Going Past the Golem
The Emergence of Smart Architecture

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Abstract

At a time when the notion of smart architecture is gaining foothold as the next cutting edge in architecture, the paper attempts to provide a much needed historic overview of the emergence of smart architecture in terms of technologies and concepts. Additionally, the paper traces the many exciting current developments, challenges and opportunities from the viewpoint of architecture.

Introduction

The central act of coming era is to connect everything to everything. All matter, big and small, will be linked into vast webs of networks at many levels. Without grand meshes there is no life, intelligence, and evolution; with networks there are all of these and more (Kelly 1994).

Smart architecture is rapidly becoming a buzzword and promises to be the next cutting edge in architecture. As the manifestations of technology metamorphose from the adversarial PC sitting on a desktop into a community of Bluetooth®-enabled wireless devices adorning the much coveted belt loop, the notions of smart, intelligent and responsive architecture are also evolving. When technology becomes more mobile and devices become continually connected to the global communication networks, their environments must follow suit. Through a survey of the history, available technologies, and current status of smart environments, this paper intends to put in perspective the evolution of concepts, technologies, and models of smart architecture. Given the fact that
most of the research, development, design, and implementation are taking place in engineering disciplines, one of the objectives of this paper is to bring the discourse about smart architecture back into the discipline of architecture. Ultimately, smart architecture is a matter of architecture.

**Golem, HAL, and Beyond- What is being Smart?**

Homo Sapiens’ desire to control their environment through technological agencies that border on magic is nothing new. As Arthur Clarke once pointed out, any advanced form of technology is indistinguishable from magic. From the perceived need of protection from the outside world came the alchemical man, Homunculus, and from him grew the Cabalist myth of the *Golem*, the protector formed of river clay on a frame of tree branches and rags. In a sixteenth century myth of Golem, the Rabbi Yehudah Levi ben Betzalel writes instructions on a piece of paper, which he then inserts into the Golem’s mouth. The written word then causes the Golem to work independently in the absence of verbal commands. Eventually the Golem accumulates enough knowledge and expertise that it becomes a menace and is unmade by the Rabbi himself.

Yet another powerful illustration of Western culture’s take on intelligent architecture lies within the movie adaptation of the Arthur C. Clarke novel, *2001: A Space Odyssey*. HAL 9000 (short for Heuristic Algorithmic) is the computer-controlled brain of the spaceship Discovery that maintains the mechanical, sensing, and information systems. Capable of speech recognition, natural language understanding, and lip reading, HAL 9000 represents a more recent iteration of man’s desire for intelligent artifacts, but these are examples of one of the two fundamentally centralized or hegemonic notions of intelligence.

In nineteenth and early twentieth century, the notions of intelligent environments revolved around a central agency that controlled everything. Today’s notion of intelligence, in the context of smart architecture, is about distributing the aspects of processing, learning, and controlling into a variety of everyday objects that are able to sense and communicate their own and other objects’ statuses through a ubicomp (ubiquitous computing) network, allowing a greater degree of autonomy, robustness, and fault-tolerance. The notion of intelligence is evolving to become more disembodied, which is a significant departure from the pre-1990s notions of central computational agencies akin to the adversarial concepts represented by Golem and HAL 9000.

So, what does it mean for architecture to be smart? What is the measure of smartness in architecture? How does it differ from previous attempts at making architecture mechanically and/or computationally intelligent? Is there a possible architectural (in addition to computational) framework that can be used to provide the necessary direction to the myriad academic and professional pursuits currently underway at various institutions? What are the formal and spatial implications of smart technologies in architecture?
The Past: 1950s to 1980s

To understand smartness in architecture, smart architecture must be viewed as a tapestry with independent threads of history that come together. It is not a simple product, such as the rise of concern for building efficiency or kinetic buildings, but the sum of all these factors including other cultural developments and perceptions of the future that provide true architectural intelligence. What began as mechanical system automation in the 50’s grew into intelligent buildings movement in the 80’s and the all encompassing smart environments at present. The most important feature of these transitions in history is: the change in the role of the inhabitant from the pointing omnipotent finger at the button that feeds commands to the role of the inhabitant as immersed in a transparent ubicomp intelligent environment as a central participant.

The 1950s – The Automatic Decade

The flash from the atomic explosions had radiated out into the culture as interest in technology began to flourish. Bolstered by the return of troops and technologies from World War II, the construction industry boomed, creating hundreds of buildings with larger footprints. With these burgeoning facility sizes and with the introduction of “manufactured weather,” environmental controls and switches were scattered all around the buildings, creating the need for a trained force of human operators for everyday operations. In the name of efficiency, the world of environmental control was revolutionized with the introduction of the pneumatic sensor-transmitter, which was capable of local indication and remote signaling, thus reducing the sprawl of controls to a more manageable “control room” (Kolokotsa 2004). Within these central cores, the trend of miniaturization had started, resulting in the reduced physical size of the elements.

Control over the environment eased into entertainment as the living room turned into a control room with the inventions of the “Lazy Bones” and “Flashmatic” television remote controls by Zenith in 1950 and 1955. Even though the predominant theme of the 1950s was consolidation, the inhabitant’s role was still predominantly that of a skilled operator of evolving mechanical apparatuses.

The 1960s – Control

The decade of the 1960s is best defined in terms of control. On the automation front, the benefits of automation became more apparent in the 1960’s as control companies had emerged to operate building mechanical systems. Stepping closer to ubiquitous environment control, the inhabitant’s comfort could now be outsourced according to set preferences. New electromechanical multiplexing systems were introduced which lowered installation costs and maintenance since wiring was reduced from hundreds per multiplex to a few dozen per multiplex. As the buildings became even more domesticated, miniaturization continued, and the control center panel became the control center console. Equipped with new intercom systems and phones, this console was the nervous system through which the
building could now signal its ills through the new nerves of twisted pairs or coaxial cable. Commercial indication and logging systems could record specific parameters in unusual or dangerous conditions. Temperature, air flow, and pressure were just a few of the items that could be recorded. Before long, the first computerized building automation control center would be marketed.

Two diametrically opposed perceptions of the future of automation dominated this decade and still survive through today. The first vision was the direct descendent of the automation dreams around the 1950s, including Tex Avery’s animated short film *The House of Tomorrow* (1949). In 1962, televisions had their audiences “meet the Jetsons,” in the animated series, *The Jetsons*. The premise of the show was the comic antics of a working man, George Jetson and his family in the utopia of tomorrow where houses styled like the Seattle Space Needle soared above the clouds, and daily life was leisurely due to the incredible number of sophisticated appliances.

The second example was significantly darker than *The Jetsons*. As the Vietnam war continued and the public seriously questioned the authoritative powers there came the previously mentioned system HAL 9000 in the movie *2001: A Space Odyssey*, which was released in 1968. As opposed to *The Jetsons*, where a series of devices that activated when needed provided the highest standard of living, HAL 9000 represented a model wherein the machine became complete caretaker for man. Becoming self-aware and self-preserving, HAL began to exercise his power against those who tried to shut the system down, becoming in the process a grave warning against technological frameworks wherein humans become completely dependent.

**The 1970s – Efficiency**

As the previous decades had illustrated, progress in smart architecture did not transubstantiate itself. As the oil embargo of 1973 would illustrate, the (un)availability of resources and current events were the grand determinants. Advocated by Architect Paolo Soleri was the new fusion of architecture and ecology, labeled arcology. As building profits eroded due to rising energy costs, the new term “EMS” (energy management system) emerged in control manufacturer's advertisements. These new features were offered through the introduction of application/software packages including “…duty cycle command control, optimum start/stop, optimum temperature, day/night control, and enthalpy control” (Kolokotsa et al 2004).

While multiplexers were becoming smart enough to operate in stand-alone environments and field interfaces allowed agents in the field to process data remotely, the most important technological advance came from Intel in 1971 in the form of the microprocessor, which was advertised as the “computer on a chip.” Interfaces became more user friendly with the invention of the keyboard. Personal computing would come to the foreground through the birth of Apple Computing on April 1, 1976. Their first product, the Apple I, was not a computer as we know it, only a motherboard with CPU, RAM, and basic textual-video chips. The Apple II, introduced in 1977, would become the symbol of the personal computing phenomenon. It had an open architecture
and used “easier to understand color graphics,” but also introduced the floppy disk drive allowing consumers storage. These inventions had begun transforming the notion of intelligence as applied to buildings. Still, except for a few places like Carnegie Mellon University’s architecture program, the majority of the discipline of architecture remained actively oblivious to the potential of these evolutions to transform architecture. The profession was captivated by the postmodernist movement that was sparked by the publication of Robert Venturi’s *Complexity and Contradiction and Charles Jencks’ The Language of Postmodern Architecture*. Explorations of intelligence in buildings remained in the realm of engineering.

**The 1980s – Intelligent Buildings**

With the personal computing revolution that occurred in full swing and a further reduction in hardware costs, the development of new technologies soared. In 1981, IBM released its PC. The public was not hesitant to embrace this technology and take it into their homes; when *The Jetsons* re-aired in 1984, the character of RUDI, George Jetson’s computer was introduced. In a poll conducted for *TIME Magazine*, when the computer was given the award of 1982 Machine of the Year, the majority of Americans believed that computers would become an excellent learning tool (67%) and eventually would become as commonplace as televisions in the home (80%). The public was avid for all things that embraced this new technology, and the role of technology in humans’ lives became one of empowerment as opposed to enslavement.

The definition of what was an “intelligent building” had also begun changing. Where any form of automation was considered intelligent before, now the building itself could be automated entirely. Through distributed direct digital control, (DDDC), conventional pneumatic control systems were replaced—the building operator console, powered by the personal computer, became the major interface. Communication and programming occurred through high level languages such as Pascal and C on actual proprietary local area networks (LANs). Market forces prevented further networking, however, as competitive interests prevented the issuance of standards. Kolokotsa, et al. had this to say:

Stand-alone energy management systems, lighting control systems and fire detection and suppression systems are now common, but integration of these systems is rare… If there is a need to expand or upgrade the control system, a building owner has been forced either to return to the same vendor who installed the existing system, replace it in its entirety, or install a separate independent system because the communication protocols for other products are incompatible (Kolokotsa et al 2004). In the field of entertainment, new computing technology gave more than empowerment, there was potential for new environments, new realities within the virtual realm of the system. Best illustrated by the 1982 movie *Tron*, where a hacker is literally transported into the world of a computer and forced to play gladiatorial games before a friendly security application
helps him to escape. This virtual reality was supposed to become a hallmark of everyday life in the future. Yet, beyond the graphic problems and the hassle of the bulky interface, gloves, and helmet (and the rest of the unit), there were conceptual problems with virtual reality. Virtual reality is a rejection of the physical body in favor of placing the mind within a virtual framework; the human experience becomes even more subservient to the computer in this context, dependent for every aspect of this new reality. While entertainment and defense industries maintained a small stake in virtual reality, the majority rejection of virtual reality has implications through the present, as the new trend of ubiquitous computing began coming to the foreground where the computer was forced to live among the humans in the world.

The 1990s and Beyond: Smart Architecture

Just as the terminology of energy-efficiency and appropriate technology have changed into “sustainable design,” the terminology of intelligent buildings and building automation found a new phrase, “smart architecture,” in the late nineties. The notion of smartness went beyond machine intelligence as represented by HAL. Smartness is as much about strategy as it is about technology. Also, the word “smart” carries with it a positive connotation in distinction from a more neutral or menacing term “intelligence.” There is no “it-versus-us” sense of doom in the emerging notion of smartness. Smart bombs, smart cars, smart growth, smart dust, smart cities… we are in the midst of a “smart” deluge. A variety of factors are contributing to the emergence of smart architecture. Technologically, smart architecture can be summed up in three terms: wireless inter-networks, ubicomp, affordable sensor-actuators. Conceptually, it is about connecting peoples of the world like never before and putting their physical environments in their tele-control.

The Internet Revolution

With the emergence of the internet into the commercial world and homes across the world, a new revolution has started, changing not only how firms do business, but affecting the world on a human level—how the common person can purchase goods and services and obtain information. The rise of the World Wide Web (or simply the Web) allows person to person exchanges like never before in history. Time and distance have collapsed as users come to the Web to exchange and mutually develop ideas. Through the virtue of being digital, the internet provides a method of storing and transmitting data more efficiently than any physical tome or communication system. By reaching to minds at a scale and method beyond the capabilities of a printing press, the internet has become a fertile ground for the rise of new cultures.

The Building As Network For Living In

As computers became even smaller and more inexpensive, this exposed their potential as design tools to a new type of architect. While computers aided in the traditional requirements of detailed schematic production with computer aided design (CAD) software that had been
released since the mid-1980s, the impact of digital technologies on architecture would be much more profound. The emergence of a new “hybrid practitioner” (Leach 2004) came as architects investigated roles as architect-builders. Through new and creative reapplications of digital means and software, architects such as Frank Gehry and Peter Eisenman were able to come up with new shapes too complex for previous methods of hand drafting. Whereas until the 1980s smart buildings were those able to regulate a variety of environmental parameters in the interests of build efficiency, as digital technology became intrinsically linked with contemporary architecture, architecture became responsive, emphasizing the interactive natures of social, commercial, and environmental needs. Taking the responsive need to a literal level, buildings grouped under “kinetic architecture” suggestively became mechanical, moving organisms. Some visionary architects are beginning to realize that the nature of building was changing, that the structure of connectivity, the network was just as important as the structure of the materials holding the buildings together (Senagala 2005).

(Smart) Architecture Without Architects

As a result of disinterest from architects, most of the current work in the field of smart architecture lies within other disciplines such as engineering, business, and computer science. The current definition of smart environment has derived from established computer science and consists of requirements including ubiquity, automation, natural interfaces, multimodal inputs, aware computing, and adaptable computing (Gouin and Cross 1986). The flaw of current models has been pointed out as:

Many of the current models of smart architecture are based on certain assumptions about human behavior and aspirations. In general, these models assume that physiological comfort is the goal of smart environments….to avoid a steep user learning curve. Yet another assumption is that the humans want more and more hands-off comfort. The flip side of such an approach is that as architecture gets smarter with more and more “sensors,” human senses become more and more numb, anesthetized and potentially atrophied. As more of the decision-making is transferred from the users to the smart systems, the users stand the danger of losing the visceral connection to the building and its surroundings (Park 2003).

Without the training and knowledge of the building culture as represented by architects, the current trend of smart architecture, while it has advanced significantly, has remained primarily device-centric and not human-centric. As responsive as these scenarios are initially to humans, they neglect the irrational nature of human behavior. What happens when the inhabitant wants to practice Bikram Yoga and the smart system has been told to maintain a pleasant 72 degrees Fahrenheit, which is a far cry from the heat and humidity required for proper exercise? What happens when the architecture conflicts with the intent of the inhabitants? These are some of the conundrums that still need to be addressed.
Sensor-ship

We are in the midst of a sensor-actuator revolution. While a multiplicity of wireless sensors are available like the Berkeley Crossbow Motes (http://www.xbow.com) which operate with five sensors installed to cover temperature, light, acoustics, acceleration/seismic, and magnetic spectrums, the prime issue with sensors is the issue of interpreting the data to understand the context and intent. To be more effective than a nuisance, a smart architecture system must be multimodal, which is discerning the context from two or more sources of information. One solution is the listing of typical and frequent behaviors of the inhabitants, thus the problem becomes a matter of classifying the activities based on a pre-ordained list (Cook et al 2005). This context sensitivity is very important, especially in terms of human activities, which rarely have clear beginning and end points. However, the problem of this preordained list comes from activities that overlay one another, such as a problem as simple as sitting down in a smart environment to study when, all of a sudden, there is a knock at the door. As the inhabitant leaves to answer the door, the settings reset to accept that familiar guest when the inhabitant would have liked to send the person away (who maybe her estranged boyfriend!) and try to get back to her studies.

Smart Services

A smart environment offers many possibilities in terms of consumer and protective services. Refrigerators can already read, through the help of RFID tags, the contents and rate of consumption of foodstuffs; the possibility of appliances ordering what the inhabitants desired based on past trends or set preferences would be enormously convenient.

As far as protective and maintenance services go, The Internet Home Alliance (www.internethomealliance.com), which is a multi-corporation collaboration between GM’s OnStar, Invensys, ADT Security Systems, HP (BuilDog platform), Panasonic, and others, stands as a productive model to pursue. Essentially the building adaptation of GM’s OnStar automotive service, which turns the automobile from dumb object to computer-embedded node networked through satellites, the operator would be able to access the most critical systems of the home remotely and notify the inhabitant of any deviations from the norm while dispatching a technician should the building be unable to sense the error and repair itself. The biggest evolutionary jump for automobiles is not in their growing engine size or seductive body shape; it is in the pervasive computerization and wireless digital networking. According to some sources, nearly 80% of all innovations within automobiles are derivatives of electronic systems (Leen and Heffernen 2001). That is a far cry from the pre-nineties automobile industry when manufacturing and fabrication issues took the center stage of innovation. These developments have interesting correlations to the current developments in architecture, where manufacturing and fabrication issues are abuzz at the moment.

These homes would be at the beck and call of the homeowners wherever
they travel in the world. If someone, say a UPS® courier, were to ring your doorbell, the Panasonic Smart Door Bell would send a visual in real-time to the homeowner who maybe on the other side of the globe so that the owner can take appropriate action. A host of other features make this model an intriguing possibility.

**Immersive Interfaces**

The current interface model of PCs stands as a WIMP (windows, icons, menus, and pointer) interface which, while considerably more user-friendly than the punch cards of yore, is still not a natural interface. A large problem in the face of the wide spread use of smart architecture is the fact that GUI (graphical user interface) forces the user to work with the computer on the computer’s level. The next generation of interfaces, the PUI (perceptual user interface), intends to correct this through multimodal inputs of the user’s speech and actions. However, it is now possible to track motion, identify by facial appearance, and recognize the actions of the inhabitants with minimal computational resources. Smart clothes and smart rooms have been established that can identify people; the next leap is the recognition of sign language, ultimately to the understanding of a casual shrug as the building asks if the current temperature is fine.

**Connecting the Dots—Current Projects in Smart Environments**

Many initiatives and projects are moving in this direction. MavHome (University of Texas at Arlington), Adaptive House (University of Colorado at Boulder), House_n (MIT), Aware Home (Georgia Tech), Gloucester Smart House (UK), Microsoft Easy Living, Philips Smart Home, and many other ongoing projects are exploring myriad technological and technical challenges of smart homes. The authors regret not being able to go into the details of these projects due to the limitations of paper length and focus.

**The Prospect: Challenges and Opportunities**

Smart architecture is a far cry from the crude mechanical automatons of the 1950’s. It is also a significant evolution even from the electronic and digital building automation systems and intelligent buildings of the 80’s. Now, smart architecture is about an architecture of connecting, sensing, and responding to a multitude of factors toward a more ubiquitously networked and data-driven world. Still, while computation is at the heart of smart architecture, as mentioned earlier, it is ultimately a question of architecture. Here, we trace some of the challenges and opportunities that await us.

**Technical Limitations**

The first major hurdle to clear in the path to smart environments is the technological one. Significant work must be done on all parts of the equation of smart architecture from environmental automation to areas in adaptability, natural interfaces, and, especially, multimodal inputs. The technology will only be widely acceptable as the easier and more reliable it becomes. This will prove exceptionally tough due to the impatient nature of
human beings as the tolerance between annoyingly late and magically quick is less than 5 milliseconds according to some studies (Mozer 2005).

**Market Forces**

Market forces come from both the potential consumers and amongst the manufacturers themselves. Until the manufacturers can form coalitions and release their proprietary protocols to create uniform networks that can adapt to the purchase-consume-dispose lifestyle prevalent across the world, smart architecture will be in the realm of series after series of objects that work in separate groups. These separate groups will become outmoded and have to be replaced with models from the proprietor’s line, which is difficult should there be an interruption in the supply chain.

The more important of the market forces is the force of the consumer dollar. Without that lubrication of the system, any system will grind to a stopping halt. To be profitable, smart environments and devices will have to appeal not only to the small segment of the market concerned with the latest and greatest in terms of technology, but the common consumer who may very well be unable to program a VCR and is looking for convenient management of mundane activities to focus on living life in the situations at hand. The key to this is not only the actuality of making interaction with buildings simpler, but, as mentioned before in Weiser’s vision of ubiquitous computing, that it disappears. Even the thought of the possibility of a system going down becomes an annoyance. As Mozer observed, “One would really like to know whether ACHE [adaptive control of home environments] is useful and whether people would want such a system in their homes. Although ACHE appears surprisingly intelligent at times, it can also frustrate. Most of the frustration however…when ACHE is disabled, the home seems cold and uninviting. Although this may sound implausible to one who hasn’t lived in an automated home, reverting to manual control of the lights is annoying and cumbersome” (Mozer 2005).

**Human Considerations**

There are several large factors to consider about humans themselves that will shape the future of smart environments. At the most basic levels, humans themselves pose significant problems. What is the role of the humans in the environment? Furthermore, how can smart environments adapt to the inevitable levels of change in a lifespan? Will it be necessary for the consumer to go and buy new equipment to outfit the home every time their hobby changes? What happens to the investment in a home when a family is transferred to another city? Could some settings be saved to disk and taken along while the hardware is left behind?

Secondly, smart environments must realize that the human inhabitant is more than a body that derives pleasure from being in a comfortable balance of temperature and humidity; there are psychological and spiritual needs to meet also. While a series of devices can meet the physiological needs, the realm of architecture will be the satisfier of the spiritual and aesthetic needs; needs that are often times irrational. A smart environment that may sense that the
inhabitant is sad and brighten the lights and play joyful music will be sorely unappreciated if the inhabitant has come back from a traumatic event and wishes to be sad.

**Conclusions**

The desire for smart buildings dates back to prehistory. However, it was only since the 1950's that we began seeing some manifestation of that desire in the form of usable technology. The historical overview of the many threads of development in mechanical systems, architectural thinking, computer science, and ubiquitous computing indicates that we are on the verge of a revolution of smart architecture. Wireless technologies, inexpensive sensor-actuators, communication protocols, global communication infrastructure, and renewed interest from the corporate sector confirm this trend.

We are trying to go past the Golems and HALs. Many challenges lie ahead, most of which are human-centered and architectural. The paper has addressed the need for professionals in the architectural discipline to play an active role in defining, clarifying, exploring, envisioning, enframing, and pioneering smart architecture.

**References**


