Building intelligence: mapping socio/spatial activity for ambient visualisation and sonification in sensate spaces

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ABSTRACT: Building intelligence is the result of a responsive feedback loop in which buildings have the capacity to sense information and transform that data into a meaningful representation for its users. Sensate spaces are responsive environments enabled by embedded sensor technologies. This paper explores the application of data from sensate spaces to generate ambient visualisation and sonification to create an informative display reflecting the social and spatial activities of its occupants. Much attention has been given to designing those innovative materials, embedded sensors and intelligent furnishings capable of capturing data derived from human behaviours and interaction. This paper provides a strategy for representing the data gathered from sensors embedded in the fabric of buildings in a socially reflective and informative generative design. Preliminary discussion explains current sensate technologies and the ways in which building intelligence is augmented. Active (performative) and passive (embedded) sensor technologies are compared, regarding expediency for capturing data in buildings. Considerations are presented for mapping data to a representation that can be easily understood and aesthetically sustainable in human-centred building innovation and ambient displays.

Conference theme: Computers and architecture
Keywords: building intelligence, sensate spaces, visualisation, sonification

INTRODUCTION

Data captured in buildings can be used for two purposes: intelligent responsive actions and automated processes, (e.g. automatic doors, emergency and surveillance responses, adjusting lighting, etc.); and for monitoring and displaying an interpretation of the data. This paper investigates the potential for providing ambient displays (infotainment installations) informed by social and spatial activity in a building. Social activities include clustering, flocking and interaction between people, indicating areas of flow and transition, interesting areas where clusters of people congregate and hubs for utilities. Spatial data refers to information about user locations, the number of people, and proximity to specific objects, walls or regions of interest. A system of generating responsive information in real time invokes further user interaction and provides a recursive, reflexive system. Ambient displays, in this context, are intended to provide information feedback in an aesthetic and decorative way that augments and enhances both the visual and sonic interior of a space and our understanding of its functionality in social and spatial terms. This paper explores using a generative (growing and transforming) structural design process rather than a fixed, constant set of representational rules, in order to sustain interest and engagement for an ongoing ambient display. Some works by other artists/scientists are considered, both to analyse their mapping efficacy and approaches to sonifying/visualising abstract data for public spaces.

1. SENSATE TECHNOLOGIES AUGMENTING BUILDING INTELLIGENCE

1.1. 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. Performative sensors are often attached to a participant’s body for wireless communication and provide indications of deliberate movement, indicative of individual activity. 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, infrared sensors, temperature, proximity and ultra-sonic sensors. Passive sensing is optimal for sensitive 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. Embedded sensors are optimal for capturing data about groups of people such as flocking and the number of users.

1.2. Hardware and software configuration

This research uses pressure sensitive mats and simple, inexpensive light, proximity, temperature and other sensor devices. The information is transformed into ambient (auditory and visual) visualisation reflective of occupant behaviour using Max/MSP + Jitter (Software,
2003), a visual interface for object oriented environment programming to process sound and video (graphics) in real time (Fig.1). Mapping correlations between actions, representation and the generative design process are discussed in following sections. Max/MSP is used to control the input and generative output activated by users’ movements on pressure mats, via Teleo module interfaces (MakingThings, 2003) in the Key Centre of Design Computing and Cognition (Faculty of Architecture, University of Sydney) Sentient Lab. In addition, a Kroonde wireless receiver with 16-sensor kit allows sensors to be attached to people for performative sonification evaluation. These sensors can detect flex, orientation, gyroscopic rotation and speed, as well as pressure and position, adding sonification parameters involving motion and velocity in a space. For experimental purposes, the following Max/MSP patches have been developed:

**Figure 1:** Configuration of sensate system indicating input from digital pressure sensor mats (and other sensor devices triggered by user interaction – button, infra-red, piezo pressure detection, temperature, light-sensitive photocells, proximity, RFID tags) that provide data for the generative process.

![Figure 1](image1.png)

**Figure 2:** Max/MSP main patch in which sensor input from pressure mats trigger colour alteration according to position, branching formation according to activity, distance, speed and generative Lindenmayer system for creating branching visualisation design.

![Figure 2](image2.png)

**Figure 3:** L-system generator patch in Max MSP used to create branched visualisations on screen. Different behaviours modify the algorithmic process of design generation. The two examples (left) show the changed outcome achieved by using different variables to determine the length and shape of branches in the visualisation.

![Figure 3](image3.png)
• to transform colour according to position (pitch density and frequency)
• ChangeColourSend patch for responding to each pressure mat trigger
• FloorSimulationMatrix patch to represent and simulate pressure mat activation during testing and construction of the generative process
• the FootpadCounter patch which measures activity and can track events to sets of footsteps
• the FootpadDistance patch calculates the distance between concurrent footsteps – indicative of user interactive energy and affected by the number and position of users; the L-system patch produces an output string in response to a pressure mat input “bang” (and a sub-patch to keep track of progress of the generative system)
• the L-systemGenerator patch, simplified to a few generation functions due to the string processing power of Max/MSP
• the TimerL-system patch measures the speed of footsteps
• the Turtle patch translates the L-system output into graphic visualisations on screen
• the MainConnected patch sends input from pressure sensors; and the Main patch (Fig. 2) that controls which messages are sent to patches, and which embodies all other patches. Implementation is seen in Figure 3.

1.3. Augmenting building environment design
Enabling buildings with responsive, “understanding” and feedback capability facilitates flexibility and access to environmental comfort, navigation for the visually impaired, building awareness (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 information 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, contributing to the picture of our increasingly responsive environment. An example developed in the KCDC Sentient Lab demonstrates an iterative, reflexive system of interaction in which motion, speed, number of users and position in a space (captured by pressure mats under the carpet) determine the growth of a visual design drawn with a Lindenmayer generative algorithm (L-system) (Fig. 3).

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. A second example 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. Sensing technologies provide clear potential for improving building accessibility.

2. MAPPING ENVIRONMENT AND BEHAVIOURAL DATA TO AMBIENT REPRESENTATIONS

2.1 Motivation
In practice, real time responsive display is central to designing interaction. Evolutionary (somewhat unpredictable) designs have the potential to trigger emergent, novel design outcomes that further motivate interaction with the spatial system. The curiosity factor provided by generative design can be applied to visualisation or sonification or both. Sonification has a powerful capacity to create/focus attention alongside everyday activities, ideal for ambient display. Inadequate consideration has been given to sonification mappings in real time for representation in unlearned systems especially compared with the vast field and relative maturity of information visualisation. Ambient display depends on relatively intuitive recognition and comprehension of its communication and connection with interaction.

2.2. Mapping
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. This paper examines mappings of meaning and interaction to ambient display (visualisation or sonification). It considers the relations between spatial/social activities and visual and sonic (musical) representation. The correspondences between levels of activity, spatial distribution of people, number of people, other social attributes and sonic characteristics (e.g. pitch, intensity, rapidity, pulse, harmony) and the correspondences with visual metaphors (Beilharz and Reffat, 2003) (colour, distribution in space, patterns and design growth) form the basis for connecting building intelligence with ambient display. The following table (Table 1) maps a high-level framework for correspondences between auditory and visual representation with the environmental conditions or activities that trigger the response. This table maps broad correspondences between social/spatial activities and using an algorithmic process for generative sonification.

### Table 1: Sonification schema of correspondences

<table>
<thead>
<tr>
<th>Sonification / Visualisation</th>
<th>Activity / Trigger</th>
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<tbody>
<tr>
<td>Pitch (frequency)</td>
<td>Length / scale / scope of graphic display on screen</td>
</tr>
<tr>
<td>Texture / Density</td>
<td>Number of branches or iterations of generative algorithm (embeds history by amount of activity)</td>
</tr>
<tr>
<td>Rhythm / Tempo of events</td>
<td>Proximity and rapidity of display (animation)</td>
</tr>
<tr>
<td>Intensity / Dynamic loudness</td>
<td>Heaviness and distinction of onscreen drawing</td>
</tr>
<tr>
<td>Timbre (tone and distribution on colour)</td>
<td>Region / spatialisation – topology, zoning</td>
</tr>
<tr>
<td>Harmony</td>
<td>Design artefact</td>
</tr>
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</table>

The connections are intended to be semantically intuitive or metaphorically logical creating a system of representation that is easily understood without learning complex relationships. Comprehensible representation is consistent with the immediacy required to stimulate interaction. There is a natural inter-relationship between activities and sonification, for example, it is likely that multiple users (compared to a single user) will likely more spatial regions and activates an increased number of triggers (speed and density). This overlapping or blurring of mappings (orthogonality) is a realistic mirror of the interactive experience.
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. Mapping to a generative design process
Most informative sonification models map data directly to a fixed value in the display. A distinguishing feature in this approach is mapping time-based activities to a generative algorithm that will simultaneously represent actions and produce a growing, evolving design in order to maintain a dynamic design display and interest over time. Not only does this approach embed a “memory” or “history” of the activity that led to the moment, but it provides an auditory display that is sustainable due to its constantly changing state and curiosity. Ambient displays are intended to inform and enhance an environment. Such installations require aesthetic “freshness” that will be provided by generative design (Beilharz, 2004b; Beilharz, 2004c; Beilharz, 2004d).

2.4. Related works using generative design processes
The foundation for utilising generative processes in responsive visualisation/sonification has been laid in the heritage of (art) installation works that use generative processes to create designs and in those that use generative and evolutionary (or genetic) algorithmic processes to respond directly to interaction. Algorithmic design includes many stochastic and serial methodologies as well as those algorithmic techniques pertaining to genetic transformations or other generative elaborative processes, such as the cellular automata (Johnson and Trick; 1996; Skiena, 2003). In the broadest sense, algorithmic generation incorporates all classes of solution-generating algorithms, including linear functions, network growth and fractal algorithms; those based on genetic evolution (Krevel, Overmars, Schwarzkopf et al., 1997; Skiena; 1997); and Stochastic processes, e.g. applied to musical composition and architecture by Iannis Xenakis (Beilharz, 2003b; Xenakis, 1971). Algorithmic generative systems have been used by designers and artists as diverse as Brian Eno, Francois Morellet, Simon Penny (Balbert, 2003) and Marvin Minsky (Minsky, 1981; Minsky, 2003).

Contemporary media artists, Christa Sommerer and Laurent Mignonneau (p.297) (Grau, 2003; Whitelaw, 2004) build on the alliance between art, nature and technology using natural interfaces and Artificial Life (“A-Life”) (McCormack, 2003) and evolutionary imaging techniques. These allow people to interact with natural spaces and patterns (exotic worlds of luxuriant plants, swarms of butterflies, microcosmic organisms, growing ecologies) applied to installations. Jon McCormack’s Future Garden (McCormack, 2003) is an installation displaying patterns generated using the algorithmic technique, cellular automata, also utilised by Creativity and Cognition Studios sound designer, Dave Burraaston (Burraston, 2003) to produce a continuous stream of permutations and evolving generative designs. McCormack’s Universal Zoologies (Fig. 4) is an interconnected series of autonomous, self-generating spaces. Eden -a networked self-generating sonic ecosystem environment, and Future Garden - an electronic “garden” of Artificial Life as part of the Federation Square development in Melbourne, represent installations of generative processes in large-scale publicly interactive spaces (Bandt, 2004; McCormack, 2003). Successive generations of artificial fauna tend to become more complex. Bernd Lintermann’s SonoMorphs (ZKM, Karlsruhe, 1999) involves user interaction to perpetuate the 3D mutation process. In building design and architectural processes, generative algorithms have been designed to provide multiple interpolations, i.e. for idea generation, e.g. Michael Rosenman and John Gero ‘Evolving Designs by Generating Useful Complex Gene Structures’ (p.345-364) (Bentley, 1999) for generating house shape designs using different room configurations.

![Figure 4: McCormack’s Universal Zoologies is an interconnected series of autonomous, self-generating, poetric spaces that are navigated by people experiencing the work. The project aims to represent emotive, abstract, artificial life digi-scapes, each based around a thematic metaphor evoking the qualities of the natural world (McCormack, 2003).](image)

2.5. Related sonification mapping
Following are some examples of designers who have sonified data for artistic installations and exhibitions (Beilharz, 2004a) (Table 2):

<table>
<thead>
<tr>
<th>Table 2: Sonification as art</th>
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<tr>
<td>Fabio Cianniello Ciardi’s sMAX: A Multimodal Toolkit for Stock Market Data Sonification 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 multidimensional data (Fig. 4).</td>
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<td>MarketBlitz is another sonification of real-time financial data, in which the authors claim, “auditory display is more effective and consistent for monitoring the movement of volatile market indices” (Ianata and Childs, 2004). This system requires user training and serves as an indicator more than an aesthetic ambient display.</td>
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<td>Andrea Polli – Atmosphernics/Weather Works. A number of artists and scientists have sonified meteorological data. In Atmosphernics/Weather Works, Polli uses sonification because it has the potential to convey temporal narrative and time-based experiential and emotional content that enhances perception (Fig. 5).</td>
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<tr>
<td>Garth Paine’s responsive installation sonifications include Reeds – A Responsive Sound Installation and Plants, an installation at the Sydney Opera House during the Sonify-Festival (part of IAD: 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 building (Paine, 2004).</td>
</tr>
</tbody>
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and increasingly “intelligence” is integrated into building materials and devices. Designing the user experience is part of understanding the lifecycle of the environment, contributing to healthy workplaces, technical innovation and integration of building technologies. Scientific sonification or visualisation of abstract data is usually designed to illuminate or augment our understanding of abstract (usually non-visual) data. 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 Barrant, 2002), appropriate mapping between data and sound features (Walker and Kramer, 1996), and average user sensibility for subtle musical changes (Vickers and Alty, 1998).” This paper views visualisation and sonification as 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, 2004a). Thus 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, work place and public spaces. This is where the established practice of installation art works meets domestic infotainment.

3.2. Musical inspirations for sonification
To cite some sonifications developed for scientific informative purposes, (e.g. Interactive Sonification Toolkit for analysis of large general data sets tested with helicopter flight data (Hunt, 2004); sonifying EEG data (Hinterberger, Baier, Mellinger et al., 2004); sonification of geo-referenced data (Zhao, Plaisant, Shneiderman et al., 2004)) the mapping of data to sound is either a) immediately clear and literal or b) a complex new language/codification that must be learned in order to be able to interpret the system but, above all, c) not the quality and characteristics of sound design that would be desirable and sustainable within the framework of infotainment or ambient display, in which music and sound qualities of variation and interest are pertinent characteristics critical to social acceptance and the additional aesthetic agenda of ambient display. (Sonifications can commonly consist of plain sound samples, alerts, earcons, and digital amplification of graphical waves). While the constitution of sonically appealing, or simply acceptable, sonification remains subjective and, to a degree, individual (just as for visualisation), we can reasonably assume that interest and variation concurrent with achieving the goal of communicating information, enhances potential social acceptance and ambient display sustainability. To this end, a generative system provides aspects of interest, curiosity, novelty and change while retaining the rules of sonification (codification) that embed meaning (see
Table 1: Sonification schema of correspondences above). Further, the quality of sound generation and sufficient complexity (representation of rich data across a number of parameters) are measures the sonifier can implement to position an ambient display more closely to “music” or meaningful sonic communication than to “noise”.

CONCLUSION
Ambient sonification and visualisation displays illuminate social and spatial human-to-building symbiosis, heightening our awareness of flocking, emergent and interactive behaviour in an informative way. The intonation aesthetic framework in which mapping activity to a transforming digital generative design occurs creates live, iterative décor integration for sensate social building spaces (e.g. foyers, cafes, meeting rooms). Reflective art contributes to our understanding of the buildings we inhabit while enhancing the immersion of the experience. The strategy of sensing, mapping and responsiveness outlined in this paper expounds a latent potential for innovative sensate technologies in architectural environment design.

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