Architecture as Ecosystem - Edge Monkeys: The Bartlett, UCL.

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Buildings resemble natural ecosystems, where objects and people interact in complex rhythms according to the time of day, time of week and time of year. This argument extends to concepts of creation and decay, obsolescence and renewal.

The argument runs counter to many centralized approaches to "intelligent buildings," if nothing else because it places building occupants in a larger situated system, with possibilities of emergent behavior. Centralized control has been frightening writers and filmmakers since the possibilities of automated control systems were first imagined.

Most buildings are still designed with centralized management systems. Some of these are exceedingly complex and hugely expensive. A typical BMS (Building Management System) diagram is essentially hierarchical; the bottom of the hierarchy is where we as people live, work, and play and where the spatial and material world exists. Many management systems do not allow us to control the local world in any way at all; the management system switches the lights on, controls the blinds, the airflow, the temperature and humidity -- even the smell of the air.

Research by Bill Bordass and others has shown that many people do not like this and want more direct control of their environment, either through electrical switching or physically by opening and closing windows, blinds and shutters. This causes real problems for complex BMS systems because human behavior is not optimal.

There has been a move away from the concept of central control. Some buildings now include "intelligent" components that are autonomous in their actions. A good recent example is the façade system at "*Plantation Place*" designed by Arup Associates. In this system, the individual façade elements decide their local preference according to local conditions without reference to a centralized management system. This leads us to imagine the possibilities of an environment where people and individual, "active" building elements can be thought of as a wider transient population of potentially intelligent objects.

The idea of a potentially anarchic collection of autonomous machines and people is also a major influence on fiction and film, where it is usually portrayed in a negative fashion. Machine anarchy is sometimes used as a suitable scenario for humor. The films of Jacques Tati are good early examples, especially the film *Mon Oncle*. Tati's film is funny because it counterpoints Msr. Hulot's incomprehension with the stable behavior of people in relationship to each other, their machines and the buildings they are in.

The metaphor we use is that of an ecosystem where all parts integrate to maintain a sometimes fragile stability. The overriding characteristic of a stable, natural ecosystem is that energy (usually in the form of sunlight) is converted into a disparate group of plant and animal life forms that coexist successfully -- usually in the form of a range of closely inter-linked food chains. For us, the term can only be a metaphor in that it is not usual to design buildings that contain populations that eat each other. The metaphor is useful.
Ecosystems evolve in response to specific inanimate environmental conditions, to contain specific habitats for specific creatures and plants. If we describe buildings as an inter-linked set of different habitats, then we can use the metaphor of an ecological niche. For example, just as there are warm dark habitats in nature, these are found in buildings.
An attraction of this way of thinking is that it allows us to re-examine the notion of the use of robots in the built environment, by considering them as being situated in local building habitats. The architect / engineer can design both robot and habitat, creating a stable ecology with a niche in which the robots might thrive.

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The concept of the automaton as part of the built environment has been a staple part of literature and film for over 150 years and has been well researched. [Wood, Gaby. 2002] Effective robots have been confidently predicted "in the next 10 years" for the past 40 years. The reasons why this has not happened have been most cogently examined by Duncan Graham Rowe in *New Scientist*. He describes how

The first domestic robot went on sale in 1966. Called the Aqua Queen, it was a mechanical device that crawled along the bottom of backyard swimming pools, scouring the tiles and filtering the water. Each time it hit a wall it bounced off in a different direction. Its manufacturer, Aqua Vac of Florida, is now one of a dozen or more companies making and selling pool cleaning robots. These pool-cleaners are real robots. They're mobile and autonomous, and they can sense if they've strayed out of the water. Just pop one in your pool and retire to the sun lounger. But until the late 1990s pool cleaners were the only domestic robots in town. Why did it take so long for them to crawl out of the swimming pool? The reason, to borrow a bit of robotics jargon, is that pools are a structured environment.

We argue that this is the key to effective architectural robotics. Robots have a great future in structured environments.

Graham Rowe suggests that there are inherent risks in environments that are directly occupied by people, where people pick things up and put things down in complex patterns. People are soft and extremely physically vulnerable when faced by a determined machine that has gone wrong. People space usually has a dynamic structure, which reaches high levels of moment to moment unpredictability. This is, for now, restricted territory for robots -- although some small cleaning robots have been developed for it and are now on the market. There is an ongoing risk of a lawsuit if someone falls over a moving domestic robot and hurts themselves badly.

This essay looks at edge conditions, considering them as very specialized habitats whose occupants might communicate and co-operate in their search to regulate energy use. Edge conditions of buildings are complex boundaries with a thickness.

The external edge of a building always has a perceptual thickness, even if this is the thickness and reflective quality of a double-glazed glass panel. In many cases, this thickness is substantially bigger; historic examples are, generally speaking, thick for both technical and experiential reasons. The layered envelope has historically been "active" with opening windows, shutters, doors and screens being operated by people. These can transform a façade.

More recently, facades have been developed to act as double skin systems where substantial gaps between the inside and outside faces exist to assist airflow in heating and cooling. Mechanically active louver blind systems are also common. These thick boundaries can be regarded as separate "places" with special characteristics, both technical and experiential. From a technical point of view, the boundary goes beyond its tangible limits. Façade control can be a complex software problem; it can also be a difficult local, mechanical problem as actuators proliferate. Actuators are often expensive and they break down.

The boundary is a crucial area in the design of buildings, both technically and aesthetically. It is also a potentially structured world, with its own rules. Our argument is that the boundary could be a place for robots. We call our hypothetical robots "Edge monkeys." Edge monkeys are designed together with the boundaries that they serve. The "Fauna" is designed together with the "Flora." The ecology is complete and specific. Edge monkeys are visible, they have a job to do in the boundary zone; they also have the power of communicating beyond it. There are good reasons for "boundary to inside" communication. Edge monkeys are energy misers. Part of their function is to gesture meaningfully to internal occupants when the internal occupants are clearly wasting energy by, for example, keeping the blinds down and the lights on when this is unnecessary. The reasons for external communication are not as clear; perhaps edge monkeys could have some way to create Mexican waves and similar façade effects to entertain passers-by. On the other hand, the monkeys may be intrinsically delightful or funny as they go about their daily tasks.

Edge monkeys trade off their local technical complexity against the possibility of a very fine grain of very simple multiple façade actuators. The same monkey can activate shading devices, ventilation devices, movable insulation and security screens. These could all be standard products with a mechanical monkey interface. Monkeys could also clean the windows. Monkey actions could be "read" anthropomorphically in terms of mood and culturally in terms of contemporary theatre and dance. Edge monkeys have potential individual and collective behaviors. It is this possibility that leads us to consider that building envelopes which contain edge monkeys could enter the realm of "time-based" art.

A simple example occurs when we look at a single monkey operating sun shading louvers. In the summer during the day, the monkey's main tasks are to shut down the louvers to spaces that are unoccupied and to go from louver to louver, modifying the louver positions of occupied rooms as the sun moves around the building. This is a slow repetitive task. Urgent action is required when someone comes into a previously unoccupied space and puts the lights on. At this point, the monkey must locally crack open the louvers unless there is a specific instruction to keep them shut.

Urgent action is also required when someone in a space calls for the louvers to be closed (for a slide show, for example). An irritated monkey must get to the appropriate louvers and shut them. Less urgent but equally irritating to the monkey is the occupant who persists in having the light on when the louvers are open. This is a more mundane task of probably opening the louvers a little more (or pulsing them) to encourage the occupant to turn off the light.

It is unlikely, except in the smallest building, that one façade will contain only one monkey. There are good technical reasons for providing at least 3 monkeys so that one can break down without loss of service, and large buildings will undoubtedly require large troupes on each façade. Complex behavior can emerge through the application of very simple rules.

When nothing urgent is happening, the monkeys "browse" optimally to service the boundary. The monkeys have individual territories defined by the level of previous activity. A monkey serving a group of largely unused spaces would have a much larger territory than a monkey serving a very highly occupied space. The monkeys can "hear" all requests that are placed on them when they are in browsing mode, they ignore anything but immediate requests on their own territory. When overloaded, they call for "help" and initially, this produces a territorial reconfiguration as help needs are evaluated collectively. Monkey behavior is progressively more and more group-like. Sometimes a major environmental change occurs and travels across a façade, for example the immediate impact of a façade heating up under prolonged solar exposure. We show shadow tracking by a troupe of monkeys.

The physical nature of a hypothetical monkey must be designed in the context of a local habitat with which it is in symbiosis. The monkey and the environment are designed together and subsequently share their immediate world with occasional human maintenance staff. A common type of façade is divided into separate zones that relate to internal floor levels. "Monkeys" will operate across single zones and could travel along tracks. This type of monkey is relatively easy to make. Group behavior can only occur in horizontal bands, as in line dancing; true troupe behavior is impossible in this case. If one of these monkeys breaks down, then there is a potential passing problem with areas of the façade left without service. Smaller vertically and horizontally free-roaming monkeys get around this problem. Open lattice façades occur less frequently than the horizontally zoned alternatives, because human window cleaning and maintenance safety is harder to achieve. Vertical airflow is, however, much improved in this type of double skin. In this type of habitat, it makes sense for the monkeys to perform simple maintenance tasks such as cleaning the windows. Monkeys in open lattice skins must be designed to "freeze" onto the lattice if they cease to operate. Buildings with detached louver systems are similar. Monkeys that inhabit these types of environment must be waterproof.

This line of thinking leads us to reconsider the window cleaning robot proposed by researchers at Hong Kong University. This robot has not been considered together with its environment. A more sensible approach to robot window cleaning assumes that the outside of a building will be fitted with robot handholds from the first instance, in the way that traditional Saharan mud brick buildings are constructed with external climbing bars to facilitate re-facing the mud surfaces after driving rain.

Climbing robots have been the subject of a range of design and theoretical investigations. There is the challenge of making a totally "free-swinging" robot which works in a totally unstructured environment. The aim is to make a robot Gibbon and the nearest model of this is the "*Brachiating Robot*" developed at Nagoya university in Japan. This robot swings under a horizontal ladder, controlling its movements by observation of its arms and the ladder. The brachiating robot is a speculative piece of research with no attributed functionality.

Most of the theoretical investigations to date have been concerned with mechanical and software control problems. The issues of power source and power storage have been largely ignored. These are major limiting factors. Edge monkeys will consume a certain amount of energy depending on their weight and the forces that they must exert during their "work." Their energy requirements will probably go beyond the levels of power that can be obtained through solar cells. Monkeys must be able to "feed" off a power source. Although batteries are possible, they will inevitably add weight, and are probably best avoided. Ideally monkey "hand holds" should also act as power sources at all times. This can be done in a number of ways, the most immediately obvious of which is an Inductive Power Transfer System. Our prototype monkey was actuated using heavy-duty stepper motors. Actuation comprised 65% of the overall weight. This type of technology is, on reflection, overkill and is the foundation of our view that future monkeys should be pneumatically operated, with lightweight actuators such as air muscles.

It is possible to imagine the monkey plugging itself into a pneumatic pressure grid on each move. A pneumatic grid has many advantages in terms of safety, and a controllable direct link between power source and air muscle actuator is possible. Pneumatic connectors are water-resistant in a way that direct electrical connections can never be. A very small battery charger and battery arrangement could be pneumatically powered to provide power for local computation and solenoid switching.

The prototype was constructed partly as an attempt to gain an understanding of the technical problems of climbing robotics and partly as an attempt to iterate the design process, by trying out some wild ideas. The experimental monkey consists of a torso with two arms, allowing it to climb by a method of gripping, sitting, and swinging, which was considered as much for its visual possibilities as for its practical merit. There are opposing ways of imagining how this type of monkey could operate in mental and physical space. In the one case, the monkey "knows" its surroundings and operates by rote to progress through them. The problem with this approach is that any error in the construction environment or the behavior of the monkey is cumulative. We have taken the view that the monkey must reset its physical position at every move. The algorithm for this type of movement and sensing is exploratory.

A central processor or "brain" can control all monkey activities following a structured plan. Most industrial robots work on this principle. We take the view that the technical challenge needs to be broken down into more simple problems. In our design, each part of the monkey has a built-in intelligence, which allows it to operate semi-autonomously of other parts of the device. This follows the "Subsumption architecture" design methodology set out by Rodney Brookes. Edge monkeys relate specifically to local habitats. We have already indicated that subspecies must be developed as habitats change. Subsumption architecture allows local evolution as monkey actuation and sensing systems are developed together with cladding systems.

Safety affects the design of all building elements and the most crucial safety issue with a climbing robot is to be absolutely sure that it does not fall off and hurt someone when it fails: this is especially the case with external window-cleaning monkeys. The key to this is the number of elements that are fixed during motion, and the reliability of each subsystem. Systems that grip with power off and only release with power on are inherently more safe than other options. Risk is further reduced by making monkeys small, light and with low power actuators operating at relatively fine levels of granularity in the building boundary. Our enthusiasm for monkey / human interaction means that this is limited by human perception. A monkey the size of a "Tamarin" is feasible in a way that nano-monkeys would not be. Perception is related to distance and this could affect the scale of monkey that is developed for a particular use.

When a monkey goes wrong, it will either malfunction neurotically by, for example, cleaning the same window again and again or it will "freeze" and cease working. Two levels of maintenance are required. In the first instance, a monkey "zapper" is needed to deactivate it. A frozen monkey must be saved by a human repair man or woman who can climb in a monkey environment. This means that the habitat must be "human climbable." This is a further defining criterion for its design. However, in normal service, one of the most valuable aspects of the edge monkey concept is that the complex mechanical and control elements of a building come to the maintenance engineer for regular maintenance. In effect, they can go to the doctor for checkups on a regular basis, rather than expecting the doctor to come on a home visit with all the associated costs and risks.

The relationship between human inhabitants and edge monkeys is in some ways similar to the relationship between P.G. Wodehouses' Jeeves and Wooster characters. The ineffable Jeeves always understands the "big picture" and gently steers the erratic Wooster out of the social predicaments that he creates through his own ineptitude. Similarly, the edge monkey operates in a building-wide system to modify the behavior of the human inhabitants of individual spaces. Our Woosters will express their needs by pulling levers or turning analogue knobs. Like Jeeves, the Monkeys communicate by the way that they undertake their tasks, either individually or collectively. Jeeves' aim is always to modify Wooster's behavior so that it is more sensible, and we need all the persuasion we can get to modify our behavior before the planet is compromised.

In a world where one can buy a toy robot dog with complex behavior patterns for € 1,500, it seems appropriate to re-examine the use of robots in buildings. Our work to date suggests that the use of edge monkeys in the structured world of building facades is intrinsically feasible. Edge Monkeys will have positive efficiency and environmental benefits and provide entertainment and a sense of performance in 21st century architecture.

Bibliography

W. K. Bordass, K. Bromley and A. J. Leaman, "*User and occupant controls in office buildings*" in E. Sterling, C. Bevia, and C. Collett, Eds., Proc. International Conference on Building Design, Technology and Occupant Well-being in Temperate Climates (The American Society of Heating, Refrigeration and Air Conditioning Engineers Inc. Atlanta, 1994)

Stephen Kennett, "*Market Value*" in Building Services Journal: the Magazine of CIBSE (March 2004)

Gaby Wood, "*Living Dolls, A magical history of the quest for mechanical life*" (Faber, London / Alfred A. Knopf, US: 2002)

Duncan Graham-Rowe, "*Jobs for the bots*" in New Scientist 10, February 2001.

Alfred Hermida, "*Wireless power charges gadgets*," BBC News online, Friday, March 21, 2003, 08:58 GMT

R. Brooks, "*A Robust Layered Control System for a Mobile Robot*," IEEE Journal of Robotics and Automation, RA-21, p. 14-23 (1986)

Sir. Pelham Grenville Wodehouse, K.B.E., "*Stiff Upper Lip, Jeeves*" (Herbert Jenkins: London, 1963), p. 189