An Anatomy of Intelligent Buildings – A Discussion Primer

Vic Callaghan & Graham Clarke
University of Essex

Introduction

If we use the metaphor of the body for an approach to buildings, in their many and various forms, it is clear that for the greater part of history we have been dealing with entities that have a skeleton and a system of muscles and sinews, and which use some form of plumage for display, but which have lacked for anything that might be called a nervous system. Even now with most homes in the western world fully electrified, connected to a telephone network by wire and a communications network via broadcast terrestrial and satellite providers, the nervous system of the house is almost entirely undeveloped. There are a number of computers embedded in modern appliances and more and more homes include a PC or PC like standalone computer that could act as the 'brain' of an integrated local network but very few houses have moved in this direction. Even the much vaunted Gates' house is more geared to automation of some aspects of the systems in the house than to the overall problem of making a building intelligent. However, it is not at all clear that centralised computer control is the correct solution to this problem. As a first stab at anatomising an intelligent building we need to distinguish between different types of 'intelligence' in so far as this term might be applied to systems within the building or to systems that constitute part of the building. We also need to distinguish between some forms of automation of function and intelligent building approaches to the same and other functions.

Does an IB need a Brain?

If we think of the nervous system of higher animals these are remarkable for having a developed node usually associated with the head of the creature which is a rich centre for sensory organs and processing. Effectors on the other hand are usually more distributed. As we develop our understanding of the needs of intelligent buildings we will perhaps find that this differentiation between sensors and effectors is less warranted. We need a much more distributed set of sensors capable of perceiving in parallel the concurrent activities of many different occupants all over the building and responding to those in particular, rather than making a generalisation over all these behaviours and responding to that. For example if there were several different people changing the setting on the room temperature thermostat at the same time in different rooms we wouldn't want to average this out and apply an average shift to all of the thermostats. We would want each to respond specifically to local conditions. This means that local sensing carries on simultaneously and is not normally affected by the global view of what is happening. This is much more like the nervous system of the spine than it is like brain processes.

Are Intelligent Devices Enough?

There is an increasing market for intelligent devices of one sort or another, from refrigerators that tell you when your milk has passed its sell by date, to doors that can open and close automatically enabling someone, who is in some way disabled from opening and closing the door themselves. One might talk about this process as part of an intelligent building if the system was able to differentiate between different people and thus prevent access to a room for some people whilst allowing others free access. If this was done on the basis of a subcutaneous chip communicating with the door controller this would be at a higher level that pure automation but would not be particularly intelligent. If however the 'system' (by which I mean some sub system of an intelligent building) was able to differentiate between different people and on the basis of its previous experience deny access to specific people this might indicate intelligence. Of course it might just have some preset rules that told it to allow particular people through and disbar others, and it may be that people were identified not by chips under the skin but by pins or some other machine recognisable badge. Maybe, as in lots of science fiction stories it will be their fingerprints or their cornea that is used for identification or maybe a verbally produced password like 'open sesame' or so-called 'smart' card. To be sure there will have to be a degree of pre forming of the rules that the intelligent building system operates on in order to satisfy certain safety criteria if nothing else. It would be unacceptable having a system that disallowed people from exiting from a door in the case of fire because they were not allowed to use this route normally. Nor would it be acceptable for the fire doors to be opened by the system while a fire was raging allowing it to spread. So from the point of view of safety there are a number of constraints that would have to be built into any intelligent building system to guarantee the safety of the occupants and minimise the potential damage. One could imagine an intelligent building that, once it recognised there was a fire in one part of the building, warned all immediately affected people and helped them to move to a place of safety. It would then isolate the area and attempt to expunge the fire whilst in parallel informing the fire services. When the fire fighters arrived it would be able to provide a comprehensive picture of the state of the building, including the location of all the occupants.

Learning from the user

Clearly there are various levels at which one can attribute intelligence to devices and systems. In the case of a building we would want to argue that only if the whole system was performing tasks that would normally require human intervention to perform, could it be called intelligent. This would therefore exclude a building that was full of locally intelligent devices, or had a high degree of automation of systems, but did not in some way, both, learn from its users, and care for them, in the sense of sometimes refusing to do what they wanted it to do on the grounds of safety.

Powering the IB system

There are systems of home automation that make use of the power supply and a truly intelligent building will need to have effectors that need to be powered from somewhere. Whether it is locking locks, or opening curtains, or turning on or off lights and televisions, or adjusting the height of beds and hobs, some route to effective control of many different devices will mean that the intelligent building system interfaces with, and has some control over, the power supply of the building. At the limit it might be able to shut down power to the building itself, which raises the question of whether the intelligent building system should itself be powered separately and in a fail safe way, and how it would respond to a shutdown of many or all its sensory inputs.

Smart Devices

Video conferencing, or interactive digital services of one sort or another, whilst they might make life more interesting and may enhance the environment for specific users are not, in and of themselves crucial for an intelligent building. However, it may be that experiments associated with the sourcing and management of video conferencing or other digital network services do provide interesting and useful examples of some aspects of intelligent building systems potential. For instance if your television, or stereo, or both, (or some integrated TV, radio, hi-fi, computer system) engage you in conversation when you enter the room, to establish if you would like to hear some music, or watch a program, login to the net receive your voice mail etc., this would be an example of an intelligent device. If that intelligent device was connected to an intelligent building system and so was aware of the approach of someone to the room, and had a capacity to model the user, that was based upon the intelligent buildings monitoring of the person, then the device could be seen to be part of the intelligent building system. If however the device, as well as being able to recognise that someone had entered the room, was capable of enquiring if the person wanted to watch television, and of monitoring television use in such a way as to build up a sophisticated profile of television use by the different occupants, so that as well as asking if they wanted to use the TV it could suggest that something they might like to watch was on TV in five minutes, but this device was still separate from the intelligent building system, the presence of this 'smart' TV would not make the building intelligent.

Intelligent Buildings

So what we wish to stress is the distinction between devices, however smart, and automation, however sophisticated, and intelligent building systems proper, which involves built in constraints for the safety of the users of the building and for the efficient use of resources - energy usage for instance - and which is capable of learning from the user, modelling the user(s) in some regards, and being proactive in that, after a particular pattern has become recognise and remembered, the intelligent building system will be able to anticipate and respond accordingly without being told.

Historical Perspective - Development

The aim of producing a semi-autonomous building control system is at the leading edge of current research. From a computer-science perspective, intelligent-building work can be categorised into three generations as follows:

IB Generations (a computer-science definition)

1st. numerous independent *self-regulating* (automatic) sub-systems

2nd. as 1st but connected via specialised *network* (eg BACnet, ESHA, Lonworks, CEbus, X10) and various physical media for remote/centralised control (simple sequencing)

3rd. as 2nd but *self-governing* (autonomous) systems ie learn, make their own rules (and perhaps collaborate) etc

Thus, the early work consisted of what was often sophisticated but disconnected sub-systems such as advanced HVAC or lighting control systems. By interconnecting these systems it became possible either to remotely control them (eg from the buildings services managers office) or to facilitate some central scheduling (eg securing areas or turning on/off systems at some scheduled time). Thus, although the first and second generation intelligent-building technology greatly increased the ease of operation of the building systems, it didn't give the building any functions that were akin to human intelligence. Only now are researchers facing up to the challenge of giving building control the capability to autonomously govern the building by learning the needs of the building stakeholders.

Components and Services - Functionality

From our computer-science view of an intelligent-building we see it as being composed of numerous sensors, effectors and control units interconnected in such a way as to effectively form a machine. Typically, the kind of sensors, controllers and services involved are:

Typical Buildings Sensors (augmented for Care home)

temperature	light	pressure pad	appliance
window	smoke	movement	person ID
call alarm			

Typical Building Controllers

heating	lighting	alarm	appliance
window	door		

Typical Building Services

Safety	emergency assistance
Energy conservation	Automatic lighting
Location of personnel	Building access
Control of doors and windows	Control of appliances
Security	Behaviour logging
Appliance self-checking	

Staff Monitoring	Water temperature monitoring

For the building to function as a system, the vital technological ingredient to the above is a network to "glue" all the devices together. The network needs, ideally, to be real-time and have simple device interfaces comparable with the cheap nature of building devices such as light switches. Thus, numerous standards for intelligent-building network have emerged which aim to provide a good solution (eg BACnet, ESHA, Lonworks, CEbus, X10).

Existing Technology - Nervous System

As a brief overview, if one wished to build an intelligent building today then perhaps the main options would be:

X10 – This is the oldest commonly available IB technology and is available from numerous resellers. A reasonable range of common household control devices (eg lights, power, alarms etc) and user software is available starting at prices in the order of few tens of pounds each. X10 arose from Pico Electronics Ltd, a Scottish firm, which developed several chips for a variety of purposes in the 1970s known as X-1 to X-9. In 1976 they developed X-10: a way for consumers to control lights and appliances remotely, without having to re-wire the home. An audio company, BSR, went on to market it under the BSR name. The X-10 project evolved into the first commercially available modules that could control lights and appliances through the *power-line* wires. Using the 60 Hz or 50 Hz power lines as a carrier, the technology involves modulating a 120 kHz burst as the power crosses the zero crossing. The presence of a burst equates to a digital 1, and the absence of a burst equates to a digital 0. There is a simple addressing protocol that allows each unit in a common wiring environment one of 256 unique addresses. The limited speed, address range and lack of device polling are the biggest drawback to X10.

CEBus - This standard was made available to the world in 1992 (having begun in 1984 by members of the EIA - Electronics Industry Association). It covers devices that communicate through power line wires, low voltage twisted pairs, coax wires, infrared, RF, and fibre optics. The CEBus standard involves device addresses that are set in hardware at the factory, and include 4 billion possibilities. The standard also offers a defined language of many object oriented controls which include commands such as volume up, fast forward, rewind, pause, skip, and temperature up or down 1 degree. All of the hardware components, language, protocol and "developer kits" are available from the Intellon Corporation in Florida.

LonWorks -. communicates through power line wires, low voltage twisted pairs, coax, infrared, RF, and fiber optics. The standard involves device up to 32,000 individual devices in a network and offers a defined language that includes commands such as volume up, fast forward, rewind, pause, skip, and temperature up or down 1 degree. The principle focus of LonWorks is a chip known as a "Neuron" chip, which acts as a network node and includes all of the communications hardware, communications protocol plus a fuzzy-control like language. The Neuron chip is being manufactured under license by Motorola and Toshiba, and can be installed in any consumer product. The philosophy of Lonworks is to provide the underlying network technology and to encourage 3rd parties to provide the building control devices, which it would interface. There are agreements on interoperability with other networks such as BACnet. LonWorks is a well established product being by companies such as Honeywell.

BACnet - is a data communication protocol for building automation and control networks originated by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [Newman 96]. It is an open system and modelled on the Open Systems Interconnection (OSI) basic reference model. The BACnet philosophy is that any information which needs to be conveyed between devices in a BACnet network should be abstracted from the implementation details through the use of standard objects [Bushby 96]. The mapping between standard objects and the underlying data and processes is left to the vendor. The advantage of using this approach is that it shields BACnet from obsolescence with respect to networking technologies as it is able to adapt to new networks as they are developed. Thus, whilst BACnet provides a powerful macro level solution it often operated in tandem with a more physically oriented IB technology such as LonWorks. Honeywell use both

BACnet and LonWorks in their products. For those interested in immediate IB solutions, Honeywell provide one of the most comprehensive offerings ranging from kits for the home costing only tens of pounds for devices, through to high end professional systems costing many thousands of pounds.

Space doesn't allow all the available technologies to be described. There are a number of other notable offerings such as Novell Embedded Systems Technology (NEST). Novell is aiming for NEST to be used everywhere: offices, cars, homes, indeed everywhere where intelligent devices may be useful. Given their dominant presence in data-networking their ideas and products merit serious consideration. Another pedigree contender, from a complimentary market, is CAN (Controller Area Network) which was originally developed by the German company Bosch for the automotive industry. It operates at data rates of up to 1 Megabits per second and is robust and potentially cheap being link to economies of scale of the car industry. Other highly regarded work is being conducted by the European Home Systems Association (EHSA). They are a co-operating body of manufacturers comprising large multinationals such as Siemens and Philips. Like BACnet, their IB specification has a complex architecture which allows connection to a network using any collection of media and thus supporting the open systems principle. A number of systems conforming to the EHSA specification exist. One member company, Remote Meter Systems, has done extensive research into the communications capacity of electric power transmission lines, showing they can be made to carry a surprising amount of additional data into and out of the home [Boivin and Anguill 96].

The IB Challenge of Autonomously Learning - Intelligence

Our research is highly focused on enablement of individuals and hence on the people using the building. As such our technology seeks to be assistive learning the special characteristics and idiosyncrasies that go to make up our unique character and needs. Thus, the problem is not deterministic or amenable to modelling and hence cannot be solved by classic real-time control or automation. The challenge involved in producing an intelligent building that can learn to adapt to user needs, be reliable and practical can characterised by the following:

Characteristics of IB system

- ⇒ situated in real-world (senses & acts directly on physical world)
- ⇒ in dynamic, unpredictable, complex world (eg involves people and natural phenomena – difficult, if not impossible, to model)
- ⇒ uses inaccurate, imprecise sensors & imperfect control
- ⇒ ideally, requires small, cheap hardware (comparable to building devices)
- ⇒ ideally, should be reliable, extensible & interconnected

Robotic researchers will note that these characteristics are all similar to those encountered in mobile robot work. Being roboticists, we decided to investigate the applicability of mobile robot control techniques to intelligent-buildings. In particular we set ourselves the challenge of determining:

Research Challenges

- ⇒ if a behaviour-based system (ie goal driven reactive operation) is capable of controlling an intelligent building.
- ⇒ whether there exists a set of basic behaviours that equate to IB needs.
- ⇒ the form that an embedded IB adaptive agent could take.
- ⇒ the form that a macro-architecture (multi-agent) could take.

The Question for Discussion

Are the scientific and research challenges associated with applying computer science to the management of high-tech living spaces a viable research area? What would the characteristics of these intelligent environments be, and what would be the main research challenges. Is this something we want to (or can) investigate?