Interactively Determined Generative Sound Design for Sensate Environments: Extending Cyborg Control

Dr. Kirsty Beilharz
Key Centre of Design Computing and Cognition
University of Sydney
+61 2 9351 4031 / 0408 033 514
kirsty@arch.usyd.edu.au

ABSTRACT

Sensate environments provide a medium for humans to interact with space. This interaction includes ambient/passive triggering, performative artistic interaction and physical sensate spaces used for games and interactive entertainment. This paper examines aural representations of data activated by interaction, shaped by user activities and social environmental behaviours. Generative art forms, for example genetic algorithms and evolutionary design systems, provide methodologies for creating new material. This paper addresses ways in which the generative innovations can relate to human experience in a comprehensible representation using constructs shared by behaviour and sound.

The purpose of site-specific generative sound is to respond intelligently to human participants with feedback: sonic indicators of social activity. The affects of the environment contribute to the generative process – the number of occupants, busy-ness (motion), environmental measurements (e.g. temperature, position relative to specific locations in the space) or direct controls – proximity to sensor walls, movement on pressure sensitive flooring. An examination of comprehensible correspondences between sonic parameters and socio-spatial behaviour articulates a methodology for auralisation of social data. Human interaction contributes to the initiation and modification of generative procedures. The central concern – to make generative responsive sound/music clearly indicative of its social context – is applicable in virtual environments as well as wireless sensate physical spaces. Sensate spaces, as a growing and cutting-edge phenomenon at this time, require constructs for expedient computational processing and purposes to which the vast stream of sensed data can be meaningfully applied for the edification of the users.

Keywords

Generative music, sensate environments, genetic art, algorithmic generative processes, evolutionary design, auralisation

1. INTRODUCTION

"I consist of a biological core surrounded by extended, constructed systems of boundaries and networks … networks establish a space of links and flows" [1].[1]

Environmental sound here is the product of a computational system for real-time sound and ambient music generation, derived from data sensed in the environment in which it is situated. This provides feedback about the participation and movement in the environment (both social and interactive). The applied contexts for environmental generative sound include online (multi-user), synchronous virtual environments, digital installation spaces (e.g. intelligent rooms, virtual reality and immersive environments) and sensate physical spaces.

Generative processes for creating sound and graphics are long established but, operating in isolation, offer no particular relation to user interaction. This paper examines the conversion of data into representation – addressing some issues and strategy for situated generative sound design. There is a difference between indicative and meaningful auralisation. Indicative generative design may reflect or transform and represent data from a sensate environment while meaningfulness implies that the generative outcomes can be interpreted by users and comprehendingly related to context.

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[1] Mitchell, W.J., *Me++ : The Cyborg Self and the Networked City*. 2003, Cambridge, Mass. USA: MIT Press. 259 p. Mitchell goes on to say: "Now the body/city metaphors have turned concrete and literal. Embedded within a vast structure of nested boundaries and ramifying networks, my muscular and skeletal, physiological, and nervous systems have been artificially augmented and expanded. My reach extends indefinitely and interacts with similarly extended reaches of others to produce a global system of transfer, actuation, sensing, and control. My biological body meshes with the city; the city itself has become not only the domain of my networked cognitive system, but also – and crucially – the spatial and material embodiment of that system." Ch.2 p.19 'Connecting Creatures'. Thinking in this way, the sensate space is an extension of our networked body and intentions. The realisations that occur in the sensate environment logically should connect with our interactive networks.

Deliberate interactions, triggers and passive (or unconscious) methods of generating data provide the mechanism for initiating generative processes. Several different generative algorithmic processes reveal potential opportunities for environmental data and prevailing conditions to determine and feed into the generative design. Modification of genetic evolutionary systems and stochastic grammars provide socially relevant interest and variety while maintaining the situated design. Embodiment of data and auralisation metaphors contribute to the comprehensible representation of data, essential for user satisfaction and purposeful functionality of the sound design. This interaction is illustrated in Figure 1.

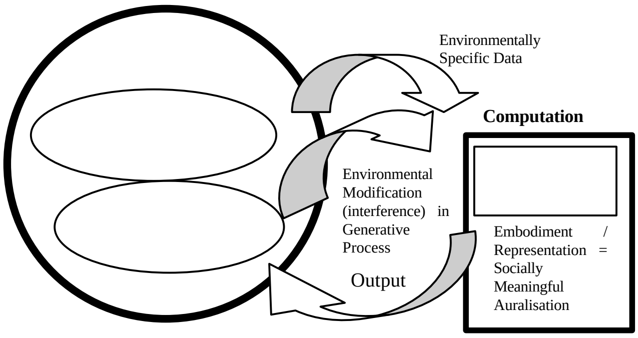

Figure 1. The structure of this paper is based on the interplay between sensate environments, environmental data, generative sound processes and people.

Throughout this paper, virtual environments (VEs) refer to online (multi-user, synchronous) 3D environments, for example Active Worlds [2] or VirTools [3], in which human users are represented by avatars and the computer keyboard interface is used to move around the environment by walking, flying or teleportation. Sensors in virtual environments are triggered by interaction (keyboard and mouse-operated direction, mouse-clicking on objects) and by events (collision/intersection with 3D objects in the VE, objects loading). In contrast, digital environments (DEs) refer to physical environments – intelligent rooms or installation spaces in which the human users move physically and interact by activating sensor triggers, interfaces (haptic, clothing, body sensors), or in which motion is detected using tracking hardware and software. An example of the latter is the planned intelligent room in the author's University. Sensate spaces are a subset of digital environments, often even synonymous.

The type of sensate space focused on in this paper is one in which passive and performative (or proactive) interaction occurs, in which sensors located in the space, walls, materials or activated by sensor devices (rather than intrusive or invasive wearable or implanted technologies) provide data for computation. Although the gamut of sensate spaces can be broader than specified in other contexts, it is important to the social functionality considered here, that non-invasive, passive sensing occurs to permit natural social interaction between people, people and space, as well as human-computer interaction.

2. SENSED (VIRTUAL) ENVIRONMENTS AND TRIGGERS

Virtual environments can provide input for environmentally connected generative processes and thus, by using the triggers and sensed data in VEs, an inexpensive simulation or model of the generative processes required for a sensate physical space can be tested before implementation. Responsive sound in virtual environments can provide information about its user and social patterns, as well as providing immediacy to warnings, feedback, sound-emitting beacons or strategic landmarks for way-finding and guidance [4-6]. The basis of the sensors are the triggers available in Active Worlds: when an object is first loaded; when an object is bumped or passed through; activated by a mouse left-click; when the end of a non-looping animation is reached) [7].

3. SENSATE (PHYSICAL) ENVIRONMENTS

Sensate spaces refer to social and 'magnetic' (i.e. attractive) spaces in which the sensors are inherent and unobtrusive, often embedded in the space itself. Users may not have to wear special clothing, goggles, or implants. Appropriate data for social reflection emanates from a wireless, sensate physical space, 'passive' sensing or unconscious human activation of sensor devices, e.g. pressure sensitive floor mats, infra-red, video tracking and analysis, microelectromechanical systems (MEMS) (p.66-67) [1] or radio frequency emitting identification (RFID) sensors that are minute, embedded or distributed, networked widely and inexpensively in a space. In the future, nanoelectromechanical systems (NEMS) (p.69) [1] may even become currency in the inter-human sensing process.

4. METHODS OF INITIATION IN SENSATE ENVIRONMENTS - SENSOR DEVICES, RECEPTORS AND MODES OF INTERACTION

Different sensor technologies activate and detect human behaviours and interaction – with other people, within the space and with specific devices. This section categorises those sensors and briefly summarises the ways in which information is retrieved. Current technologies are divided into two types: those of which the user is intrinsically aware – wearable, invasive, wired, haptic or tactile interfaces; and embedded, discreet, unobtrusive sensing that can transmit data without requiring the user to be overtly aware of the process. The latter category refers to suitable sensors for sensate social spaces rather than performative or interactive art and entertainment spaces.

4.1 Wearable, Active Triggering Technologies

This paper looks at sound design primarily as environmental sound and feedback, rather than purely as entertainment or performance, though both approaches share many technology interfaces. The following examples provide some evidence of practical implementations of sensing devices in performance (Table 1). Several performers have used off-the-shelf motion detectors and inexpensive pressure triggers, as well as custom-designed hardware, to map body location within a space into MIDI data (p.316) [8].

Table 1. Some performance artists' application of sensor devices [8-10].

Artist	Title	Data sensing
David Rokeby	*Very Nervous System*	Tracks human movements in a large space using video and computer analysis of consecutive frames to detect motion; uses MAX.
Paul Garrin	Interactive video installation, *White Devil*	Dancers and other participants influence the compositional process based on location and movement. Video image projections track and respond to viewers' movement [11].
Rob Lovell & John Mitchell	Virtual Stage Environment	Identifies 'hotspots' within a video field of vision and actions within these areas are interpreted by MAX [12] to control the musical process and video disk playback [13].
Max Matthew	Radio Drum / Radio Baton	Spatial controller consisting of radio-frequency transmitting batons moved across a receiving surface, controlling data in 3 dimensions. This system has been used in sophisticated ways by composers, Andrew Schloss and Richard Boulanger. A 'drum' object for custom MAX is designed to receive stick-position data, trigger-plane hits and velocity [14].
Donald Buchla	*Lightning*	Infra-red signals are used to locate the performer within a user-definable 2D grid [15].
Jeffrey Shaw	*The Legible City (Amsterdam)* (see Figure 2)	Bicycle interface, sensing pedalling rotational direction and handlebar steering orientation, to navigate direction and depth in immersion 3D projected environment [9, 16].
Petra Gemeinboeck, Roland Blach & Nicolaj Kirisits	*Uzume*	Immersive real-time stereo projection system in a CAVE with video-sensed motion detection influencing projected patterns and triggering musical interaction (see Figure 3). *Uzume*'s sonic response, shaped by spatially moving sounds, develops individually modulated passages along the traces of the visitor's movements [17].

Figure 2. Jeffrey Shaw's *The Legible City (Manhattan)* (1989), shares its interactive interface for negotiating 3D terrain with *The Distributed City Legible City* (1998) and *The Legible City (Amsterdam)* (1990). This kind of performative, interactive art work requires deliberate, conscious, single-user interaction.

Figure 3. *Uzume* by Gemeinboeck, Blach & Kirisits projects a visual representation of the performer's choreography. The work responds sonically and in stereo projection in real time in a CAVE system. Video-sensed motion detection influences projected patterns and triggers musical interaction[2] [17].

Body sensor devices are those attached to participants' bodies: especially arms, legs, hands, fingers [18], e.g. an extreme case would be Stelarc's *Exoskeleton* (1999) or *Ping Body* (1996) [9, 19] (see Figure 4). In comparison, body sensor devices can include wireless devices for ease of motion and in order to be as unobtrusive as possible. The glove object, for example, receives eight gestural variables from simple interfaces like the Mattel Power Glove for the Nintendo Entertainment System: X, Y, and Z location, rotation and bend of the thumb and fingers. The object reports these values whenever a trigger (or "bang") is received.

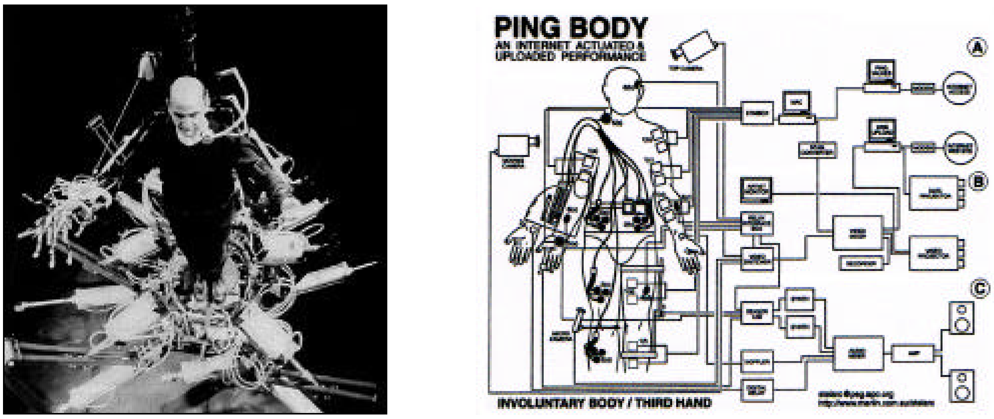

Figure 4. Stelarc's *Exoskeleton* and the schema for *Ping Body* [9]. In the former, the artist's gestures activate mechanical, electronic and software components: the machine's choreography derives entirely from arm gestures. The latter is designed for Internet actuated and uploaded performance and an involuntary third arm.

Numerous compositions have successfully utilised this gestural information. Potential for these sensor devices relates input to collection of environmental data that results in relevant,

[2] Gemeinboeck, Petra: Photograph of *Uzume* installation in a 3D CAVE provided by the artist.

informative sonic feedback – not purely entertaining or performance-oriented.

Design and fabrication of textile-based computing - washable, wearable technologies [20] may lead to more common-place integration of computation with fashion and mobility beyond our current array of portable wireless devices. The MIT Responsive Environments Group projects [21] include a number of wearable devices for transmitting and transceiving data: the UberBadge and Radio Frequency Random Access Integrated Node (RF and IR communication with extensive memory and storage expandability); and the Gait Shoe (measuring parameters from each foot using the Sensor Stack to provide data for analysis of gait). Sensate tactile objects and purpose-specific devices include: sensate cook-tops (transduction in glass ceramic surfaces for sensing pots); and the Trible (Tactile Reactive Interface Based on Linked Elements – multimodal sensate "skin" on a ball) [21]. These devices are clearly intended for deliberate, specific interaction.

4.2 Wireless, Embedded and Unobtrusive Sensing Technologies

In the sensate environment, spatial sensors respond to the location and movement of a person/performer in space, often without the user consciously touching any hardware devices (e.g. infra-red sensor grids, pressure-sensitive floor mats). Edmond's Creativity and Cognition Studios, for example, use infra-red and pressure-sensitive mats in installation performative works such as *Elysian Fields.*[3] Pressure sensors usually function by piezoelectric conductivity. There are a range of commercially available sensate or pressure sensitive floor mat solutions for embedding discreetly under carpet or flooring surfaces. Similarly, the Magic Carpet [22] uses carpet on top of a mesh of piezoelectric wire (tracking foot position and dynamic pressure) and a pair of Doppler microwave motion sensors (to respond to movement of the arms and upper body) for immersive musical installations.

Radio frequency (RF) transmitting devices and magnetically coupled resonance (LC tag) technologies that can be embedded (or comfortably wearable) and networked widely, wirelessly and inexpensively represent the greatest potential as availability becomes ubiquitous [1, 23]. Gesture Sensing Radar developed by the MIT Responsive Environments Group [21] explores microwave sensing for detecting non-contact gesture. Z-Tiles "develop a sensate floor made from networked sensor tiles, each of which contains small pressure sensors connected to an embedded computer" [24]. Smart walls developed at MIT [23] with infra red and video, using computer vision, provide a non-tactile alternative to most commercial digitising tablets and smart whiteboards that require contact and pressure. Gesture walls and laser range finding detect human motions and interactions with wall-mounted displays and the LaserWall provides an inexpensive scanning laser rangefinder that can be retro-fitted, requiring fairly direct interaction and intention [23].

[3] Brigid Costello, Ian Gwilt, Andrew Martin and Dave Burraston: *Elysian Fields* (2003) investigate presence and intuitive interaction with mixed reality environments. Participants walking over a grid of pressure-sensitive mats to activate a visual metaphor of compressed grass strands in an animated, rear-projection display. Edmonds, E., *Sparks CD-ROM*. 2003, Creativity and Cognition Studios, University of Technology, Sydney.

5. GENERATIVE PROCESSES

"Creative steps may be found in inventing a new structure, for example serial music … the search for order is a fundamental attribute of human perception" [25]. In musical compositions and architecture by Iannis Xenakis, and architectural rules applied to designs by Le Corbusier, the expertise lies in designing the grammatical, generative system rather than the artefact itself [26]. Stochastic, algorithmic and genetic evolutionary systems provide underlying generative processes for designing sound and interpreting environmental data.

5.1 Stochastic Processes for Generation and Transformation

Stochastic / probabilistic processes provide a related group of algorithms capable of generating complex sets of values for representation as new sonic or visual material. Stochastic and serial processes have been applied to musical composition and architecture by Iannis Xenakis [26]. The underlying mathematical bases for his application exemplify some methodologies for augmenting and creating design. Due to the interdisciplinary nature of mathematical processes, this foundation transcends the barrier between visual and sonic representation with the potential that like structures can generate material in both domains from a common process, reinforcing the structural integrity of design works.

5.2 Algorithmic Generative Processes

In general, algorithms are procedures or formulae for solving problems. This broad class 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* [27, 28]. In the broadest sense, algorithmic generation incorporates all classes of solution-generating algorithms, including linear functions, network growth and fractal algorithms, and those based on genetic evolution [29, 30]. For any algorithmic process, the relation to its environment lies in the way in which modification and selection occurs within the system, extrapolated in Section 6 for Genetic algorithms.

Jalbert connects generative art and music with generative grammar in the field of linguistics, deducing that music and the visual arts are really languages that have their own grammars [31]. Beilharz concurs that musical compositional structures by Complexist composers are a form of design grammar [32]. Jalbert's discussion raises interesting issues that relate to designerly or artistic implementations of algorithmic generation: that certain sequences or juxtapositions, whether by an artist or a programmer, can create effective communications; that certain systems use a small set of rules with various permutations; other systems use loose sets of rules and a large vocabulary; some algorithms provide little or no permutation within but sequencing the algorithms turns into a language or grammar. It is interesting that generative design is related to grammar, the vehicle of meaning. Algorithmic generative systems have been used by designers and artists as diverse as Brian Eno, Francois Morellet, Simon Penny [31] and Marvin Minsky [33, 34]. Roman Verostko's *Algorithmic Fine Art: Composing a Visual Arts Score* (pp.131-136) [35] claims that algorithmic processes in the production of designs has burgeoned in the last quarter of the Twentieth Century due to computational possibilities, a view corroborated by Ernest Edmonds. "The creation and control of these instructions [code for generating forms] provides an awesome means for an artist to employ form-growing concepts as an integral part of the creative process" [35]. Section 6 of this paper connects generative processes with environmental context as a means to retain social meaningfulness. The direct relation to sensate spaces is in the methodology for integrating environmental conditional data with generative designing.

6. ENVIRONMENTAL MODIFICATION OF EVOLUTIONARY GENERATIVE PROCESS

Generative processes provide the means for real time actualisation of sound creation. Environmental modification of, or interference in, the generative process shapes the generative outcome to be socially indicative. If the representation is then sufficiently metaphorical to be widely understood, the outcome is also socially meaningful.

6.1 Integrating Evolutionary Design Methodologies with Social Indicators to Reflect the Environment

The potential for utilising evolutionary design lies in the relation between its generation and using environmental data as part of the initial values and fitness test for evolving designs and novel design. Genetic algorithms serve as a formative basis for idea/material generation. Genetic algorithms were developed by John Holland in an attempt to explain the adaptive processes of natural systems and to design artificial systems based upon natural systems [36-39]. So-called genetic art-forms and generative design are not new. Artists and designers, especially in visual domains (but also for sonic purposes) use stochastic principles and algorithmic interpolation to produce new variations and fresh material, e.g. Lorenz linear functions, Network growth drawing evolving designs to screen using Flash ActionScript [40, 41].

Two of the most important contemporary media artists, Christa Sommerer and Laurant Mignoneau (p.297) [42, 43] build on the alliance between art and technology. They pioneered the use of natural interfaces that, together with Artificial Life ("A-Life") [44] and evolutionary imaging techniques, allow people to interact with natural spaces and patterns (exotic worlds of luxuriant plants, swarms of butterflies, microcosmic organisms, growing ecologoies) applied to installations. Jon McCormack's *Future Garden* [44] is an installation in which the patterns displayed are generated using the algorithmic technique, *cellular automata,* also utilised by Creativity and Cognition Studios sound designer, Dave Burraston [45] to produce a continuous stream of permutations and evolving generative designs. McCormack's *Universal Zoologies* is an interconnected series of autonomous, self-generating, poetic 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 qualia of the natural world. The work creates a rich and elaborate visual space –of strange and numinous creatures that have been evolved through a complex process of rule-based selection. *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 [44]. Successive generations of artificial fauna tend to become more complex. Bernd Lintermann's *SonoMorphis* (ZKM, Karlsruhe, 1999) involves user interaction to perpetuate the mutation process. In building design and architectural processes, generative algorithms have been designed to provide multiple interpolations, i.e. for idea generation, e.g. Mike Rosenman and John Gero 'Evolving Designs by Generating Useful Complex Gene Structures' (p.345-364) [36] for generating house shape designs using different room configurations.

6.2 System Relations Sensate Environments

Bentley explains a simple interrelation between genetic processes and design, between creativity, optimisation and evolutionary forms utilising algorithmic knowledge based on biomorphic procedures (p.36) [36]. Genetic algorithms present just one way in which evolutionary and infinitesimal variations of design coordinates can be implemented. The interest and usefulness lies in the adaptation of the system to relevant virtual or sensate environment indicators – social and motion attributes or interaction. Initial values are derived from the sensate environment, and the fitness test and evaluation phases measure against current conditions in the environment. Below is an adaptation of Bentley's general architecture of evolutionary algorithms indicating opportunities to relate the evolutionary design to its context (Figure 5).The fitness function juncture in the computation is also the opportunity for human intervention if interactive control over the music is integrated with the system. In the domain of sound or music, some non-algorithmic controls can augment the outcome in order to offset any occurrences of repetitious or banal features. Sample variation, filters, time distortion and delay techniques serve to destabilise predictable processes without detracting from the sensed and social input in the generation process.

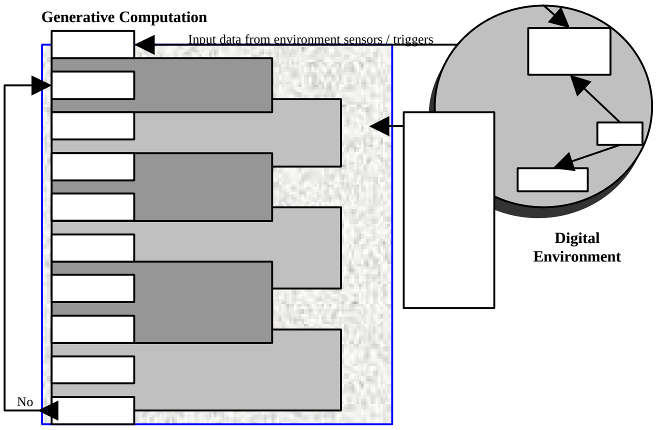

Figure 5. Modified architecture of evolutionary algorithms (p.28) [36]: initial values derived from the sensate environment (not random values), running the fitness function against criteria in the environment to ensure an interrelation between new growth and extant conditions.

An example of the way in which this modulation of the generative process might occur in evolutionary response to the sensed environment would be a situation in which the harmonic and pitch context remained relatively constant due to steady temperature and lighting conditions in an artificially controlled environment. Emergent novel ‘builds’ on different parameters would dominate perception. If the generative algorithm constantly measured against and affected by current conditions, large-scale shifts in sonic character might evolve as a clustering of parametric attributes concur due to the interrelatedness of the sensed physical and social traits, i.e. busy-ness, a temperature rise, more frequent incidences of unusual pressure exertion, higher indications of participants, greater traffic and increased interaction at key points, maybe even convergence in a specific zone are all likely and interrelated results of heavy population. This would have, in the scenario described, a combined effect on values generating sonic density (texture), pitch, harmony, tempo, timbre (tone colour) and initiation of recognisable distinctive events.

Further extrapolation of this genetic system to generate contextualised evolution could be manipulated by taking phenotype data and feeding it back into the genotype formative data. That is, like in the physical ‘real’ world, evolutionary transformations take place based on characteristics of the current generation (with latent inherent genetic qualities) rather than always originating from the primal source genes. A reflection of social morphology occurs in this way. This would be interesting applied to a social sensate space in which behaviours may change to reflect socially-influenced trends over long periods of time.

7. ‘EMBODIMENT’ / REPRESENTATION AND SOCIAL INFORMATION AURALISATION

In designing an auralisation of social behaviour, meaningfulness is expounded in the correspondences between domains and underlying metaphors of connection. One way to arrive at those correspondences is to have an underlying, interdisciplinary logic or mathematical generative process that is contextual but not domain-specific.

7.1 The Relation of Sound Design to Spatial Design

Thematic design makes the interface and environment more intelligible as well as providing a methodology for the environment designer [6]. Arbitrary warning signals, feedback sounds, even ambient music and landmarks can be themed according to the governing metaphors of the design. Relation of musical, sound and spatial design through shared or parallel parameters is established, for example correlations between musical and spatial (architectural) designs by Iannis Xenakis (composer and architectural assistant to Le Corbusier) [26]. Interdisciplinary relationships between designing sound and space and shared mathematical strategies demonstrate ways in which musical characteristics (pitch, tempo, rhythm, textural density, articulation, colour) connect with spatial dimensions and architectural characteristics (dimensions, materials, density, location). This forms the basis for translation between data sensed in the digital environment and its application to sound generation in real time [46, 47]. Designing space in architecture and in music are both three dimensional practices. While music operates predominantly in the dimensions of pitch/register, duration/rhythm and time, architectural design governs primarily the three geometric dimensions. Further parameters of condition such as colour, dynamic intensity (music) and texture apply to both. Stochastic rules of design in both disciplines are informed by a further interdisciplinary influence, i.e. rules of mathematics. Mathematical bases of both space and sound provide the computational connection between these domains.

7.2 Relation of Sound Design to Social Attributes

“Successful technologies are those that are in harmony with users’ needs. They must support relationships and activities that enrich the users’ experiences” [48]. Metaphoric designing of the sensate or virtual environment connects and adds meaning to the collection of web-based technologies forming the user’s experience. Parameters influencing sound generation derived from environmental and social sensors include: the number of users in a digital environment, interaction between users, constructive intensity, and proximity to sensor objects.

Edmonds emphasises the importance of correspondences between sounds and visual images in his Video Constructs in order for the structural relationship to be understood [25]. The reverse situation, a constructivist environment in which users actively aim to determine their experience can be observed in Edmonds’ *Communication Games* in which negotiating the logic generating computer response forms the substance of the game. Both the constructivist scenario and the responsive sensate environment rely on adequate recognition of correlations between spatial, visual and social data with experiential sound (or graphics). For these correspondences to be easily understood, direct metaphoric connections could be represented in ways explained in the following table of correspondences (by way of example) (Table 2).

Table 2. Correspondences between social/spatial environmental data and parameters of sound design, in which the auralisation will be affected by human behaviour in the sensate environment.

Social / Spatial Data	Auralisation Parameter	Variables/Range
Number of participants	Textural density (number of sonic events triggered)	Ranging from none/few to many sonic events: affecting complexity of sonic experience
Rate of motion / speed [49][4]	Tempo / velocity	Ranging in speed of realisation from slow to fast: affected by human motion/gestures in space or movement from one place to another within the sensate environment
Zone / Spatial location	*Timbral* (tone colour) effects	A range of filters on sonic process affecting colouration or sample utilised: affected by distinct spatial regions
Activity / busy-ness (motion tracked over) time	Rhythmic cells	Attributes characterising the generation of rhythmic cells classified by internal complexity (perceived activity)
Traffic at key juncture & Proximity to key objects	Pitch	As sound quality and particulars of pitch result from generative processes, ranges of pitches, group rules equivalent to notions of frequency create distinctions
Unusual pressure exertion (jump/stamp/impact)	Distinctive Event trigger	Specific aural events or algorithms prompted by significant environmental impacts
Lighting & temperature in the environment	'Key' / harmonic orientation of samples and generative pitch subsets	Rules affecting combinations of pitch produce harmonic inflections. Different variables in the algorithm can be assigned to degrees in temperature variation or measured in lumens for lighting intensity

8. DISCUSSION

Generative sound production addresses several aspects of sound design in dynamic multi-user environments: real time realisation, relevance and contextualisation, innovation and change (creative interest), originality of content for copyright purposes and, above all, as an indicator of environmental conditions. Utilising genetic algorithmic processes to produce new generations or material is itself not innovative but the connection between its derivations and the source environment gives a new relevance, immediacy and importance to sound design for sensate and digital environments. Seeking to address ambient and informative sound design in virtual environments and sensate environments builds up the hitherto neglected auditory realm of communication and interaction in digital spaces. This provides feedback about the participation and movement in the environment (both social and interactive). The group of applied contexts for navigational cues and environmental generative sounds include online (multi-user), synchronous virtual environments and digital installation spaces (e.g. intelligent rooms, virtual reality and immersive environments) - an emerging and growing field for contextualisation. The outcomes of a sensed generative sound system will develop greater social awareness for users. Relation to the environment, location and to other participants is articulated in the sonic design. Sensate environments are new, emerging spaces with rapidly developing technological and social potential. Sensate spaces require new strategies for meaningful design reflecting social interaction.

[4] Composer Iannis Xenakis, drawing correspondences between mathematical, spatial and musical representation, utilises stochastic processes to determine speeds of pitch slides, accelerating or decelerating, distribution calculated on the basis of density of concurrent mobile sounds. Speeds are mobile entities and hierarchy is isotropic - producing symmetry. Xenakis used Gaussian distribution applies and Boltzmann's kinetic theory of gases to establish the probability of speed. Xenakis, I., *Formalized music: thought and mathematics in composition*. 1971, Bloomington: Indiana University Press. x, 273.

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