possession of technologically advanced countries" (Kua and Lee 2002). This is a common preconception nurtured due to the perceived economic burden that an intelligent building poses. Himanen (2003), Gray (2006), Katz and Skopek (2009) and Matthew et al. (2009) recognise the benefits of the 'Intelligent building concept' as decrease in building maintenance and energy costs; increase in productivity, rental incomes, investments, occupancy rates, retention; and accommodation of flexibility. They identify the true cost of an intelligent building as not simply its cost of construction but also the operation and maintenance costs over the structure's life span. Intelligent buildings also guard against repair costs, productivity loss, revenue loss, and loss of customers to competitors.

As noted by Frank Spitzer, senior associate, Intelligent Buildings International (IBI) Group, intelligent buildings yield cost reduces in operation and maintenance through optimising automated control, communication and management systems. An intelligent buildings' security operation is a cost-effective example as one security guard can efficiently keep an eye on security functions, track people in the building, lock and unlock doors, and monitor the fire system from a single location. Thus eliminating the need for a group of security personnel making rounds. (Clarke, 2008)

Intelligent Buildings can also provide an immediate return-on-investment and reduce the expected time of payback in terms of higher employee productivity and reduced operating expenses (Katz and Skopek, 2009). According to a study by Himanen (2003) *"it has been calculated that in office work the cost of labour is 80 per cent, other costs 10 per cent, and the space costs 10 per cent (Mölsä 1991, Anttila 1991 and Martela et al. 1991),* *or alternatively 86 per cent, 9 per cent and 5 per cent (Huhtanen 2000). Hence, the small increase in work productivity can easily pay back the investment costs, especially if it is true that the cost of building automation is 1 per cent of the total building investment".*

Neil Cameron, GM at Johnson Controls, speculates *"over a period of 40 years, it is estimated that only 11% of the total cost of a facility goes into the initial construction of the building; 14% into financing; 25% into operations and 50% into operational expenditure".* He implies that if one invests in designing an energy efficient building from the start, costs will be reduced in the short and long term (IT-Online, 2012). As all of these are critical factors for business success, owners have an advantage by investing in an intelligent building to reinforce the future of their business.

Case Studies

Matthew et al. (2009) conducted a survey in India with an aim to find out whether the investment on intelligent buildings has any impact on the working environment and long-term economy. Three office buildings in India were chosen with varying levels of intelligence such that Intelligent Building 2 (IB2) had the maximum number of intelligent technologies; Intelligent Building (IB1) was lower in intelligence than IB2; and the third building (non-IB) was conventional with no inclusion of intelligent technologies. It was observed, IB2, which is the most intelligent building among the three, has the lowest 'Yearly energy expense per sq.m. of built area' while the non-IB has the maximum. Also on observing the percentage savings of Intelligent Buildings as opposed to conventional ones it is clear that IB2, which boasts of superior intelligence than IB1, saves almost two and a half times more money than IB1.

The 500,000-square-foot campus of Ave Maria University, Naples is an example of reduced operating costs owing to the use of intelligent integrated systems. Ave Maria University saved over $1M in building costs by eliminating the redundant wiring and cabling of multiple isolated building systems; reduced staffing costs by enabling IT to assume tasks of building maintenance staff with an estimated $350,000 savings annually in human resource costs; and enabled significant efficiencies in utility usage (Frost and Sullivan, 2009). The estimated cost of the project was between $3.60 and $4.25 per square foot, based on the architecture but operating costs stood at about $3.15 per square foot for utilities, thus saving the university a lot of money (Madsen, 2008b).

Discussion

This article has explored the relationship between intelligent buildings and sustainability in the built environment context, using the definition of sustainable development to characterise intelligent buildings from an environmental, social and economic standpoint. The concepts that collectively characterize an intelligent building are related to sustainable building strategies and design, illustrating the benefits; limitations; and considerable overlap between these two current trends in design and construction practice.

Benefits

Intelligent buildings have the potential to promote high efficiency and low-energy consumption, which can be the answer to a multitude of environmental concerns. They can also reduce water usage as well as the release of harmful green house gases into the atmosphere. (Ehrlich, 2007; Rios-Moreno et.al., 2007; Clarke, 2008; Mazza, 2008; Moore 2009a; Wu and Noy, 2010; Liu et.al., 2010; Kolodny, 2011; and Pandharipande and Caicedo, 2011) Improved user comfort, safety, security, social ambience, sensory stimulation, indoors air quality and illumination levels is known to enrich the social experience of occupants of an intelligent building. It can be safely assumed that intelligent spaces provide enhanced living environments that provide for social sustenance. (Wacks, 2002; Clements-Croome, 2004; Matthew et al., 2009; Chappells, 2010; Chen et. al., 2010; Karjaleinen, 2010; and Moran and Nakata, 2010) Intelligent buildings significantly lower operating costs with accurate monitoring and control of energy intensive building systems to make a bankable difference (Himanen, 2003; Pitts, 2004; Gray, 2006; Madsen, 2008a; Mazza, 2008; and Matthew et. al., 2009). Intelligent building technologies give building management professionals the tools they need to better serve tenants, occupants, and users. A significant benefit to the building owner is that intelligent buildings will get above-market rents, have lower vacancy rates, and additional revenue expectations (Clements-Croome, 1997; Harisson et al., 1998; Gray, 2006; Matthew et al., 2009; and Katz and Skopek, 2009).

In conclusion, a review of various literature and documented cases suggested that the main operational benefits of installing intelligent building components include:

- energy efficiency and higher environmental sustainability;
- increased user comfort and productivity;
- improved safety and reliability;
- improved operational effectiveness; and
- enhanced cost effectiveness.

Common Attributes

It can be observed that the benefits of intelligent buildings contribute to the 'triple bottom line' of sustainable development i.e. the environmental, social and economic aspects in most of the cases. Intelligent buildings are smarter, better connected, self-monitoring spaces providing safer, comfortable, secure, efficient environments capable of self-managing utilities; and maximising occupant performance, investment and operating cost, savings and flexibility. The aforementioned characteristics bear resemblance to the common objectives of sustainable buildings that are designed to reduce the overall impact of the built environment on the natural environment, human health and economy by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation.

As is evident intelligent buildings and sustainable buildings are striving towards common goals. In keeping with this theme the Continental Automated Buildings Association (CABA) has introduced the concept of being intelligent, green, and profitable which is aptly described as a Bright Green Building. *"A bright green building is one that is both intelligent and green. It is a building that uses both technology and process to create a facility that is safe, healthy and comfortable, and enables productivity and well being for its occupants"* (Frost and Sullivan, 2009).

Limitations

In spite of these purported benefits, the main barriers to the promotion and acceptance of intelligent buildings can be attributed to the lack of:

- financial resources and confidence to undertake new and 'untested' technologies;
- professional capacity to incorporate and manage intelligent technologies;
- knowledge of developers and owners on the environmental impact of inefficient buildings;
- information on opportunities presented by intelligent technologies;
- institutional structures to encourage and support uptake of such technologies.

Conclusion

With the advent of various intelligent building technologies, in the times when sustainable development is a rising concern, it was quite necessary to assess whether intelligent development is sustainable or not. By conducting this study the researcher aspires to provide an optimised solution of sustainability and intelligence that will help the agenda of living in a healthy, comfortable, and technologically advanced world. The study started with a review of existing intelligent building literature against the theoretical framework of the definition of sustainability.

This article has reviewed key concepts pertaining to intelligent buildings and sustainable development to provide documented evidence that sustainability can be achieved using intelligent technology. A thorough awareness of the academic context helped in the identification of common attributes to both intelligent and sustainable buildings. It can be concluded through this research that intelligent buildings are sustainable on all the three fronts analysed i.e. environmental, social and economic, though a few inconsistencies were noted in each field. Implications from the study also suggest that though intelligent buildings have a positive impact on the environment, people and economy there is still a wide scope for enhancement.

This study has set down the foundation for a meticulous examination of intelligent buildings and sustainability in the built environment context. The development, which will result from this research, shall help establish a relationship between sustainability and intelligent architecture. From a practical perspective, it provides a way for developers or design teams to value sustainability of intelligent systems and lay emphasis on a sustainable design strategy. It can help set up industry standards in the future, which clients can refer to and decide the best suited intelligent green design for their organizational needs. It will also help enhance the productivity and effectiveness of organizations by optimizing energy consumption, increase user satisfaction, minimize operating costs, and address key environmental issues. Owing to the continuous, evolving technological progress that intelligent buildings are a part of, this subject area warrants further exploration.

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