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What is a Smart Building?

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Abstract

Purpose – Within the building sector a lack of clarity in terminology does not help designers, clients or researchers. Non-domestic buildings have shown rapid increases in the use of advanced technology and control systems with varying drivers, many of which are labelled as intelligent. The term smart has been used interchangeably with intelligent without any clear distinction between the two. If the term Smart Buildings represented a separate, more advanced grouping, it would provide an opportunity to focus the future progress of non-domestic building development. The paper aims to discuss these issues.

Design/methodology/approach – Drawing upon academic and industrial literature and experience, this paper reviews the scope of Intelligent Buildings and the current available definitions of Smart Buildings to form a clear definition of both smart and Intelligent Buildings.

Findings – These definitions define the border between the intelligent and the (more advanced) Smart Building. The upper bound of the Smart Building is defined by (the future development of) the predictive building.

Originality/value – This work provides a clear focus which will allow the progression of the non-domestic building sector by providing guidance and aspiration, as well as providing a platform upon which a large amount of technical work can be based.

Keywords Building performance, Intelligent buildings, Building progression, Non-domestic building, Smart Buildings, Thinking buildings

Paper type Research paper

1. Introduction

Intelligent Buildings have been researched and developed over the last three decades, but in more recent literature, roadmaps and industrial reports the term smart has started to be quoted more regularly. This seems to be the case in all aspects of the built environment sector; smart sensors, smart materials and smart meters within buildings

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are seen to be the latest, most advanced technologies in our efforts to develop high-performing buildings. Smart cities are commonly seen to be the future of the urban built environment, with increasingly populated conurbations, demanding more functionality from more constrained resources and more stringent building regulations.

However, when put into the context of buildings themselves, there is a clear confusion as to the differentiation between smart and Intelligent Buildings. There is sparse academic literature currently recognising a distinction between the two – even though buildings are increasingly being referred to as smart. This lack of clarity in terminology does not help designers, clients or researchers.

By focusing on the key drivers behind building development past and the present, this paper aims to assess the meaning of Intelligent Buildings and bring together a definition for a Smart Building that represents a more advanced grouping, learning from and building upon the successes and limitations of previous terminology and meeting the criteria upon which a high-performing building is assessed. The upper and lower bounds of a Smart Building will be defined, creating a base upon which future research can be established.

2. An introduction to building progression

Although relevant advances have been made in the domestic sector, this paper focuses only on non-domestic buildings, as used in UK building regulations. Anonymous, 2013a, b); these are buildings which have no residential purpose. This is in contrast to the ASHRAE definition of commercial buildings, which may include multi-family residential dwellings (Anonymous, 2010).

2.1 The drivers behind building performance

It is evident that the design and expected performance of non-domestic buildings has changed throughout history. A century ago, hospitals, offices, schools, venues and universities were robust stone and brick buildings with basic gas, water and electrical systems. Modern equivalents are being conceived, designed and built as dynamic and technically complex buildings. In order for any change to be described as progress, it is required that the drivers for the resultant evolution have been met to a higher degree than previously. The drivers for the development of buildings can be said to revolve around adding value to a building (Smith, 2002). This value will, to an extent, depend upon the context and building category, but traditionally have formed from themes relating to the cost of the building over its lifetime, and the performance, comfort and satisfaction of those within the building (Shabha, 2006; CABA, 2008). Reducing energy consumption has now become a driver in its own right, due to increasingly stringent regulations and awareness of climate change. This is recognised in modern buildings as a significant design criterion (Sinopoli, 2010; GhaffarianHoseini *et al.*, 2013).

With the operating costs of a non-domestic building being significant when compared to the capital cost and a "shifting culture towards value rather than initial cost" (Clements-Croome, 2011) it is suggested that a more suitable representation of this driver would be its ability to maintain value over a long period of time under changing use and external conditions; its longevity. Therefore the three distinct drivers for building progression are:

(1) longevity;

(2) energy and efficiency; and

(3) comfort and satisfaction.

Whilst the latter two drivers are very traditional terms, they are reflections upon their broadest sense and encompass more contemporary terms such as energy effectiveness and well-being.

Therefore, an advanced functioning building will have its energy consumption minimised whilst consistently allowing the maximisation of the performance, comfort and satisfaction of its occupants over a long lifetime.

2.2 Methods to achieve progress

The implementation of the changes required to meet the drivers has largely been enabled by increasing knowledge, research and the availability of new materials and technologies, such as rapidly evolving communication systems (Drewer and Gann, 1994; Smith, 2002). It is possible to express the changing genres and aspects of buildings through the different levels shown in Figure 1, which demonstrates that as buildings have progressed there are four aspects that vary:

(1) the methods by which building operation information is gathered and responded to (intelligence);

(2) the interaction between the occupants and the building (control);

(3) the buildings physical form (materials and construction); and

(4) the methods by which building use information is collected and used to improve occupant performance (enterprise).

In different categories of building, these four methods are focussed upon and utilised to different extents. Although each method has developed over time to be more effective, the methods have largely been developed independently of each other.

3. What is the meaning of intelligence?

Evolving definitions of Intelligent Buildings have been developed since the 1980s (Wong *et al.*, 2005) and these are continuing to be suggested using the latest knowledge and experience (Brooks, 2011; Clements-Croome, 2011). In 1990, Powell defined an Intelligent Building as being:

> "A building which totally controls its own environment" (Stubbings, 1988). This seems to imply that it is the technical control of heating and air conditioning, lighting, security, fire protection, telecommunication and data services, lifts and other similar building operations that is important – a control typically given to a management computer system. Such a definition for a conventionally Intelligent Building does not suggest user interaction at all (Powell, 1990).

Wong *et al.* (2005) show in their review of Intelligent Building research that most of the early definitions revolved around minimising the human interaction with the building. The early definitions of Intelligent Buildings are what would be expected, since at that time architects and building engineers were progressing from what can now be seen to be automated buildings, as demonstrated in Figure 1. Generally, definitions of intelligence within buildings refer to the integration of numerous systems which revolve around building operation (Carlini, 1988; Holden, 2008; Healey, 2011; Langston and Lauge-Kristensen, 2011); a basic example of which would be the integrating of the building management system (BMS) with the lighting systems. However, since their initial conceptualisation, definitions of Intelligent Buildings have expanded the number of features involved in order to accommodate the latest understanding of

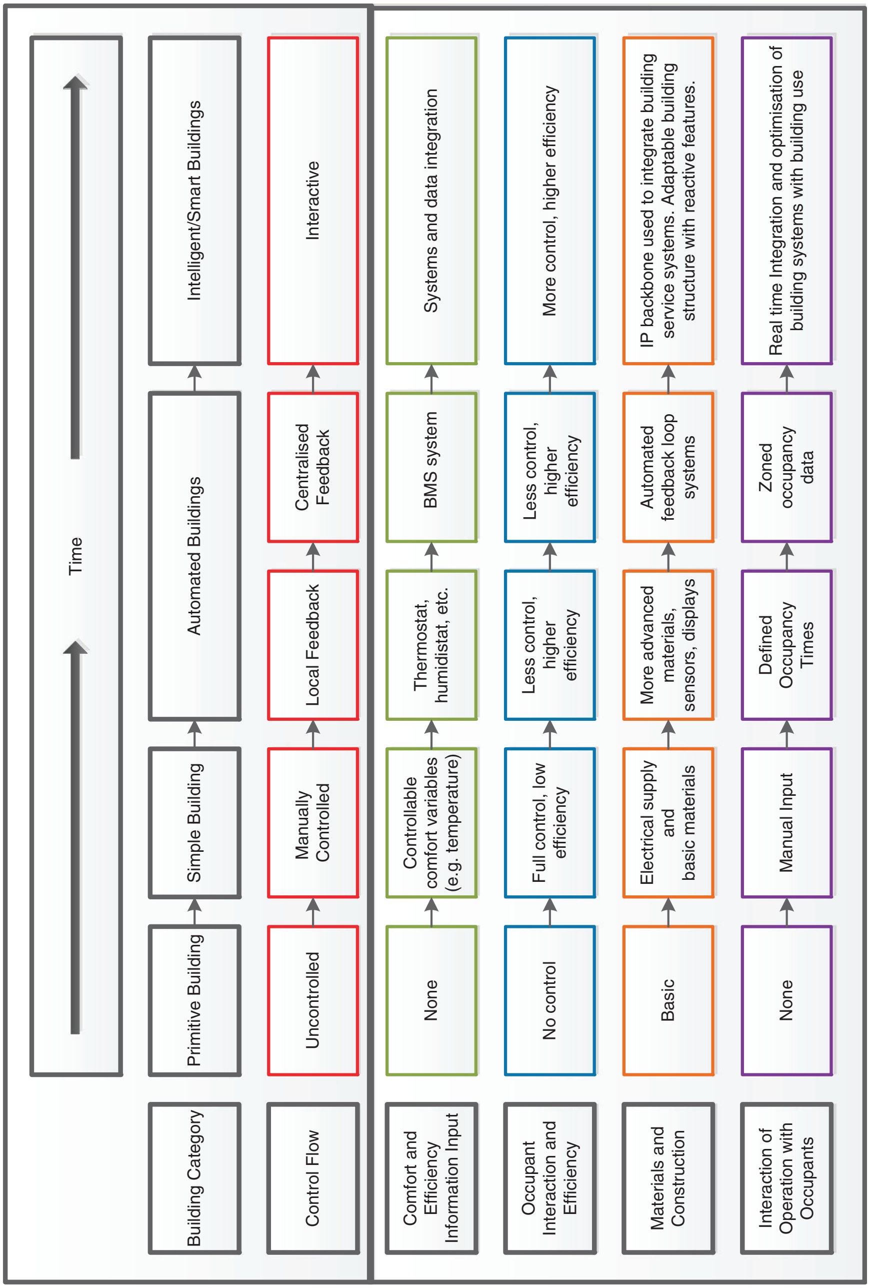

Figure 1.
Building progress

building requirements; especially regarding the ways in which occupants interact with a building, and the effect of this on building performance. Smith suggests that many of the earlier buildings described as intelligent do not fulfil the majority of currently accepted definitions (Smith, 2002); indeed many modern buildings are likely to push the traditional definitions to their very limits of acceptance. In 1995 the Conseil International du Bâtiment Working Groups defined an Intelligent Building as:

> A dynamic and responsive architecture that provides every occupant with productive, cost effective and environmentally approved conditions through continuous interaction among its four basic elements: places (fabric; structure; facilities); processes (automation; control; systems) people (services; users) and management (maintenance; performance) and the interrelation between them." (CIB, 1995 as quoted by Everett, 2008).

Furthermore in 2009 Clements-Croome developed the following definition which he later repeated:

> An Intelligent Building is one that is responsive to the requirements of occupants, organisations and society. It is sustainable in terms of energy and water consumptions besides being lowly polluting in terms of emissions and waste: healthy in terms of well-being for the people living and working within it; and functional according to the user needs (Clements-Croome, 2009 as quoted by Clements-Croome, 2011).

As the definitions expand, the term intelligence loses both meaning and focus; which is contrary to what the updated definitions were trying to achieve. In order to try and make some correlation between the two and provide direction upon which the research is based, Everett (2008), for example, offers different definitions for Intelligent Buildings. Brooks (2011) later suggested that Intelligent Buildings are equivalent to the BMS within them. The BMS is usually seen to be just one of the integrated tools within a building and not the entire system. This significant difference to other previously mentioned definitions is possibly due to the loss of meaning in the term. Other research recognises the lack of focus and is conducted with regard to trends in definitions (Katz and Skopek, 2009; Wong and Li, 2009), whilst Yang and Peng (2001) suggest that the implementation of Intelligent Building concepts is being hindered due to a lack of understanding by owners and developers. A focus on progression in the building industry and research sectors cannot be achieved if the aims upon which the research is being conducted are constantly changing.

There is an academic view that smart systems are a subdivision of Intelligent Buildings (Kaklauskas *et al.*, 2010; Clements-Croome, 2011), although there is sparse literature that justifies this relationship. By recognising intelligence as the ability for a building to gather information and respond to it, as described throughout the literature, there is now an opportunity that can limit the addition of sub clauses to definitions of intelligence and allow progressive research into future building design. Using the drivers addressed previously it can be recognised that intelligence will play a significant part in future building designs, but can be built upon using a term which has been increasingly used in recent literature; Smart Building. Smart Buildings are Intelligent Buildings but with additional, integrated aspects of adaptable control, enterprise and materials and construction. In Smart Buildings, the four methods used to meet the drivers to building progression, mentioned previously, are developed alongside each other, utilising information from one in the operation of another. This is in contrast to Intelligent Buildings, which have largely developed intelligence independently of the other methods.

The defining of the term Smart Building will address the need for focus and progression and will also prevent the further fragmentation of terminology in the building sector where Intelligent and Smart Buildings are often classed as synonymous to each other (Drewer and Gann, 1994; McGlinn *et al.*, 2010).

3.1 Progression from Intelligent Buildings

Applying the term smart to buildings has been increasingly used in both industrial reports (The Climate Group, 2008; Powell, 2010; Harris, 2012) and also in the recent academic literature (Cook and Das, 2007; Bach *et al.*, 2010; Kleissl and Agarwal, 2010; Kiliccote *et al.*, 2011; Wang *et al.*, 2012a, b). This increasing use of new terminology demonstrates that current terminology does not cover all aspects of the most advanced buildings and industrial pressure to create a distinct advancement in building technology. However, the lack of a clear definition to what a Smart Building actually is, results in an unclear end goal with few methods by which it can be achieved. It is a similar situation to that surrounding the definition of zero carbon homes (UK Green Building Council, 2008) or the confusion and ambiguity incurred when referring to something as sustainable.

The need to define a Smart Building is similar to the need to define Intelligent Buildings in the 1980s; in order to put a clarification on a term that was most probably developed "to sell or rent more floor area in commercial and/or office buildings" (R. Geisler, 1989 as quoted by Arkin and Paciuk, 1997).

Just as Intelligent Buildings were developed from automated buildings, a concept supported by the CABA Building Intelligence Quotient Programme (Katz and Skopek, 2009), Smart Buildings are developed upon Intelligent Building concepts (The Climate Group, 2008; Agarwal *et al.*, 2010). Katz and Skopek (2009) show that Intelligent Buildings contain aspects of automation and similarly intelligence is an important aspect of Smart Buildings (High-Level Advisory Group and REEB Consortium, 2009; Wang *et al.*, 2012a, b; Shaikh *et al.*, 2014). Automation in buildings requires "a lot of 'intelligent' devices" (Runde and Fay, 2011) and Intelligent Buildings are increasingly using a number of smart devices, materials and sensors (Arkin and Paciuk, 1997; Wong *et al.*, 2008; Gilder and Clements-Croome, 2010).

This development from the use of intelligent to smart sensors within buildings is just one example of the progression towards a smart built environment (Shabha, 2006). Deakin and Al Waer (2011) demonstrate the transition from intelligent to smart cities and Fadlullah *et al.* (2011) show the use of intelligent systems within an overarching smart grid.

3.2 Current Smart Building definitions

Although there is an increasing amount of academic, popular and industrial literature addressing Smart Buildings as a concept, there are few justified definitions as to what they are, and, at the time of writing, the authors can find no literature addressing how this emerging concept can be achieved or assessed. In creating an appropriate definition for a Smart Building, the current literature addressing the subject shall be used in order to gauge an indication of the new aspects and advantages that academics and industry feel Smart Buildings can provide.

An academic view is given by Wang *et al.* (2012), agreeing that Smart Buildings are part of the next generation building industry, suggesting that they:

> Address both intelligence and sustainability issues by utilising computer and *intelligent* technologies to achieve the optimal combinations of overall comfort level and energy consumption.

Kiliccote *et al.* (2011) propose that Smart Buildings are self-aware and grid-aware, interacting with a smart grid whilst focusing on the real-time demand side response and an increased granularity of controls. The theme of responsiveness, adaptability and flexibility recurs in further descriptions of Smart Buildings and is a key area in which Smart Buildings can differentiate from previous generations (Cook and Das, 2007; Wang *et al.*, 2012a, b).

The use of increasing knowledge, or information to achieve the drivers for building progression is highlighted in many publications; McGlinn *et al.* (2010) define Smart Buildings as "a subset of *smart environments*" where smart environments are "able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment" (Cook and Das, 2007). The authors acknowledge the need for information on both environment and occupants but suggests that the Smart Building should itself be an entire system rather than a collection of smaller smart environments, in order to encourage the interaction between all spaces in the building. Sinopoli (2010) suggests that a Smart Building revolves predominantly around integration, both of the systems within the building, and the method through which the building is designed and implemented. Sinopoli also highlights the need for technology systems to be integrated horizontally, as well as vertically in order to "allow information and data about the building's operation to be used by multiple individuals occupying and managing the building". The authors believe that this approach may resemble a Smart Building, although Sinopoli does not make a distinction between Smart and Intelligent Buildings.

In contrast to the sparse academic research in the area, there have been numerous definitions of the Smart Building which have been developed by organisations and companies such as the GSA, the Climate Group and CABA. The latter defines the meaning of Smart Buildings to be the ability to "figure out behaviour and behave according to impacts of parameters around it" (CABA, 2008). The significance of this definition is that it implies that the ability of the building is to adapt to different situations using external context-related data surrounding the behaviour of the occupants. The Climate Group suggest that the term Smart Building describes "a suite of technologies used to make the design, construction and operation of buildings more efficient, applicable to both existing and new-build properties" (The Climate Group, 2008). In a similar way to Sinopoli, they highlight the holistic nature of a Smart Building; in suggesting a more integrated design, construction and operation.

An additional recurring feature within current definitions of Smart Buildings is the focus on the occupancy and the higher level interaction with the occupants of a building (Agarwal *et al.*, 2010; Powell, 2010; Kiliccote *et al.*, 2011; Moreno *et al.*, 2014). It is a widely debated area as to how much control should be given to the occupant of a building in order to meet both comfort and energy performance criteria, but the latest concepts of advanced building research emphasise the need to create a convergence between building technology and the occupant.

4. Smart Buildings

The definition of a Smart Building will take into account the recognised need for holistic and integrated design, taking into account both the current themes described in literature, the drivers for building progression and the methods through which these can be achieved:

> Smart Buildings are buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability,

not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction. The increased amount of information available from this wider range of sources will allow these systems to become adaptable, and enable a Smart Building to prepare itself for context and change over all timescales.

Figure 2 shows the diagrammatic representation of the authors' Smart Building definition.

The four methods that meet the drivers for building progression, suggested in Figure 1, can be seen to be the four pillars in Figure 2. However, at the heart of the definition of a Smart Building is adaptability.

4.1 Adaptability

Adaptability within, and integration between all aspects of the building will allow the differentiation between previous generations of building and Smart Buildings. Adaptability utilises information gathered internally and externally from a range of sources to prepare the building for a particular event before the event has happened, which is fundamentally different to being reactive. A Smart Building is able to adapt its operations and physical form for these events. Intelligent Buildings are generally reactive; Smart Buildings are adaptive. Examples of adaptability are the ability to account for:

- different people's perceptions of comfort at different times of day and different times of year;
- changes in occupants or building use;
- varying occupancy data characteristics; and
- varying yearly average external whether conditions.

Whilst maintaining or increasing energy efficiency and occupant satisfaction.

Creating an adaptable building through the design and integration of the four methods in Figure 2 in order to meet one or more of the drivers can be defined as a smart system. Figure 3 shows the different timescales on which smart adaptability

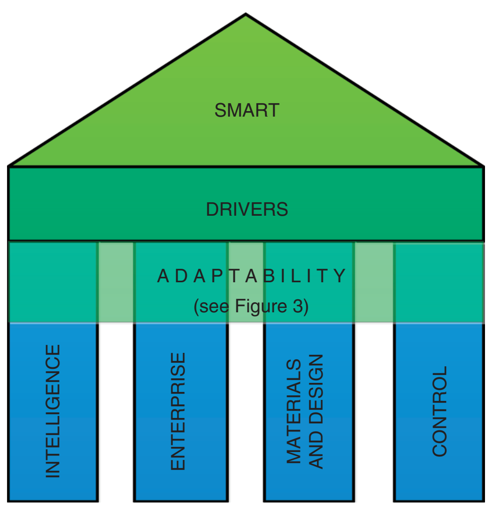

Figure 2.
Features of a Smart Building

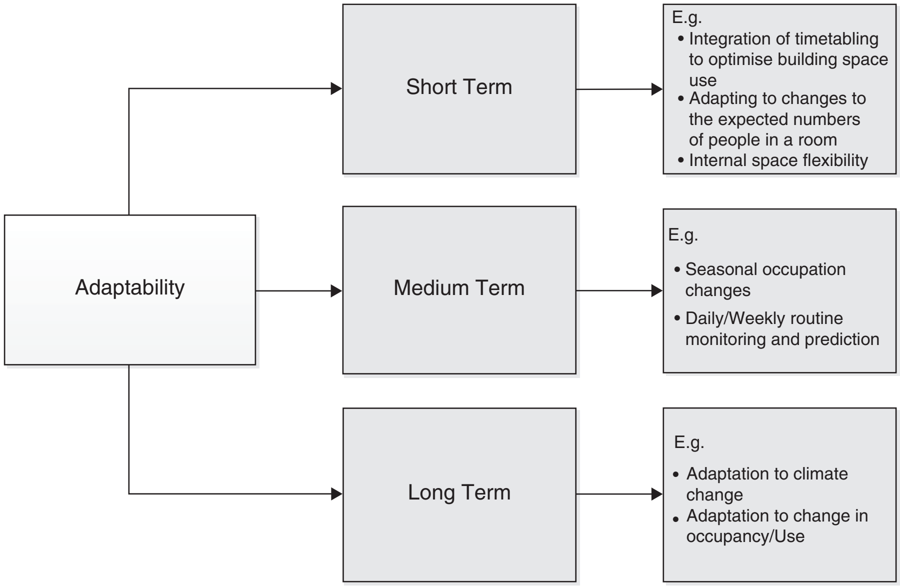

Figure 3.
Adaptability over different timescales in a Smart Building

operates. It is not new for adaptability to be associated with buildings, but the use of integrated adaptability as opposed to reactivity is a significant difference between Intelligent and Smart Buildings. The ability to adapt in response to information gathered from building use is essential to a Smart Building's successful operation. Recent Intelligent Building systems research, such as intelligent agent controllers, can be adaptable and autonomous as opposed to traditionally reactive intelligence (Callaghan *et al.*, 2009). The authors see this as a method through which intelligence can be adaptable, as required in Figure 2, and would be used alongside the three other methods to create a Smart Building. If a Smart Building is not performing to its design standard, the building systems can gather information on why and adapt to perform to the intended level in future similar conditions.

Adaptability for the long term will predominantly evolve around the materials and physical design of the building, although any intelligence and enterprise infrastructure must be able to accommodate long-term change.

4.2 Control within Smart Buildings

One of the most debated aspects around modern building design is control. When designed, implemented and used correctly, buildings with predominantly human control can perform very well, as can buildings which are fully automated. Both, however, have intrinsic risks which can result in poorly performing buildings if any of the three factors mentioned above change, an example is given by Masoso and Grobler (2010) of behaviour causing poor performance in numerous buildings. Buildings relying upon human control assume that the occupants will use the building in the way it was designed for; automated buildings tend to be designed to the theoretical climatic conditions, occupancy and use. Both types are subject to changes during construction and commissioning that differ from the design intent. Therefore both categories are susceptible to decreases in performance during change of occupancy, use or climatic conditions.

As shown in Figure 1 modern buildings are recognising the importance to re-engage the occupants with the building in order to allow them to have control over their own environment. There have been numerous studies showing that there cannot be a single set of conditions that will be suitable for all occupants (Fotios and Cheal, 2010; Logadottir *et al.*, 2011), and many studies showing that a degree of control in a workplace results in benefits such as increased comfort, lighting quality (Boyce *et al.*, 2000) and occupant satisfaction (Becker, 1985).

As Dounis and Caraiscos (2009) indicate, comfort in a building is not one dimensional but has multiple variables. In the list below, Leaman (2000) highlights a number of points that occupants of a building like and dislike. Within these points they highlight that occupants of a building like normal states which they can "utilise habitually" and in traditionally controlled buildings, the multidimensional nature of comfort opposes this ability. For example, in winter, a room may be much colder than expected, which encourages the use of inefficient electric heaters, but the air quality may deteriorate, resulting in windows to be opened which will obviously negate the effect of electric heaters and may even have a cooling effect on surrounding rooms. There is a need to strike a balance between allowing users to have control of their environment, and creating stable, reliable and comfortable conditions which allow the building systems to manage the energy consumption efficiently.

User likes and frustrations (Leaman, 2000).

Users like:

(1) situations where they need to intervene to change things only occasionally, with predictable "normal" or "default" states which they can utilise habitually, and, for most situations, forget about;

(2) opportunities to act quickly to make corrections or interventions if conditions alter; and

(3) the ability to carry out interventions quickly and effectively.

Users' frustrations.

For building users, greatest frustration arises when they are:

(1) prevented from intervening to change physical settings from an undesirable existing state to a preferred new one;

(2) subjected to arbitrary changes in conditions which they perceive and are affected by but cannot themselves over-ride;

(3) working in an unfamiliar setting which may require intervention to make things habitable or comfortable; and

(4) required to act quickly and or in stressful circumstances, e.g. in an emergency.

Smart Buildings are those which reconcile both human control and automation in order to achieve the drivers for building progression. The recognition of this need is addressed in recent research (Bourgeois *et al.*, 2006; Cole and Brown, 2009). The aim of control within a Smart Building is to provide occupants with information so that they can adapt to the building, as well as the building adapting to their preferences and requirements.

4.2.1 Examples of control within Smart Buildings

- Influencing adaptive comfort by warning occupants of the building what the likely temperature is going to be within the building before they set off from home.
- Use real time environmental information to enable occupants to be directed to an area within their personal comfort preferences. For example, in a library, informing occupants on arrival of the varying conditions in each area.

By contrast, an Intelligent Building may collect information about current weather conditions and react to them by modifying HVAC operation with little control given. Occupants may be given a method to feedback on personal comfort and therefore indirectly control their own environment (Yu *et al.*, 2013), or they may be given opportunities to open windows, but if conditions within the building fall outside of designated comfort conditions, then the building's intelligent systems will implement changes to rectify this.

4.3 Enterprise within Smart Buildings

Enterprise is an emerging theme within literature referring to Smart Buildings. Singer (2010) and Powell (2010) of GSA Public Building Service define a Smart Building as one which "integrates major building systems on a common network" and demonstrate the need for an enterprise system to be integrated within the previously integrated intelligent system. Enterprise in the context of non-domestic buildings consists of a combination of hardware and/or software used to overcome fragmented, non-compatible, non-proprietary legacy systems (Robey *et al.*, 2002) in order to allow the building operation to be optimised towards the building function. Enterprise is any method through which building use information is collected; e.g. room bookings in a university or cinema film schedules. Integrating enterprise with the BMS and real time building systems creates a huge potential for both energy effectiveness and comfort provisioning by using context-related data which will already exists but is not used for the purpose of improving building performance.

Robey *et al.* emphasise the benefits of real time information in the role of enterprise to increase the operational efficiency of a medium to large organisation, while GSA suggest that enterprise consists of such elements as business integration, enterprise management and dashboards. Enterprise systems and architecture integrated into real time building operations, using middleware, are beyond the scope of Intelligent Buildings, but form an aspect of Smart Buildings.

4.3.1 Examples of enterprise within Smart Buildings

- Using a room booking system in a university or school, for example, in order to arrange rooms in specific areas of a zoned building, allowing the rest of the building to be uncontrolled. Upon entering the building the occupants would be informed as to where their booked room is located, rather than pre-booking a specific room.
- In a hot-desking office building, specific occupant-tailored suggestions could be made as to the area in which they are most likely to be comfortable based upon previous feedback (such as "too hot" or "too cold" options on the desk or computer) and any adaptive comfort variables which can be recorded, such as external conditions.

- When a room is booked, for example a meeting room, the number of people who are likely to attend will be input into the enterprise system and this will adjust any operational system requirements in order to accommodate the specific number of people; controlling the heating, cooling and ventilation in order to maximise productivity and achieve conditions which are most likely to be comfortable.

By contrast, an Intelligent Building enterprise system may allow occupants to book a room and if no one is within the room after a certain period a PIR sensor will turn the lights and computers off. If the room is highly occupied then the sensors within the room will activate changes to rectify the unaccounted for heating supplied by the occupants themselves.

Using available information and occupants choices in a way that will allow the operation of a building to be adapted beforehand rather than reacted to afterwards will allow greater comfort and reduced energy consumption, which contrasts to the traditionally intelligent method of heating a room if it is considered too cold, or cooling a room if it is considered too hot. Within the building, intelligent control systems such as feedback loops are still used to allow Smart Buildings to build upon the decades of research and experience, to react to unaccounted-for events and discrepancies, and to provide the interoperability of the building systems and components.

4.4 Materials and construction within a Smart Building

As defined upon introduction, the materials and construction feature within the Smart Building definition represents the built form. The construction of a Smart Building needs to reflect and house the smart functions within it. A Smart Building is constructed of materials and contains features which will allow for accommodation of changes in use and climate. The internal structure should also reflect the dynamic nature of the building by being adaptable to the needs of the occupants. An example in practice can be seen in 30St Mary Axe, which was designed so that that core did not need to resist wind loads, allowing for an open planned steel structure that provides adaptable space when combined with the regular internal planning grid.

4.4.1 Examples of materials and construction within Smart Buildings

- The building structure itself could be adaptive to future climate expectations through the ability to replace features in the future to account for change. Established precedence in this area are the concepts of design for adaptability and deconstruction and design for deconstruction (Webster, 2007).
- Based upon occupancy data available from the enterprise systems, a Smart Building may be able to close zones during periods of known low occupancy. This requires the internal structure to be adaptable in order to maintain value to the occupant.

By contrast to these examples, Intelligent Buildings have predominantly relied upon the intelligent systems within them, rather than addressing the construction itself. An Intelligent Building may utilise PIR sensors to recognise when a zone is not occupied and reduce conditioning of this zone. A single person utilising a zone, however, could result in comfort heating appropriate for dozens of people. Smart Buildings give occupants control whilst keeping the energy consumption per occupant hour to a minimum.

4.5 Smart Building concepts

Smart Buildings are Intelligent Buildings with integrated aspects of enterprise, control and materials and construction, implemented both individually and as a system to be adaptable.

Smart Buildings are occupant-based, creating active participants (Brown *et al.*, 2009) by incorporating feedback both to and from occupants about their building use, alongside providing methods for inherent control through integrated enterprise and intelligent systems. The building empowers the occupants to make their own comfort decisions whilst maintaining regulated control. When this manual control is not possible, the occupant should be informed.

The role of learning and prediction in a Smart Building is important but needs to be clarified: In a Smart Building, learning will develop over time through the building systems interpreting data from past usage and adapting, allowing the choices of the occupants to be used for the purpose of creating a higher level of comfort and satisfaction. Prediction in a Smart Building will rely upon the integration of enterprise and the intelligent operational systems in the building. This will provide previously available but unused useful information through which energy savings can be made whilst potentially improving comfort. The prediction element in a Smart Building could therefore be termed more accurately as "informed prediction". Other forms of prediction are likely to be used in future generations of building.

4.6 The upper bounds of smart

As discussed above, the lower bounds of Smart Buildings are the upper bounds of Intelligent Buildings; the ability to integrate intelligence, enterprise, control, and materials and design in an adaptable manner to allow the building to prepare for event before they occur.

In order to avoid similar confusion in the future, it is important to attempt to define the upper bounds of a Smart Building. The authors believe that less informed prediction will be significant in the next generation of building. As opposed to Smart Buildings, predictions will be decided through Artificial Intelligence systems. The building systems may be able to adapt comfort settings which will be dependent upon more ambiguous forms of data collected by new technologies. The authors believe that future building development will create buildings that build upon Smart Buildings, using new technologies, processes and knowledge. Figure 4 expands upon Figure 1 to draw upper and lower bounds to the definition of Smart Buildings.

5. Conclusion

Fragmentation and a lack of clarity within the building sector will create confusion rather than direction. Non-domestic buildings should aim for user comfort and satisfaction, energy reduction, resource efficiency and sustainability into the future. The definition of Smart Buildings given in this paper builds upon the foundations set by previous generations of building design, including Intelligent Buildings. Research into Intelligent Buildings has advanced significantly since the 1980s and Smart Buildings combine some of the more recent research with a more holistic view of buildings.

Smart Buildings are buildings 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. The

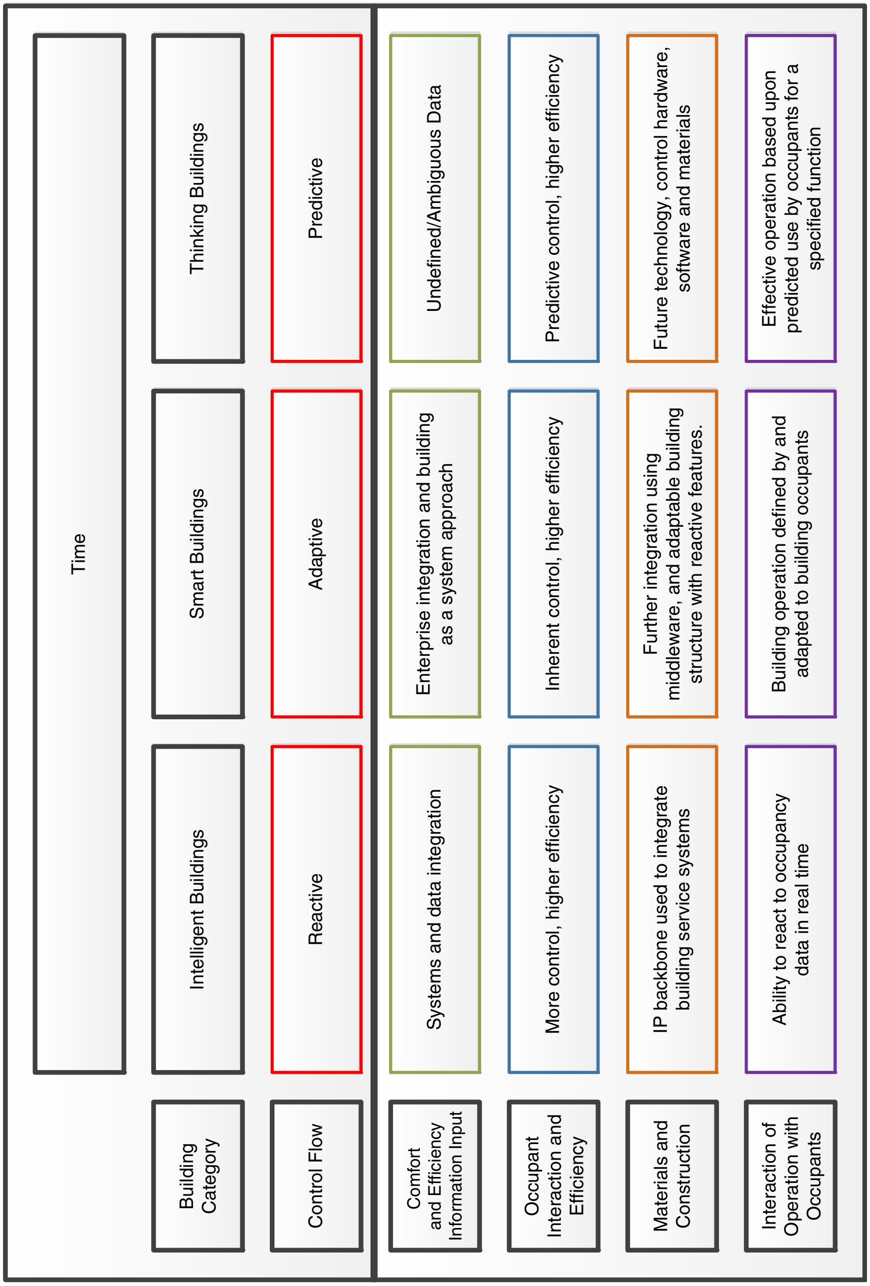

Figure 4.
Upper and lower bounds of a smart building

increased amount of information available from this wider range of sources will allow these systems to become adaptable, and enable a Smart Building to prepare itself for context and change over all timescales. By contrast, Intelligent Buildings meet the drivers to building progression by focusing on intelligent systems which reactively utilise information; control, enterprise, and building materials and construction are developed largely independently of the intelligent systems.

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