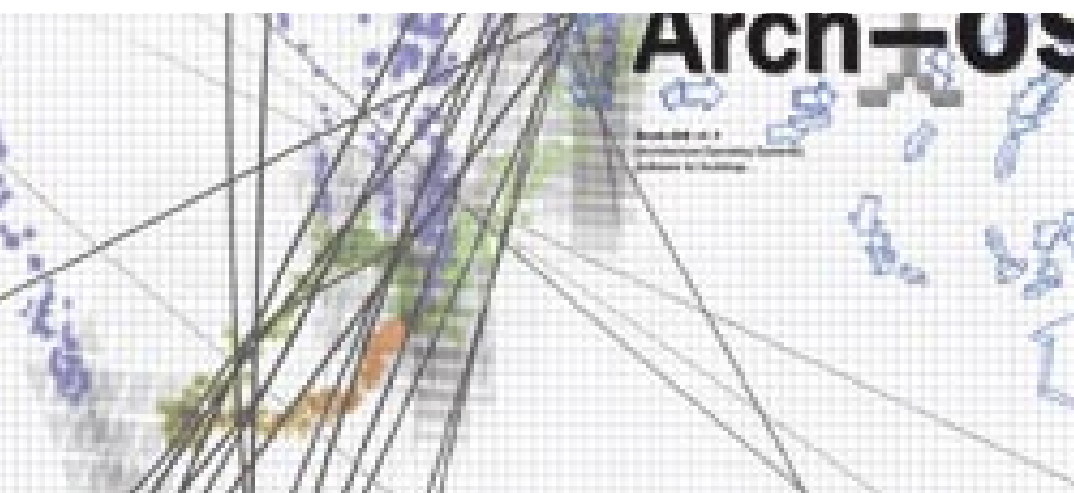


Arch-OS: an operating system for buildings

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Abstract

A review of the literature on Intelligent Buildings suggests an ideal of a building as an autonomous system that controls its internal and external environments. The model, whose origin lies with early models of artificial intelligence, effectively treats the building as a slave to human needs, and appears to invest more intelligence in the building than in its occupants. This paper proposes that automated environments be understood as extensions of human sense and awareness. It describes an operating system, Arch-OS, that exemplifies this approach by increasing building occupants' consciousness of their environment.

While changeable, program-driven buildings have occupied architecture since the late 19th century, the concept of Intelligent Buildings (IB) is comparatively new. In this paper we explore the use of this term in architecture since the late 1960s, and introduce a new concept in computer-augmented environments: Arch-OS. Our examination of Intelligent Building (IB) literature discloses the underlying values and priorities of its proponents. We argue that these

values, particularly those found in the building industry, conform to a materialist view of architectural practice and thus objectify the occupants of architecture as mechanically sustained bodies. Industrial literature proposes an autonomic ideal, the building's intelligence, characterized by the homeostatic closure of systems in service to its users. We ask whether the building-as-slave model is appropriate – or even sufficient – to address a more sophisticated model of the user:

Here we suggest instead that computation and computer augmented environments are psychosomatic extensions of their user/occupants, and that an ecological model of the user/environment relationship yields fruitful results. Countering the materialist view, this model embraces the cognitive role of the user rather than that of the building, and thereby inverts the priorities set by architectural and industrial discourse on IB. In order to demonstrate the potential of this model we will describe the installation of a computer-augmented environment at the University of Plymouth in England. The system supporting this environment, Arch-OS, was developed to serve both building systems and, more importantly, to expand users' awareness of their surroundings. As we shall see, this breaks with the closed-loop version of the cybernetic model, and shifts emphasis from technology being a slave to human need toward becoming a resource for human consciousness.

Background

The present concept of Intelligent Building is presaged by a largely 20th century interest in mutable buildings and indeterminate design. Modular building systems, originating in the late 1800s with Joseph Paxton's Crystal Palace, were applied to structures that evolved with changing needs. Such utilization of repetitive material components was a logical result of Taylorist/Fordist production models that proved very successful following the Industrial Revolution. As early as the 1930s, architect, inventor, and polymath Buckminster Fuller proposed a concept of building that offered flexibility and the capacity for reconfiguration to meet the demands of buildings' occupants (Fuller 1963). Fuller, whose own training

included naval engineering, brought his expertise to the design of industrialized, deployable buildings, notably his Dymaxion Houses and geodesic domes. The values of indeterminacy, mechanization, and the responsive environment embodied by these works form the foundation for much of the ensuing work by Yona Friedman, Archigram, and Cedric Price in the 1960s. Price's own design for the *Fun Palace* (1961) and the *Potteries Think Belt* (1964) both employed indeterminacy in the service of a dynamic, changing constituency.

Price's *Fun Palace*, co-designed with Gordon Pask, was among the first to propose an environment that responded instantly to its occupants with moving walls, floors, and ceilings, fog dispersal plants, and warm air currents. The inclusion of Pask, a cybernetician whose own work was greatly influenced by Norbert Weiner's concepts of control/response systems, was important to describing the responsive *behavior* of the building. Whereas LeCorbusier's formal equation of buildings with machines later manifested in the work of John Johansen, Renzo Piano and Richard Rogers, with Price's *Fun Palace* and particularly his later *Generator* project (1976), we see the introduction of computers as active – even autonomous – control mechanisms within buildings. Architect Gillian Hunt in a text on cybernetics and architecture wrote concerning the *Generator*:

A computer program was developed to suggest new arrangements, and the embedding of electronics in every component enabled connections to the foundation pads. The site in Florida became a vast working model, where the configuration of the processor was directly related to the configuration it was modeling. Early on in the project, the controlling processor was dispensed with because adequate processing power was distributed throughout the structure. A novel anti-inertia program was introduced which involved the computer promoting unsolicited changes should human interventions not prove frequent enough... The Generator caused considerable architectural debate and was heralded as the "world's first intelligent building." (Hunt 1998, p. 54)

Architect Warren Brody, as early as 1967, characterized such building behavior as a *soft architecture*, which not only responds to its occupants but learns from them, anticipating their needs. Indeed Brody's writings and Price's *Generator* project proposed a new model of architectural computing, one that used the processor not in the design of a building – as with CAD – but in enabling its human occupants. (Brodey 1967) This model has since applied to digitally-controlled building HVAC and security systems. (Amirante and Burattini 1996) Presently, a substantial industry has formed around this concept, with corporations such as Siemens and Honeywell supplying the technology for institutional, commercial, and residential buildings – a subject to which we will return shortly.

The AI-assisted model of Intelligent Building takes its advanced form in responsive environments, or *Smart Rooms*, developed by Alex Pentland and Hiroshi Ishii at MediaLab at the Massachusetts Institute of Technology, the experiments in ubiquitous computing at XeroxPARC by Mark Weiser, and cognate efforts at the Georgia Institute of Technology, Germany's Fraunhofer Institut, and elsewhere. Current research on smart materials, sensors and actuators, and shape memory alloys extends the *intelligence* of the building into its very fabric, with implications for an artificial environment with life-like organic and dynamic characteristics (Jones 2001; Hunt 1998; Coen 1998; Fox and Yeh 1999). Readers may find additional information on intelligent environments in Mahdavi and Lam 1997, and, regarding work done at MIT's MediaLab, in Pentland 1999, Wisneski *et al.* 1999, and Wren *et al.* 1999.

Intelligent Buildings and Industry

Contrasting with its use in research and theory, *Intelligent Building* has come to mean many things within the construction industry. The quasi-anthropomorphic ideal of the building as servant/slave is still tacit within the promotional literature of building services providers. However, says Per Bjorkdah of TA Control Pte. Ltd., it is difficult to define exactly what the *Intelligent Building* is: "One thing is for sure, the answer will vary depending on who is asked the question." Each industrial proponent of Intelligent Buildings, such as purveyors of systems for building automation, security, electronic infrastructure, telecommunications,

closed-circuit television, fire, or security, sees and manipulates the term to their advantage. Bjorkdah claims that "none of these manufacturers really defines the *Intelligent Building* beyond the use of their own products ... The definition is just partial of something that should be defined as a cohesive whole" (Bjorkdah 1999). The self-reflexive accuracy of Bjorkdah's comment can be observed in his company's specialty, the planning and installation of integrated building systems.

However, the integration of systems is not a great priority within the building industry. While Bjorkdah insists that "you cannot take a building and make it intelligent, the building has to be designed 'intelligent' from the first draft on the drawing board," another purveyor of Intelligent Buildings, the cabling company NORDX/CDT, sees no problem with installing an Intelligent Building infrastructure within existing buildings (NORDX/CT web site). Nor, apparently, do other companies with specific technologies to sell. As with the term *Smart Buildings* prevalent in the 1980s, *Intelligent Buildings* has become a promotional tool for selling infrastructural devices and installations. However, rather than dismissing the building industry's use of the term, we shall take a closer look at the virtues claimed for it by manufacturers.

Unlike its proponents in research and theory, *Intelligent Building's* boosters in industry focus on needs already identified prior to the advent of computer augmented environments. As previously noted, these include building services, communications, and security, among others. The NORDX/CDT web site, for instance, claims that "*Intelligent Buildings...incorporate information technology and communication systems, making them more comfortable, secure, productive, and cost-effective.*" All of these are virtues that conform to previous practices, except now with the added – and putative – intelligence of the system purveyed.

At this point it is fair to ask who is served by this intelligence. Some vendors, such as Cisco and Hewlett-Packard argue that the end-user benefits directly through their media delivery systems. Summarizing their claims, *Intelligent Building* is achieved by providing hotels, classrooms, and offices with Internet access – a weak claim when compared with

models set forth by Price and Brody. In Price's case, the building answers directly to the end-user through an automated control system distributed throughout the building fabric. A darker vision of this control is seen in other corporate literature. For example, the total control of the environment is an ideal sought by Eutech Cybernetics in their work for Singapore's Intelligent City infrastructure, a project whose scope embraces the management of buildings and their urban surroundings. The benefits of such control, Eutech claims, would manifest in centralized energy management, security and life safety, maintenance, and facility management. It would also be realized on an urban scale through traffic surveillance and "*integrated parking management that integrates a building's internal car park system within the framework of a citywide car park management system.*" While the taste for such totalitarian technology appears to be cultural, terms such as *autonomy* and *control* pervade the industry's literature. The *intelligence* cited in *Intelligent Building* advertisements tends less to be at the service of individual occupants and aimed more at building managers, owners, or other agents of authority. Arguably, the inhabitants of such buildings are conceived as comprising a passive, managed population whose security and comfort ensures a steady rent-flow, taxes, or other income to its investors.

A Critique of Intelligent Building

In this abbreviated history of *Intelligent Building* we have identified priorities that underlie its development. A recurring theme is the autonomy of the built environment engendered by *intelligence*. Such buildings would conform to earlier models of AI in which a *thinking* entity serves humanity through its conscription and performance of tasks. A second theme is the Intelligent Building's shoring up of materialist values in architecture and the building industry. This line of thinking, we suggest, leads to the de-humanization of the building occupant by overstating the consciousness of the building while undervaluing that of its users. In this scenario the intimate relationship between user and environment is reduced to bodies and objects. Indeed the homeostatic loop of conventional IB systems is not responsive to individual users. With most implementations of Building Energy Management Systems (BEMS) this loop generally occurs in the past tense – the lag in the sampling rate only allows feedback after

an event. Any problem with the environment can only be rectified if a pattern is repeated enough times to be noticed, attenuating any possible interaction through statistical sampling, and further removing the occupant from empowerment within the environment.

If we set aside earlier models of AI that invest artifacts with autonomy, we re-open the question of what intelligence comprises, and what it affords us. Architectural researcher Ted Krueger argues that intelligence is not inherent to things so much as it is a value assigned to them by a human observer (Krueger 2000). This suggests a human-centric view of intelligence, argued by John Searle and Roger Penrose, that vies with the claims of Marvin Minsky and others that an intelligent machine could ever exist. It is not our purpose here to debate this matter except in the case of IB, at least, to re-situate the locus of intelligence away from the object and restore it to the observer. Intelligent Building might well be re-defined with a more ecological understanding of intelligence, one in which intelligence arises through the interaction of people and their environment. We propose that Intelligent Buildings are human extensions, prosthetics of consciousness rather than automated slaves to material need. A psychosomatic model of the user/occupant would displace the passive, materialist ideal employed previously among Intelligent Building's proponents. This accords with definitions of intelligence that have arisen since the early days of AI, and restores the status of the occupant within his or her environment.

With this ecological model of Intelligent Building we can now question the autonomy of the building from its users. The intelligence that led to this autonomy was characterized by a cybernetic closure of the building systems. Sensors within the building yielded data for processing by the system, which in turn actuated equipment that affected the environment. The changes would be noted by the sensors and transmitted to the system again in an ongoing cycle. An ecological interpretation of Intelligent Building would open this homeostatic loop to include the occupant as observer/participant (Fig. 1). In the following pages we will describe a recent installation that employs this model in the creation of a *cybrid* environment, one that merges physical and cyberspaces.

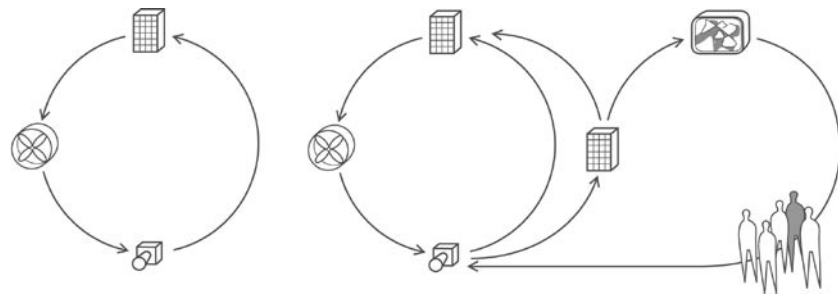


Figure 1. Relationship of conventional IB system (left) to proposed model for information ecology. Conventional systems are characterized by a cybernetic loop that encompasses sensors, computer processor, and mechanical systems. The alternative shown on the right opens the loop to other processors, displays, and direct interaction with people. The data from the interactions are detected by the sensors and re-enter the cycle or continue in the alternate loop for continued interaction.

Arch-OS

March of 2004 saw the inauguration of Arch-OS, a digital infrastructure for a new building at the University of Plymouth in the U.K. Arch-OS, as described by its designers, is an *operating system for buildings* developed to manifest the social, technological and environmental uses of a building for its users (Fig. 2). It is to provide artists, engineers, and scientists with a facility for transdisciplinary research and production. Arch-OS was integrated into the fabric of the University of Plymouth's Portland Square Building, which houses the headquarters of the Institute for Digital Art and Technology (i-DAT). It has also been commissioned for installation into three new buildings of the Peninsula Medical School, distributed across the southwest of England. The PMS is a 21st Century model for the education of physicians in the rural peninsula. Arch-OS extends the social and learning communities of these individual and distributed spaces by providing a dynamic, networked and collective public space.

The designers of the system intended it to be an interface for cybrid architecture. *Cybrids* – a term coined by one of the authors – are “*native to the increasingly mixed reality in which we live.*” They comprise integrated physical and cyberspaces that “*marry the affordances of digital media with the grounding stability of matter.*” In cybrids these physical and virtual domains become interdependent; actions in each domain mutually affect one another. The concept of cybrids is founded on a psychosomatic model of the observer – one who can understand and interact with the non-physical aspects of our world. It also treats space as an extension of the observer; something that he or she uses to think and engage with the environment. Finally, cybrids require reciprocity between physical and simulated elements. This calls for a system to mediate exchange data and thereby make coherent a composition of disparate and, at times, invisible components. Arch-OS is the first step in developing such an interface.

Conceptual Framework

The Arch-OS project was created to enable a greater transparency and understanding of the complexity of modern buildings. The system enables building occupants to reflect on the complexity of their interactions, both physically and through the extended social interactions enabled by communica-

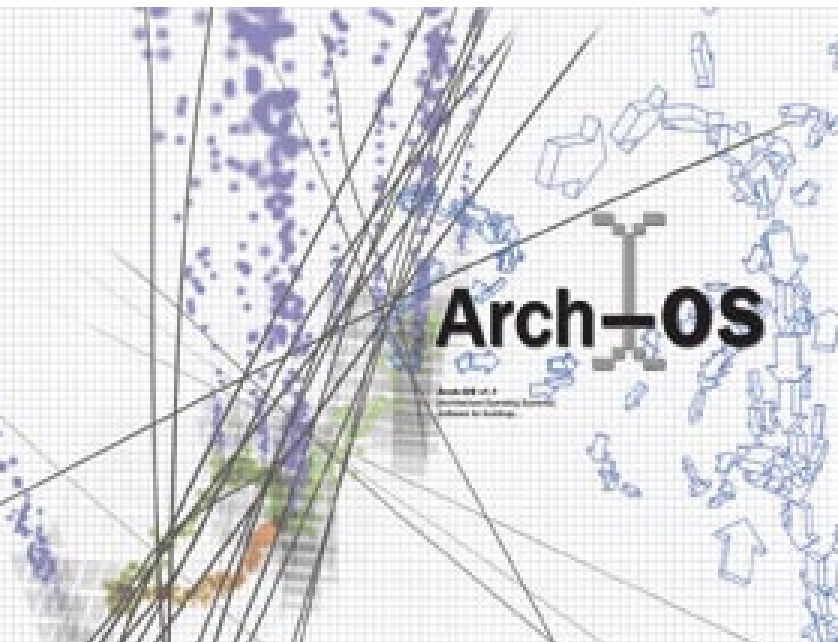


Figure 2. Arch-OS start-up screen

tions technologies. Through the acoustic and visual representation of their social activity, combined with live representations of data generated by the electro-mechanical and environmental activities of the building, occupants are able to better understand the complex relationships that exist between each other and their environment.

The system uses embedded technologies to capture audio-visual and raw data from a variety of sources including 1) the Building Management System (BMS), which has roughly 2000 sensors in the Portland Square project; 2) digital networks; 3) social interactions; 4) ambient noise levels; 5) environmental changes. This live data is then manipulated and replayed through audio-visual projection systems and broadcast through streaming Internet and FM radio. By making tangible the invisible, temporal aspects of a building, Arch-OS creates a rich, dynamic resource for research, educational, and cultural activities, as well as providing an innovative work environment. Effectively, Arch-OS is the nervous system of the cybrid at Portland Square.

Arch-OS System Architecture

Arch-OS comprises three levels of system integration: an Interface; a Core; and the Arch-OS Projects. These are described below.

1. Interface: Internal media networks and data collection devices.

The interface between the physical and virtual consists of a dedicated network that transports data from a range of sensors to the Core. These sensors include tracking cameras, microphones, as well as devices for monitoring BMS information, network data traffic, lift location, and movement.

2. The Core: System for processing/manipulation of data from the Interface.

The Core computer systems embody a range of interactive multimedia applications that generate a composite, dynamic, 3D, sonic model of the building and its activities. Among these applications are video and audio processors, neural networks, generative media, dynamic visualization, and simulation software. The

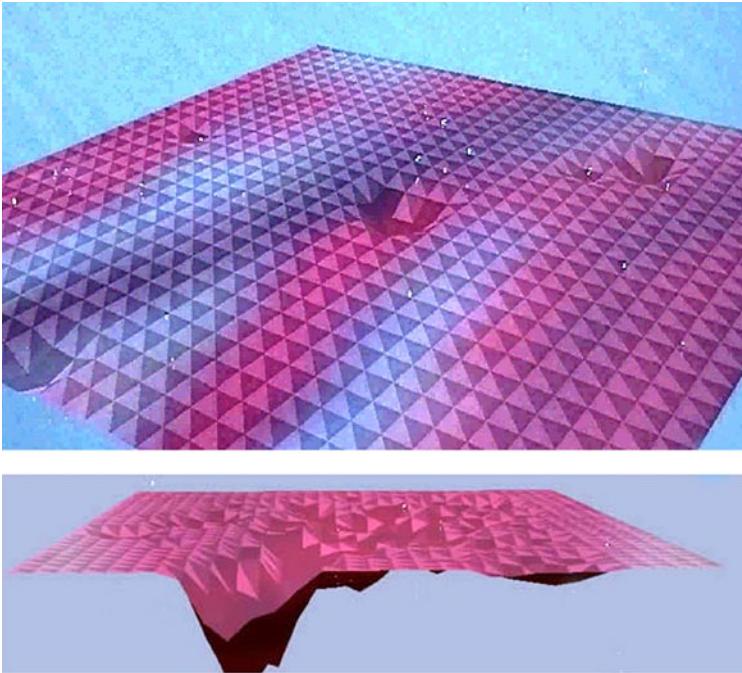
resultant model allows artists, scientists, and engineers to manipulate and control the building's media output. This can then be broadcast within and between each structure and out over the Internet. The Core enables the sensing and monitoring of social, spatial, and technological interactions and manifests these otherwise invisible phenomena to observers and occupants of the cybrid.

3. Projects: The projects enabled by Arch-OS manifest the data processed by the Core.

The Projects component of Arch-OS consists of curated, ongoing programs of cultural events, musical performances, installations, and exhibitions that take advantage of the digital opportunities afforded by the cybrid. I-DAT is housed in the centre block of the Portland Square complex and will exploit, develop and curate Arch-OS Core systems to display and disseminate digital works produced by transdisciplinary practitioners. I-DAT supports a range of residencies and workshops based around the Arch-OS system.



Figure 3. Hardware for the Arch-OS control system at the Portland Square Cybrid Building



Figures 4 and 5. Images from Chris O'Shea's Landscape Project incorporating the Arch-OS vision system

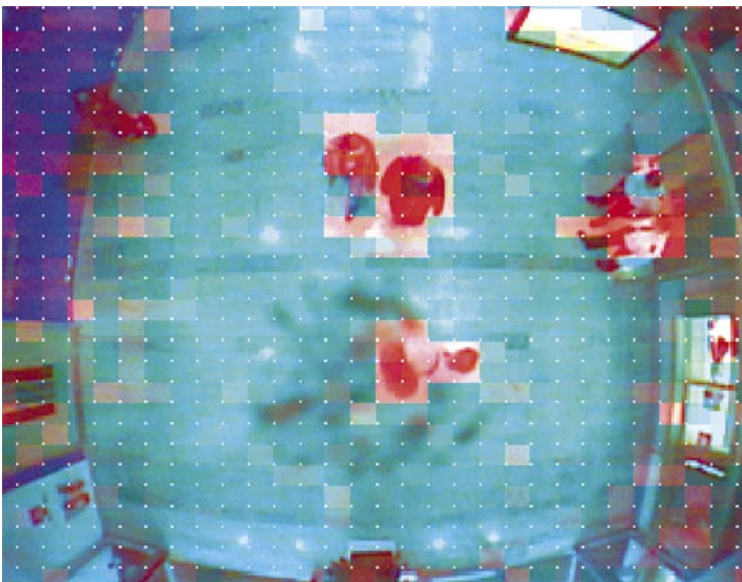


Figure 6. Arch-OS Vision Tool monitoring the flow of people through the Portland Square Cybrid building. Objects at centre of images are people seen from above. Perimeter of atrium is a rounded square owing to camera lens distortion.

Artists, scientists and technologists can carry out research using the Arch-OS systems (Fig. 3). Residencies are based at the i-DAT SoftLab and the Arch-OS control centre; however the networked nature of Arch-OS also allows researchers to collaborate online. These projects range from newly-commissioned works to prototypes for larger research projects. These current projects either build on the particular features offered by Arch-OS (such as the *Screensaver* which visualises the Core data engine) or the links between various Arch-OS systems (such as the following *Cybrid Landscape* project). Research and Development projects are a vital component of i-DAT and the Arch-OS system. In the following pages we will describe some of the projects undertaken using the Arch-OS system.

Cybrid Landscape

Chris O'Shea's *Landscape Project* uses the live data generated by Arch-OS's vision system to etch the flow of people within the building into a virtual landscape (Fig. 4 and 5). This navigable, digital landscape is transformed over time from a flat surface into a rugged embedded landscape that reveals the concentrated flow of people within the space. The Arch-OS Vision Tool provides dynamic data on crowd motion in public spaces. The data is acquired by four CCD cameras surveilling Portland Square and is made available to any computer in the Arch-OS system. The composite video signals of each camera are pre-amplified before transmission to the Core's Vision Tool. This device acquires live images with a frame grabber card and processes them using dedicated motion detection and tracking software (10 x 10 matrix) (Fig. 6). Motion information is stored every 40 ms as a data matrix using a double buffer scheme. The Vision Tool's Web server gives it access to the most up-to-date data in the form of a binary stream produced by a server-side CGI program. Additional information on this project may be viewed at the Web site:

www.pixelsumo.com/projectdetail.php?id=1

Core Model and Screensaver

The Core Model, developed by Adam Montandon, represents the combined activities of the code at work within the Arch-OS system. The Core Model is available as a live 3D model of this code and can be downloaded as a screen saver or as an online 3D

model. Every computer in the Portland Square building has the option of using the Core Model screensaver. This generates a dynamic recursive environment within the building. Sitting in the building the inhabitants can see a live, real-time 3D representation of the building, and the space they themselves occupy, on their screen. They can even pinpoint the data that is being generated by their viewing of the Core Model over their local network. The Core Model is visually very abstract, but it is in actuality a tangible and dynamic real-time inhabited space (Fig. 7). Its existence is dependent on the occupants of the building and the digital consequence of their interactions with it.

Slothbots

Slothbots, under development by Michael Phillips and Guido Bugman, are large autonomous robots that move incredibly slowly. They reconfigure the physical architecture imperceptibly as a result of their interactions with people (Fig. 8). Slothbots build on robotic technology developed by Dr Guido Bugmann that was famously incorporated into Donald Rodney's *Psalms*. This work was exhibited in the South London Gallery as a part of Rodney's last exhibition, *Nine Nights in Eldorado*, in October 1997. In *Psalms* an autonomous wheelchair uses 8 sonar sensors, shaft-encoders, a video camera, and a rate gyroscope to determine its position. A neural network using normalized radio band frequency (RBF) nodes encodes the sequence of 25 semi-circular sequences of positions forming the trajectory. The results may be viewed at the Web site:

<http://www.tech.plym.ac.uk/soc/research/neural/research/wheelc.htm>

The Slothbot control system consists of a laptop PC 586 running a control program written in CORTEX-PRO, and linked to a Rug Warrior board built around the 68000 microcontroller. Slothbots use additional technology to link between the Arch-OS Vision Tool and the autonomous architectural forms. As the use of the space changes throughout the day, Slothbots reposition themselves in anticipation of new interactions with the buildings occupants. In this sense they recall the capricious, changing walls of Price's *Generator* project.

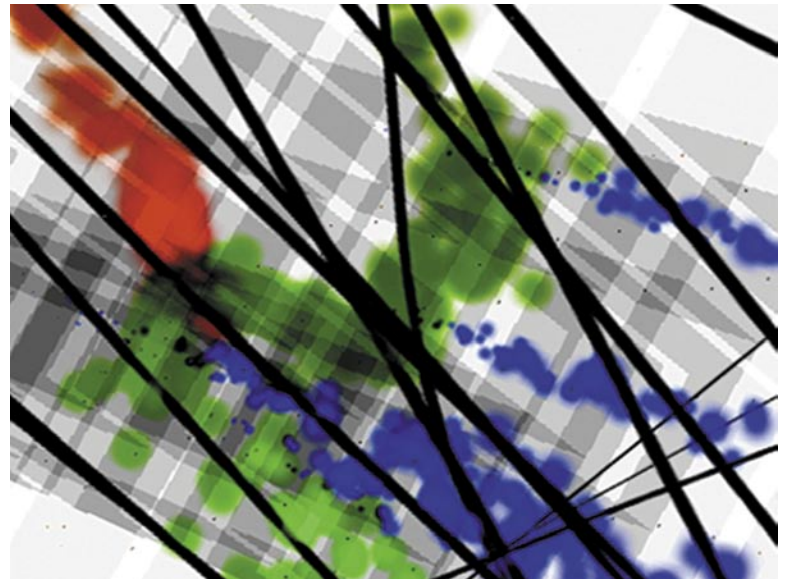


Figure 7. Arch-OS screen saver feeding of the Core data

SMS: Sonic Message Service

As developed by Matt Bilson, Richard Boyd, and James Crossett, SMS extends the space of the cybrid by enabling a dialogue with the sonic architecture of the building via direct interaction through mobile phones. Mobile phone users in or outside of the building can text messages to the Arch-OS system. This allows mobile phone users to text messages to a generative sound system within the Arch-OS installation. These messages are decoded and used as a score for the generation of audio. This dynamically and collaboratively composed audio is played through the Arch-OS Audio tool into the public spaces of the host architecture. Mobile phone users can send text from anywhere into the system; those users not in the building will be able to hear the composition online through the streaming media facilities on the Arch-OS website. To participate in the Arch-OS SMS, remote users must phone in and prefix their message with the word *cybrid*, eg: "*cybrid I sing the body electric*".

SMS uses the Arch-OS audio system that enables explorations of new sonic architectures within the space (Fig. 9). The Arch-OS audio tool consists of an integrated recording, processing and playback system, which allows an evolving library of sounds, generative audio and live recordings to be played through a



Figure 8. Simulation of Slothbots in the Portland Square Cybrid

multi-speaker system (56 in the Portland Square development). The multi-speaker system provides a unique 3 dimensional matrix within the buildings, which allows audio to be positioned at specific locations and panned throughout the space, through corridors and about the atria. Arch-OS audio can be controlled by the Core processing system (sounds tracking the flow of people captured on the Arch-OS vision system for instance), by the inhabitants of the building or through the Internet to allow users to remotely orchestrate sounds within the space.

Conclusions

In this paper we have attempted to shift the focus of Intelligent Buildings away from the materialist aims of industry and towards the recognition of user consciousness. The Arch-OS system demonstrates the effect of such a reconceptualization. The projects shown here expand, to various extents, the occupant's understanding of the space they use, both in terms of a social activity and its environmental resources (space, energy, etc). A key feature of this understanding is that it happens in realtime (with the possible exception of the Slothbots) enabling a level of self-reflection through the awareness of an event's *before* and *after*. Such temporal awareness is used to reprogram occupants' engagement with – and, perhaps, responsibility for – their use of the space. This aspect of Arch-OS departs from conventional Intelligent Building systems by restoring the agency and *intelligence* to the observer. By making the building a shared, sensory extension of its occupants, Arch-OS embodies an ecological model of intelligence, one that does not defer responsibility to conscripted machines, but, we believe, transforms buildings into tools for human consciousness.

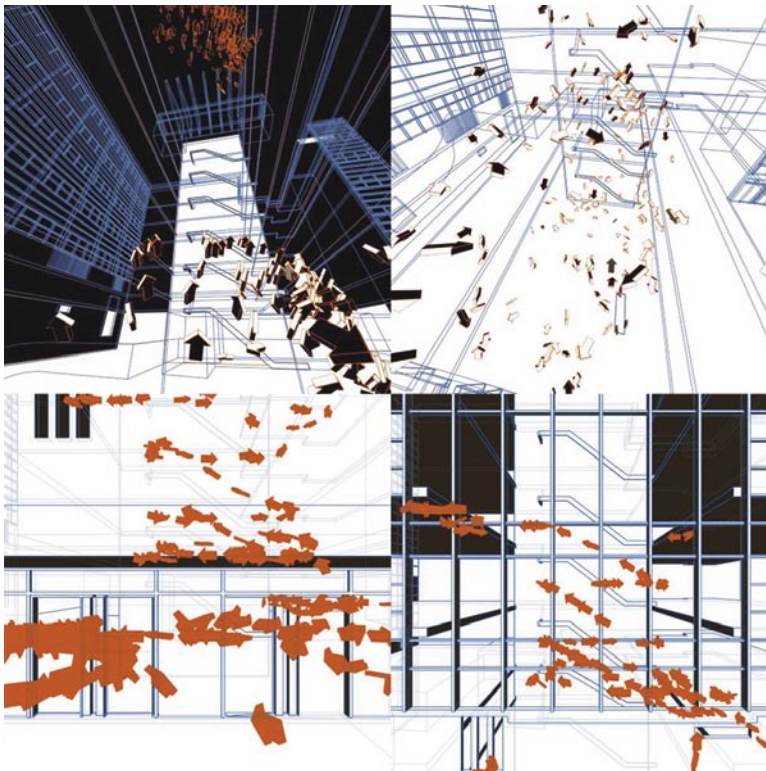


Figure 7. Arch-OS screen saver feeding of the Core data

Notes on Arch-OS Development

The Arch-OS project is managed and produced by the Institute of Digital Art and Technology at the University of Plymouth. Arch-OS is produced in collaboration with the following architects and engineers: Feilden Clegg Bradley Architects, Buro Happold, Nightingale Associates, Hoare Lea, DrMM (Derijke Marsh Morgan), Signwave/CASM.

Arch-OS is a collective of individuals working from the School of Computing at the University of Plymouth. Michael Phillips (Director of i-DAT) represents the Arch-OS development team that consists of: Birgitte Aga (webmistress), Peter Anders (cybrid architect), Martin Beck (Intelligent Systems/Genetic Data), G. Bugmann (Autonomous Robotics), George Grinsted (Sys Op), Eduardo Reck Miranda (Generative Audio), Adam Montandon (Data Architect), and Chris Speed (Tele-Social navigation/Spaceman). Previous collaborative projects include: *Psalms Autonomous Wheelchair* for Donald Rodney, the *STI Project* (The Search for Terrestrial Intelligence); Arch-OS is managed by i-DAT [<http://www.i-dat.org>].

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Mike Phillips is the director of i-DAT (The Institute of Digital Art and Technology), and deputy director of STAR (Science Technology Arts Research), one half of the CAiiA-STAR integrated research programme, at the University of Plymouth. Following a BA (Hons) in Fine Art - 4D, and a scholarship to the University of Massachusetts, he completed his postgraduate studies in experimental media at the Slade School of Fine Art, UCL. Phillips initiated and coordinated the BSc (Hons) MediaLab Arts Programme (1992) with the support of Macromedia. More recently, he founded the On-Line MSc Digital Futures programme and is now overseeing the development i-DAT.