# Responsive Sensate Environments: Past and Future Directions

*Designing Space as an Interface with Socio-Spatial Information*

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**Abstract:** This paper looks at ways in which recent developments in sensing technologies and gestural control of data in 3D space provide opportunities to interact with information. Social and spatial data, the utilisation of space, flows of people and dense abstract data lend themselves to visual and auditory representation to enhance our understanding of socio-spatial patterns. Mapping information to visualisation and sonification leads to gestural interaction with information representation, dissolving the visibility and tangibility of traditional computational interfaces and hardware. The purpose of this integration of new technologies is to blur boundaries between computational and spatial interaction and to transform building spaces into responsive, intelligent interfaces for display and information access.

## 1 INTRODUCTION

Rather than the traditional computer aided architectural design and information communication technology (ICT) integration into architecture, this paper looks designing computer-aided architecture, i.e. spaces and structures enhanced by embedded sensor technologies and responsive (computational) building intelligence. Architecture's responsibility to society could be viewed as designing a sympathetic environment for human experience and interaction. Emerging sensing technologies and intelligence research illuminate interesting opportunities for designing this experience.

## 2 RESPONSIVE ENVIRONMENTS

Responsive environments include sensate spaces, enabled by spatially- and socially-triggered devices, intelligent and smart houses (utilising video tracking and data capture), networked sensor environments, pervasive mobile computing solutions and ambient visual and auditory displays. This paper briefly reviews the benefits of extant responsive technologies that have developed since last century until the present time in order to clarify potential for future directions. Future architectural design requires a re-thinking of the way in which we design spaces that seamlessly integrate people, architectural structures, sensing and interface technologies to dissolve the distinction between human interaction with buildings and computer interaction. Current research mapping human spatial and social behaviour to generative sonification and visualisation for ambient display leads to a second capability of sensate environments: capturing interaction to observe emergent human activity. This goal utilises active and passive sensing technologies to learn more about human interaction, flow and flocking patterns in transitional and social building spaces. Such observant systems can be applied to new spaces to increase the building's awareness.

## 2.1 Active and Passive Sensing

*Active* sensors require conscious, deliberate interaction. These include bend, motion, gyroscopic and velocity sensors attached to limbs, pointer devices, 6-degree-of-freedom mice (computer mice or pointers that convey 3D directional movement, rotation and velocity), haptic (i.e. tactile) interfaces, stereo 3D vision or gesture tracking. In an art installation context, these sensors are performative interface devices. Gestural controllers (discussed later) are active sensors and triggers that enable direct spatial human interaction with information representation. For example, gesture controllers allow a person to manipulate, twist, relocate, and transform visual and auditory data using arm and hand gestures. In contrast, inconspicuous, unobtrusive, embedded or *passive* sensing captures data without the user needing to change behaviour or consciously interact with the space, e.g. pressure sensitive floor mats, video tracking, infra-red sensors, temperature, proximity and ultra-sonic sensors. Passive sensing is optimal for sensate environments or intelligent buildings in which people should continue their everyday tasks with the additional advantage of smart feedback, an environment capable of learning (with Artificial Intelligence) and reflexive ambient display.

The difference between active and passive systems lies in the awareness by the user. Commands are extracted from the data stream in exactly the same way for the aforementioned *tactile* active or passive devices. In contrast, gesture recognition and 'interpretative' command extraction is more complex in the case of non-tangible capture technologies such as gesture walls and video tracking. The technical mechanism of command extraction is not the focus of this paper, rather the concern here is the implication of socio-spatial behaviour mapping in sensate spaces that can be both informative and responsive.

## 2.2 Responsive Environment Design Using Sensors

The methodologies for implementation here are examples from the Key Centre of Design Computing and Cognition (University of Sydney) Sentient Lab design studio (Figure 1). Projects use embedded sensors, Teleo modules to convert digital and analogue signals for computation using the visual object-oriented programming environment Max/MSP software to interpolate the data and design an output experienced by the user. Output can be a generative design or directly mapped to an auditory, visual or combined display containing social information. *Mapping* is the process of representing non-visual and abstract information (for example, the number of people in a space, motion, temperature, light levels) in the sonification and visualisation display. Mappings between activities and their representation are critical to the understanding (comprehensibility) and social interest of the sonification/visualisation.

**Figure 1 The Key Centre of Design Computing and Cognition Sentient Lab showing "invisible" pressure sensitive floor mats embedded underneath the carpet, triggering the visual and auditory sound system and (right) before carpeting the grid of pressure mats laid on the floor, networked to the Teleo (MakingThings 2003) modules for conversion to a USB interface.**

Correspondences are constructed between source (activity or trigger behaviour) and its visual and auditory representation in which the mapping (correlation between motion, activity, spatial distribution and intensity) is intended for intuitive perception. Responsive generative ambient auditory display requires: an aesthetic framework that is sustainable and listenable; a generative approach that maintains interest and engagement – invoking interaction and ongoing relevance; and a schema of correspondences between social/spatial activity and sonification that lends immediacy and intuitive understanding (comprehensibility) through its network of mappings.

## 2.3 Societal Contexts for Responsive Environments

*Emergent Energy*, developed in the author's Sentient Lab (Figure 2), is an iterative, reflexive system of interaction in which motion, speed, number of users and position in a space determine the growth of a visual design drawn with a Lindenmayer generative algorithm (L-system). The design provides both an informative monitor of social and spatial behaviour and invokes users to interact with their space to influence their artistic surrounds. The design artefact is an embedded history of the movements, interactions and number of people who produced it. Another example, *Obstacle Simulation*, uses spatial sonification to assist obstacle detection and navigation by visually impaired users. Changes in the auditory display communicate information such as proximity to objects and the relative hazard of obstacles in the room using a pressure sensitive floor mat detection system and aesthetic sonification. These two examples were developed using Max/MSP & Jitter (IRCAM

2003), an object-oriented programming environment for real time interaction. Due to the versatile real time capability of this computation method, no significant problems were encountered, though the Lindenmayer algorithmic calculation on a constant data stream is heavy. Gesture/command extraction was not a concern using pressure mat sensors with direct signals to the processor because, unlike video tracking for example, or non-tactile gesture recognition, there is no ambiguity or room for interpretation in the system. The semantics of commands are determined at the mapping stage. Mapping of socio-spatial activity to visualisation and sonification was addressed according to the following criteria (Table 1):

**Table 1 Schema of mapping correspondences**

| Sonification | Visualisation | Activity / Trigger |
|---|---|---|
| Pitch (frequency) | Length/scale/scope of graphic display on screen | Distance between activities / motion |
| Texture/density | Density of events / number of branches or iterations of generative algorithm (embeds history by amount of activity) | Volume of activity, number of users and social threshold |
| Rhythm/tempo of events | Proximity and rapidity of display (animation) | Speed of actions, punctuation of triggering events, tied to velocity of events |
| Intensity/dynamic loudness | Heaviness and distinction of on-screen drawing | Intensity/magnitude of triggering events |
| Timbre (tone colour) | Colour and distribution on visual display (screen) | Region/spatialisation – topology, zoning |
| Harmony | Design artefact | Multi-user manipulation |

**Figure 2 L-system generator patch in Max/MSP & Jitter used to create branched visualisations on screen. Different behaviours modify the algorithmic process of design generation. Colour of branches indicates spatial location, heaviness of lines corresponds to the number of room occupants and motion affects the rapidity of branching. In the sonification, the number of people relates to dynamic intensity, position to tone colour and speed to pitch.**

Enabling buildings with responsive, "understanding" and feedback capabilities facilitates flexibility and accessibility to assist environmental comfort, navigation for the visually impaired, building awareness, gerontechnology (technologies assisting the elderly), and automated and augmented tasks for the physically disabled.

Nanotechnologies - embedding minute sensor technologies in furnishings, surfaces and pre-fabricated building materials - facilitate localised sensate regions and unobtrusive (wireless) distributed networks for data collection. While beyond the scope of this paper, intelligence and learning capabilities also transform household and commercial products that we use within our everyday spaces (air conditioners, washing machines, coffee machines) contributing to the picture of our increasingly responsive environment.

## 3 TOWARDS AESTHETIC AND ENGAGING AMBIENT DISPLAY

Scientific sonification or visualisation of abstract data is usually designed for the purpose of illuminating or augmenting our understanding of abstract (non-visual) data. This paper focuses specifically on ambient display (rather than attentive display) due to its purpose: infotainment (aesthetic, informative entertainment). Ambient displays utilise perception that is both peripheral and pre-attentive. For the interactive sonification explained in the later gestural section, participation with the model is integral for information analysis and manipulation in the workplace, i.e. the difference between ambient and interactive sonification is the requirement of attentive concentration in the latter. There are contexts in which sonification is more helpful than visualisation: utilising the human auditory capacity for detecting subtle changes and comprehending dense data; and to avoid overload on visual senses, e.g. during surgery, anaesthesiology, and aircraft control. These applications of visualisation and sonification contribute to our understanding of well-known issues, particularly in regard to sonification: "orthogonality (Ciardi 2004, Neuhoff, Kramer and Wayand 2000) (i.e. changes in one variable that may influence the perception of changes in another variable), reaction times in multimodal presentation (Nesbitt and Barrass 2002), appropriate mapping between data and sound features (Walker and Kramer 1996), and average user sensibility for subtle musical changes (Vickers and Alty 1998)." There is also evidence to suggest that bimodal (visual and auditory) display has synergistic benefits for information representation.

Visualisation and sonification form useful infotainment for monitoring and display in public spaces, designed to augment, enhance and contribute artistically (as well as informatively) to our experience of spaces, e.g. a foyer, sensate space, common room. Aesthetic representation and accessibility (comprehensibility) directly influences the perception and reception of a work. Granularity or magnification (pre-processing, scaling and density of mapping and data sonification) also affects our ability to comprehend the representation (Beilharz 2004; Figure 3).

It might be argued that sound is even more integrally tied to space than light: "in a natural state, any generated sound cannot exist outside its context" (Pottier and Stalla, 2000) – space is a parameter of sound design, just as is pitch or *timbre.* The following examples illustrate the variety of data that can provide informative and engaging sonification to map abstract, non-visual data to auditory display with a range of scientific and artistic motivations.

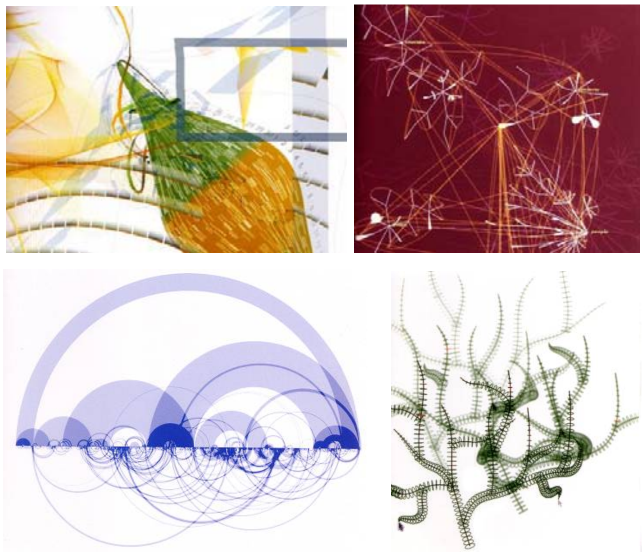

**Figure 3 Four different kinds of data used for visualisation: MIT Aesthetic and Computation Group's *Cubism Reloaded (Simultaneous Perspective in the Digital Realm)* 3D day-planner landscape; Benjamin Fry's *Website as a Visual Organism* (2000) using web server as an elegant computational organism defined by communication; Martin Wattenberg's visualisation drawing musical score as a timeline; Jared Schiffman's 3D *Manipulating a Tree Growing in Real Time***

Ciardi's *sMAX: A Multimodal Toolkit for Stock Market Data Sonification* (Figure 4) sonifies data from stock market environments, in which large numbers of changing variables and temporally complex information must be monitored simultaneously. The auditory system is very useful for task monitoring and analysis of multi-dimensional data. The system is intended to be applicable to any large multi-dimensional data set (Ciardi 2004).

A number of artists and scientists have sonified meteorological data. In *Atmospherics/Weather Works*, Polli uses sonification because it has the potential to convey temporal narrative and time-based experiential and emotional content that enhances perception. Another important consideration is raised, especially with regard to dense data sets, and that is the scope for scaling and pre-processing dense data. Both the data mappings and the scaling or information granularity have significant impact on the efficacy of communication and comprehensibility of the representation. The organized complexity of a hurricane potentially offers rich combinations of patterns and shapes that, when translated into sound, create exciting compositions. Polli also maps the location of data sources to corresponding speaker positions in the auditory display by superimposing the geographical location of data points over a US East Coastal region map.

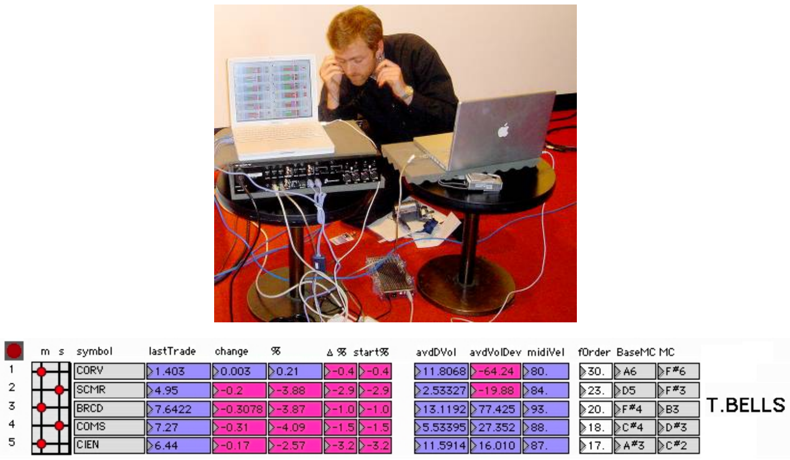


**Figure 4  Hardware configuration and part of sMax visual display**

Garth Paine's responsive installation sonifications include *Reeds – A Responsive Sound Installation* and *PLantA*, an installation at the Sydney Opera House during the *Sonify* festival (part of ICAD: International Conference of Auditory Display 2004) using a weather station to capture dynamic non-visual data measurements. Wind velocity, direction, temperature and UV level from outside the installation space conveys that data wirelessly to Paine's (art installation) sonification inside the Sydney Opera House. Direct mappings, such as velocity of musical tempo, directly connect to wind velocity drawing a clear connection to its source.

## 3.1 Ambient Display and Ambient Devices

Ambient visualisation and sonification in buildings merges informative information display with entertainment (infotainment or informative art) bringing a new versatility and purposefulness to graphical and auditory art in our homes and public spaces. This is where the established practice of installation art works meets domestic infotainment. Ambient display devices include plasma, projection, touch screens and audio amplification systems. These output devices can be used for monitoring environmental characteristics – socio-spatial activities. Ambient information representation is intentionally peripheral and may doubly serve a décor role. Ambient displays normally communicate on the periphery of human perception, requiring minimal attention and cognitive load. As perceptual bandwidth is minimised, users get the gist of the state of the data source through a quick glance, aural refocus, or *gestalt* background ambience. In relation to architecture, ambient representation that responds to the building (lighting, airflow, human traffic, as well as to social elements such as the clustering (flocking) patterns, divergences and task-specific data that are observed adds a dimension of responsiveness to the spatial habitat.

## 4 USING GESTURAL CONTROLLERS AND SPATIAL INTERACTION TO ENGAGE WITH INFORMATION

Introducing gestural controllers as a mechanism for interacting with the 3D spatial auditory and visual representation of information takes this process one step further. While gesture controllers for performing music are current new technologies and information sonification is used independently, the future approach proposed in this paper brings together these disciplines in which gestural interaction affects change in source data. There is a chain from building/computer – information – visualisation/sonification – human interaction/manipulation in which tactile, gestural and haptic interfaces provide ways to access and manipulate data and displays without the encumbrance of traditional keyboard/mouse interfaces. The barrier between humans and information, between humans and the smart building are disintegrated while computation and sensing are conflated into a single organism: the intelligent building. The science fiction film, Steven Spielberg's *Minority Report* (Maeda, 2004) forecasted a kind of interface that is already now achievable: spatial and gestural manipulation of video and computer data on a transparent screen suspended in 3D space (Figure 5-6). The notion behind gestural information access is an important one: dissolving the hardware and unsightliness of computer interfaces. As computing moves towards people acting in spaces, deviating from our currently sedentary desk-bound lifestyle, the importance of the spatial interaction and experience design, the way in which information is represented, becomes essential. Building architecture and information architecture become one (Figure 7).

## 5 CONCLUSION

In summary, this paper outlines some ways in which sensate environments can capture three dimensional spatial and social (behavioural) data and realise a representation of patterns, cliques, clusters and eccentricities in real time responsive environments. Designing the responsive experience with increasingly accessible pre-fabricated sensors and retro-fitted sensate technologies allows building design to flow into the realm of experience and interaction design, dissolving barriers between the computation machine and the visualisation/sonification space. Gestural controllers provide a mechanism for spatial interaction with data representation that absolves the need for visible computing interfaces such as the mouse, keyboard and conventional monitors. Seamless integration of spatial experience and computational response is a direction essential to the future of designing spaces. Not only information sonification but auditory displays with which we can interact provide a future direction in spatial design and interpretation.

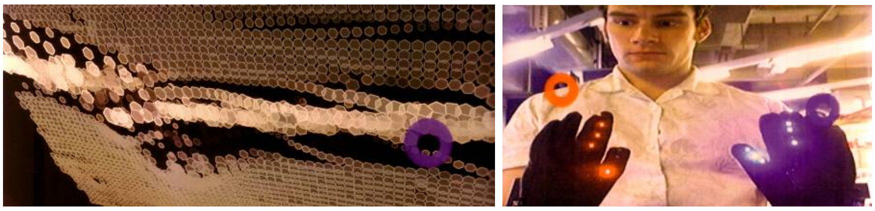

**Figure 5 Justin Manor's *Manipulable Cinematic Landscapes* (Maeda, 2004) is a glove-controlled cinematic landscape interface in 3D space**

**Figure 6 Haptic (tactile) manipulable cubes in Reed Kram's *Three Dimensions to Three Dimensions* (left) are creative tools for expression while sensors attached to digits and limbs can be used as gestural controllers for music (right) (Choi, 2000; Pottier and Stalla, 2000; Rovan and Hayward, 2000)**

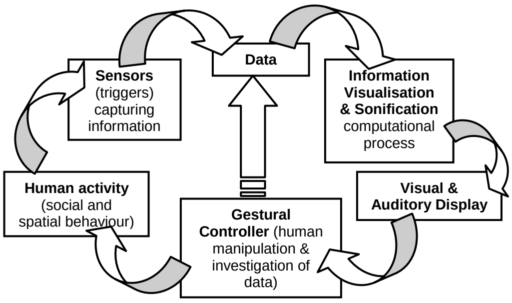


**Figure 7 A summary of the flow of knowledge (left) from socio-spatial activities to the capturing sensors to visualisation/sonification in real time and display. The cycle is completed when gestural interaction is used to manipulate or investigate this data: a new and original mode of interaction with information**

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