# ~~Not~~ What We Think: Sensate Machines for Rewiring

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## ABSTRACT

The design of programmed spatio-material environments can be conceptualized as providing new stimuli with which to rewire the human brain in the context of architectural design. The plasticity of the brain is now recognised by neuroscience – the brain can be teased to inform, continually learn and restructure itself. As a driver for stimuli that rewire behavioural and cognitive patterns, a cognitive architecture 4EA approach is employed ('embodied, embedded, enacted, extended, affected') to inform the design of digitally manufactured and interactive prototype environments that become sensate machines. We introduce a 4EA design framework, combining approaches from computational architectural design, human-computer interaction and choreography, for the design of environments in which novel cognitive experiences arise from interaction between network components. A series of creative works from the Black Project is presented as case studies exemplifying our 4EA design framework, furthering investigations into how to collaboratively design, manufacture and choreograph sensate machines for rewiring cognition through creative engagement by performers and audience alike.

### Author Keywords
4EA; body; choreography; design framework; interaction; interdisciplinary design; kinetic environment; neuroplasticity; parametric architecture; sensate machine

### ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

J.5. Arts and Humanities: Architecture.

### General Terms
Design.

## INTRODUCTION

In the new design landscape where computation and materiality collide, the boundaries between bodies, machines and environment are being called into question. Previously the digital and the physical realms could be considered separately, but this is changing as computational design processes generate new physical forms and computation becomes embedded in material objects (computational/coded materiality). Our bodies are being reconstituted as the environments we inhabit and the objects we interact with begin to exhibit new properties and behaviours of an animated, kinetic nature.

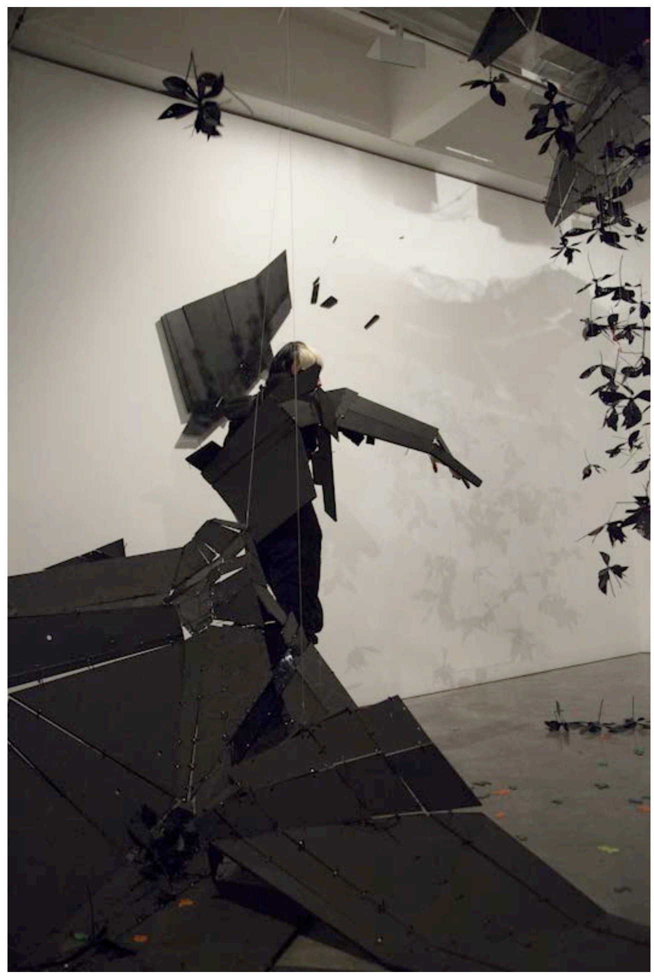

**Figure 1. Sensate machine - Black Spring**

Contemporary architecture addresses spatial interaction primarily through a performativity of the architectural body itself [9, 14], whereby aspects of the human body, and its experience and sensation of space, are marginalized. Human-computer interaction design (where by definition, human experience is central to its concerns) has outlined a challenge in the programming and behaviour of tangible materials for interaction [3]. In both fields, a rethinking of boundaries (between body, movement, space, material, modules, code) can act as a springboard for new design approaches resulting in the production of programmed spatio-material environments for novel cognitive experiences. Instead of developing architectural envelopes to be inhabited by bodies, we are developing what we call ‘sensate machines’ (Figure 1), by which the human body enters an engagement with its environment that goes way beyond mere inhabitation: a stimulative, interdependent relationship.

While interaction arguably has become a material for design itself [10], the notion of cognitive rewiring as a design driver in and through the brain’s plasticity has not yet been widely explored. Recent findings in neuroscience point to the plasticity of the brain and its ability to adapt to new stimuli and situations through neural rewiring [2]. So how then can interaction be conceptualized in order to support rewiring? We propose a cognitive architecture [5] 4EA approach in order to address these concerns and to derive a design framework for a novel approach towards interaction and computational architectural design. In the 4EA approach, *interaction* is viewed as the fundamental constituting mechanism in human cognition, where human beings are individuated as singular patterns of somatic, neural and social interaction [15]. These patterns are not fixed, but open to a forming and re-forming of relations, through continual interaction with the physical, social and cultural world. As a design approach, it focuses attention on establishing negotiable boundary conditions that invite affective engagement and the potential for new cognitive experiences.

In this paper, we introduce our 4EA design framework. A series of creative works from the *Black Project* is presented as case studies exemplifying our approach, furthering investigations into how to collaboratively design, manufacture and choreograph sensate machines for rewiring cognition through creative engagement by performers and audience alike. In the following sections, current issues in computational architectural design and human-computer interaction with respect to how the body and cognition are understood sets the scene for elaborating our 4EA approach. An overview of the 4EA approach as understood in cognitive science provides the key concepts for the translation of the cognitive architecture 4EA approach into our cross-disciplinary design framework. Architecture, human-computer interaction and choreography are brought together in the pursuit of understanding how to design sensate machines for rewiring cognition. We discuss a series of creative works that deploy complex network systems modelled through 4EA thinking. The network is envisioned as a complex system of component parts and relationships between a manufactured topography, human bodies and programmed kinetic objects, combined with programming and processing through digital data in an interactive, responsive and choreographed environment. We conclude with the recognition that a shift from programmed material towards programmed behaviour advances interaction as the key to a 4EA approach for rewiring cognition.

## CURRENT ISSUES IN ARCHITECTURE AND HUMAN-COMPUTER INTERACTION

In the field of contemporary architecture, parametric and algorithmic processes have become available to organize materials through mathematical protocols deployed to solve design constraints (e.g., object, context, material, shape, cost criteria). These protocols provide a language that describes variation in a design process, so that generations of design solutions can be firstly established and secondly analysed, so as to: embed a continuous information flow; allow control over materials and shape; and optimise design from planning to production process [9, 1]. Generative design derives highly complex, non-typological morphologies of an architectural object that is the result of a formation process [13], by which different internal and external forces (e.g., contextual change, growth, pressure, erosion) can interact on the same object, leading to transformations and evolutions of form. Yet this □systemic delay□ of design variations [16] is necessarily □frozen□ in the construction phase, allowing no latency, ambiguity or capacity for change: effectively contributing to architecture□s □ethics of statics□ [12], by which the architectural body is privileged over the human body occupying the spatial envelope. Current architectural research is investigating more latent approaches partially through code and materiality [8], yet on a one-to-one interaction level or as small-scale prototypes.

Contemporary architecture addresses performativity [9, 14], but of the architecture as an object, not primarily as an environment stimulating spatial experience. While there has been suggestions that a spatial complexity that arises through latent materiality [4] can be used to inform processes by continued exposure to context parameters (linking body, movement, space through material, modules, code), there has been no in-depth research on how to design this. This research aims at developing a descriptive language that runs from design to fabrication, to occupation, in which interaction and behaviour is a major impact on design. Current 3D modelling and scripting software predominantly propagates changes within a system, which translates into informing shaping material as a fundamental condition for production processes – yet they can further inform the behaviour of the responsive space itself. Effectively, in which way a full cycle of coding, fabrication and repeated choreographed processes affects form and aesthetics of architectural design, is not yet widely explored.

The evolving field of human-computer interaction (HCI) has embraced various models of cognition over the past several decades, with a recent turn towards models of embodied cognition. Previous models of the human as an information processor based on computationalism were predominant during the early years of HCI. Psychological theories of perception and cognition were instrumental in understanding and devising interface design principles that have become established practice in the design of graphical user interfaces. Studies of workplace practice looked to theories of distributed cognition [6], in order to understand how thinking and decision-making were distributed over a network of people, places and artefacts, rather than located in a single mind. Dourish's (2001) program for HCI of embodied interaction utilized the philosophy of phenomenology and theories of embodied cognition to highlight our embodiment and situatedness in the world [3]. He proposed embodied interaction as the foundation for tangible, ubiquitous and social computing, where meaning is achieved through (physical and social) interaction in the world.

With the advent of computational materiality, new possibilities for material and machine behaviour, autonomy and expression challenge existing paradigms of the body-machine relationship – and how to design for it. The material expression of digital data and processes shifts the focus from virtual worlds to programmed spatio-material environments. With the addition of electronic actuation, material components can be programmed to move and exhibit kinetic behaviours. This emergent trend towards animate behaviours of objects and surfaces in our everyday built environment, already signalled by the ubiquitous computing paradigm [20], invites a rethinking of the relational and interaction possibilities between body and machine. How the body and machine are figured and configured together [17] takes on a new relevance for the design of programmed spatio-material environments intended for creative engagement and expression.

## COGNITIVE SCIENCE AND NEUROPLASTICITY

Cognitive science has offered different concepts for understanding the processing between brain-mind and the environment. Computationalism models cognition as rule-bound manipulation of discrete symbols passing to a central processing unit (i.e., Von Neumann Architecture), whereas connectionism models it on neural networks - parallel distributed processing through a network [15, 18]. Cognition is understood as a change in network properties; strength and number of connections.

Both have been criticised for overlooking the embeddedness of the embodied organism in its environment. A third approach is the enactive, that of the 'embodied mind' or 4EA ('embodied, embedded, enacted, extended, affected'), which views interaction between an organism and its environment as fundamental to cognition [18]. Instead of a representational view of the world or mere information processing, cognition is understood as direct/directed action of an individual in its environment [15]. Or in dynamical systems terms, as real-time interaction of a distributed and differential system composed of brain, body and world (ibid.)

In the 4EA approach as interpreted by Protevi (2010), humans are patterns of interaction [15]. Instead of being individuated as individual substances endowed with properties, human beings are individuated as singular patterns of somatic, neural and social interaction. Process over substance. These patterns are not fixed, but open to a forming and re-forming of relations, through continual interaction with the physical, social and cultural world. The self is no longer considered as a fixed, determinate entity, but as an interactive process (ibid.), with the possibility of creative encounters that allow for a re-crafting of self and identity.

Recent findings in neuroscience point to the plasticity of the brain and its ability to adapt to new stimuli and situations through neural rewiring [2]. The adult brain is no longer viewed as a stable and unchanging entity, but is able to change its neural structure and function into old age. Given that 'lines that fire together wire together' [2], new cognitive experiences can be signalled long into adulthood after behavioural patterns have been learned, and can be continuously rewired; updated, retrained. Wexler (2008) highlights the social nature of cognition and the intense socially mediated neuroplasticity of our brains during childhood, where the brain is shaped to the major recurring features of the (cultural) environment [21, 22]. He also raises the flipside of adult cognition, where reduced neuroplasticity results in adults seeking to shape the environment to fit with established internal cognitive structures.

Our species exclusively specifies the sensory input essential to maintain cognitive and neural vitality and functionality: we alone shape and reshape the tools and environments that shape our brains [22]. The implications this raises for design are interesting, as it suggests that the objects, systems and environments we design can have profound impacts on our cognitive capacities. The design of *sensate machines* can be conceptualized as providing new environments and stimuli with which to re-pattern the brain. The way in which data, stimuli and interaction develops is hereby critical.

Complexity, diversity and asynchronicity are key characteristics in the sensing and making sense of our world, and the continuous adaptation to contextual, social, and media impacts. Moreover, cognition and creativity are not only intricately linked, but stimulative to each other. In the current, increasingly computational habitual environments, both the complexity and temporality of network spaces poses an interesting challenge. From our perspective, the 4EA approach can give an important impulse towards both the conceptualisation and programming of designed environments. When applied as a thinking frame for a potential rewiring of neural lines, the cognitive approach of 4EA can be deployed as a toolset that instigates new ways of sensing and experiencing – through interaction that is 'embodied, embedded, enacted, extended, affected'. The 4EA approach brings to the fore our capacity for learning and self-development as intrinsically linked to the environments we live in, be they 'natural' or 'designed'.

## DEVELOPING A 4EA DESIGN FRAMEWORK

We translate the theoretical principles proffered by the 4EA approach into a nascent design framework that recognises and promotes the creative potential for cognitive rewiring (viz. neuroplasticity) engendered by our interactions in designed environments. Table 1 contains our working definitions of the 4EA cognitive principles and Table 2 our applied design strategies. Note that there is not a simple one-one mapping between the cognitive principles and our design strategies. These principles act as a motivator for the design strategies and decisions we apply in the creation of designed environments for human interaction. We embrace a cross-disciplinary approach to design, combining computational architectural design with human-centred interaction design and choreographic strategies. Our design framework promotes a re-thinking of architectural environments, not as static structures with pre-defined functions, but as dynamic networks engendering patterns of interaction and behaviour with the potential for creative cognitive rewiring. This perspective re-introduces the body/brain as central to our understandings of the experience of architectural space – and simultaneously recognises the interplay between body, brain and environment that underlies cognition.

The framework provides an overarching conceptual orientation within which specific design processes, methods and tools are continually developed to fit the goals of concrete design projects. By adopting this framework, we aim to design multiple interactive pathways into a designed environment through the manipulation of relationships between hybrid elements in a network. The network is a

| 4EA cognitive principle | Working definition |
|---|---|
| Embodied | The body is central to cognition. It is our instrument for perception and mediator of the world. Our embodied capacities develop in a history of social and environmental interaction. Embodied interaction creates opportunities for self- and social- reconstruction. Learning takes place through curiosity and creative engagement. |
| Embedded | Human beings are deeply embedded in their environments. Cognition is understood as arising from the interactions and relational structures between organism and world. The environment acts as a constraint in shaping our behaviours. |
| Enacted | Cognition arises through action in the world. Humans only come into being through interactive, enactive processes. Humans as patterns of somatic, neural and social interaction. |
| Extended | Human cognition is extended, amplified and transformed through the instruments it couples to the body. The body is in prosthetic symbiosis with the tools and systems we construct. Interactive processes re-negotiate boundaries. |
| Affected | The body is a first register of environmental information. The sensations that arise upon meeting the boundary of the world produce cognitive and somatic affect. |

**Table 1. 4EA Design framework principles**

| Dimension | 4EA Design strategy |
|---|---|
| **Space** | 1. Architectural topography generated by computational design creates a new environment for shaping behaviour and rewiring cognition (beyond inhabitation). Mutant forms of familiar things trigger curiosity. Ambiguous forms enable multi-layered contextual interpretations. |
| **Material** | 2. Novel material behaviours demand a re-thinking of our habitual actions and responses, setting the stage for potential rewiring. Kinetic properties of materials result in material expression of designed behaviour of sensate machines. |
| **Code** | 3. Programmed behaviour of sensate machines ranges from autonomous to interactive. A choreographic approach is utilized to conceptualise and implement expressive behaviours. |
| **Interaction** | 4. Choreographic patterns of actual and potential behaviours provide an evolving archive of programmed and emergent interactions for performers and audience. |
| **Body** | 5. New stimuli produced by design produce cognitive and somatic affect. Evaluation of human felt (bodily) experience of interactions and space feeds back into research and design process. |

**Table 2. 4EA Design Framework design strategies**

dynamic structure, able to form and re-form through programmed behaviours and spontaneous interaction. The environments we design are a composite of digitally fabricated materials, electronics and code, exhibiting kinetic and interactive behaviours.

Beyond an incorporation of parametric modelling of geometric deformation resulting from a potential of material flexibility, the research addresses the structuring and further realisation of enclosures by material assembly – an approach exploring the incorporation of material performance combining different levels of actuation. This actuation calls into question the human impact (sensation, affect) through processes occurring when material performance engages with the choreographed, narrative movement of a dancer.

For the purposes of our research, we differentiate between human interactions of a trained performer and an un-initiated interactor (or user). The design of the interactive behaviours is developed through working with a choreographer or trained performers in order to construct a rich set of coherent, fluid patterns of interaction distributed over the human-machine boundaries. These form the basis of a set of patterns for further elaboration by un-initiated interactors, resulting in emergent patterns of interaction.

Choreography invites a poetics of interaction in conceptualizing the kinds of human experience offered by these new environments, departing from screen-based content and interactivity, towards linkages and stimulations between material expressions and behavioural response (as much of the architectural system as of its occupational network). The relations between performer and environment are foregrounded in the choreography.

The design context of a concrete project imposes specific requirements and constraints on the design process. Site, context and aesthetic, thematic drivers all contribute to the final form of a given sensate machine prototype. Design proceeds through an iterative combination of a) computational design of the material structures of the environment; b) choreography of the potential interactive behaviours; and c) experimentation of code and hardware (sensors for sensing, actuators for expression/action).

The prototypes serve multiple purposes: (a) as embodiments of the design concepts, articulating built form and behaviour responses; (b) as sensate machines offering tangible artefacts with which to interrogate and probe understandings of perception and cognition in interactive choreographed spaces, and (c) as public topographies for critical engagement.

A key aim in the research is to explore how computation in designed systems can parallel the choreographed behaviour, link it to a simulation of material response, and incorporate it as an integral part of the process. This research proposition is admittedly speculative and suggestive, but as a research probe asks questions in regards to sensate machines. In which way can relationships between the animate and inanimate be programmed? What protocols between component parts can be established, and what strategies for designing spatio-temporal continuums can be derived?

In order to begin to answer these questions, we created a series of prototype sensate machines in the *Black Project*. This project explored a network of connections between design (intent, approach, formulation), computation (abstraction, representation, model of development), fabrication (control, fabrication techniques, realisation), resulting space (topography/environment), and user (user experience, interaction and behaviour, cognitive and somatic affect). A description of the prototype sensate machines is given in the following.

## APPLYING THE FRAMEWORK – THE BLACK PROJECT

The *Black Project* deploys the capacity of swarm logic for processing change through interaction and dynamic behaviour [7], and in doing so, challenges the simplicity and homogeneity of current tectonic settings or organizational figures. In order to be responsive, experiential and adaptable, a swarm system needs to submit to a number of principles. The system is ideally composed of simple parts in a network of dense interconnection. Random encounters and interactions form a pattern that delivers a meta-information about behaviour – of the group, because if dependent on the individual it would remain a senseless assemblage of fragmented information.

These encounters, the transfers and transactions, form the primary mechanism of swarm logic that establish and administer territory and social context. When a number of components form a swarm, this transient, ephemeral society of the many behaves (reacts, acts, responds) individually and in synchronized response. The swarm integrates diverse entities in a field condition or territory while respecting the identity of each. Behavioural response is initiated by signal and frequency that act as a factor of determination. When the signal changes, behaviour changes. Yet the swarm interacts as one unit. Such a complex system is based on a persistence of the whole over time, a behaviour that outlasts its component parts (the individual).

We apply the concept of the swarm in conceptualising and generating a dynamic network of relations, and suggest how the 4EA principles can be interpreted in a hybrid system composed of bodies and components of natural and artificial origins. In a field of such component groups, form matters, but not so much the shape of the whole, but the form of a network that interlinks parts. This can be described as an interval between determined boundaries of material substance, or shifting stoppages or points in time. The interval connects agents and elements on the same field, in the same space, in one organization.

## Black Spring

*Black Spring* is an installation composed of a digitally fabricated topography made out of timber and perspex, connected to an array of suspended polypropylene 'flowers' whose movements can be controlled through programmable electronics. It functions as an interactive environment responsive to audience presence and has a separate mode for choreographed performance. It was exhibited in the Digital Interdisciplinations exhibition, Tin Sheds Gallery, Sydney, Australia in August 2012[1].

In *Black Spring*, a 3D model derived through computational design acts as the departure point and base reference to identify territory and boundary conditions of all component groups. This model has a twofold role in bridging between a diverse array of virtual and actual environments; by acting as a relational composition used to simulate material form generations; and as a programmable landscape that establishes control over a sensate environment.

Its topography follows on precedents set by structures that are self-forming through catenary behaviour, whereby a virtual mesh is set up through determined points, its crossings then are interconnected in contour line, and through force impact (gravity) a shape is generated (form induced through material properties and response). By using these relatively simple parametric tools, the topography simulates material deformation so as to provide the geometry, and is further manipulated to form centres of density for the choreography. The topography is informed by two sets of data (Figure 2). Firstly, contour lines on the fabricated manifold (laser-cut topography) organize material response, by which the segmented planes allow the surface to respond in degree to adjustments in spacing (height/width of voids) in space (set by the installation field).

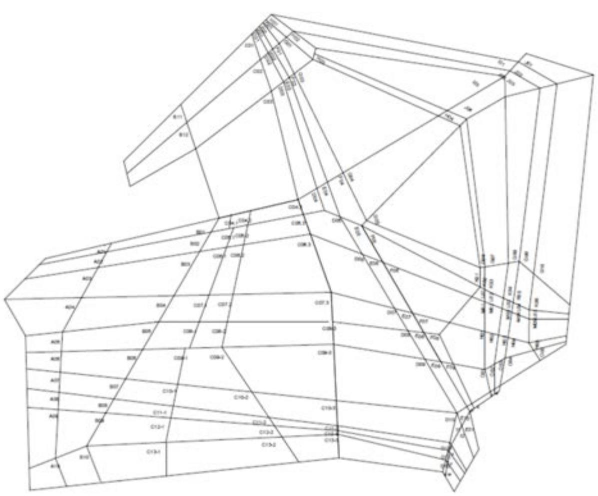

**Figure 2. Black Spring: topography**

[1] https://vimeo.com/64446752

**Figure 3. Black Spring: flower (detail)**

**Figure 4. Black Spring: swarm of diverse components**

Secondly, an imprinted system of perforations acts as a reference point for the 'virtual' topography that organises the flower modules, and enables these modular elements to respond to program signal in height changes. The flowers are a diverse component group assembled of minor variations of petals (Figure 3, Figure 4), partially equipped with reflective stems (perspex) and light emitting sources

(LED lights). These are connected to a set of servo-motors mounted above the structure, which pull tension cables that are threaded through the entire planes of the installation. The relationship between the tension cable and motor allows for an actuation (in adjustment in height, by degree) that takes into account the variable individual expression of floral bodies, their weight, directionality, dimension and rotational capacity.

The bridge between the physical installation and its virtual counterpart (the programmed behaviour and response) is enabled through continual actuation and interaction through motion and movement. In the first phase of development, motion in the flowers is deployed as a continual internal re-calibration of a movement that corresponds to the structural deformation through gravity. It is an autonomous kinetic behaviour, with no input from the environment. The potential for engaging curiosity is limited (Figure 5), but can be further extended through adding interactivity.

In the second phase, the behaviour of the installation is stimulated by a choreographed body and its states of posture and dissolution (Figure 6). The space was divided into four distinct spatial zones used to trigger different machine responses based on how we programmed the use of the input data. The sensing zones could be resized and were used in conjunction with a choreographic toolset [11]. A Kinect motion sensor acts here as the input device by skeleton tracking, and its data is used to vary the kinetic behaviour of the flowers that respond in swarm-like behaviours (with a solitary flower presiding over a segment of the landscape, apart from the swarm). Again, the movements of the flowers are controlled by servo-motor actuators.

In *Black Spring*, different sets of programming component groups were tested. In this manner, programming behaviour is coupled with material understanding, and thus informs the actuation of the kinetic structure to work intelligently with changing physical paths and gestures. Relationships between the animate and inanimate remain relatively simple, programmable yet ultimately limited to set responses, with a closed spatial continuum due to programmed pattern behaviours.

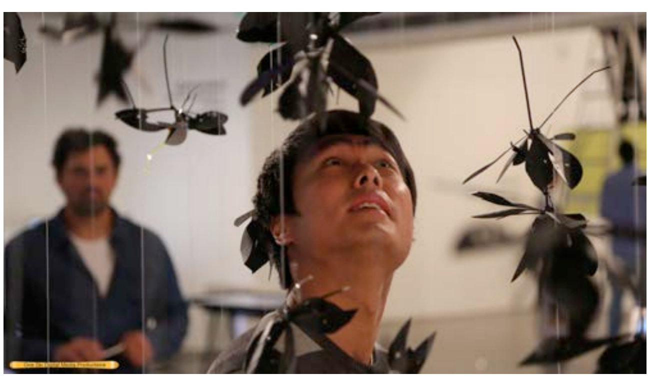

**Figure 5. Black Spring: audience engagement**

**Figure 6. Black Spring: movement behaviour (dancer)**

### Black Shroud

*Black Shroud* is the continuation of the previously described installation with decreased project parameters. It functions as an interactive environment responsive to audience presence, and was exhibited in the Organised Cacophony exhibition, Rocks Pop-up, Sydney in November 2012. Whereas *Black Spring* used a complex topography designed between the programmed behaviour and a digitally manufactured topography, this installation instead uses a clean canvas of a grid (2m x 2m) that is connected to an array of identical polypropylene 'flowers' (Figure 7) whose movement is electronically programmed, and responsive through motion sensors.

Similar to the previous work, *Black Shroud* also uses the transfers between virtual and actual environments, yet more significance is given to the temporal relationships in the network. A homogenous component group is assembled of multiplied flowers from identical petals, and hung in identical height relative to a virtual reference plane (Figure 8). These are set up again connected to a set of servo-motors mounted above the structure, which pull tension cables that are threaded through the entire planes of the installation.

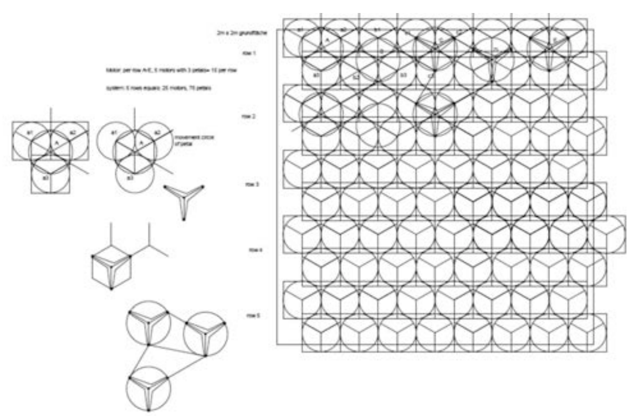

**Figure 7. Black Shroud: topography**

**Figure 8. Black Shroud: homogeneous components**

The relationship between the tension cable and motor allows for an actuation (in adjustment in height, by degree) by a servo-motor. Where in *Black Spring* a multiple complex network is initiated, *Black Shroud* seeks to establish a quiet, meditative environment that is unfolding as a choreographed movement between the dancer, its memorized traces and the spontaneous enactment by audience (and potential clashes between). Emergent patterns of interaction and behaviour generated by audience may deviate from the original choreography.

This prototype links the embodied movement of a dancer in a delineated space via embedded movement through programming to an enacted responsive behaviour of the flowers. A Kinect motion sensor acts here also as the input device, where data are used to link the kinetic behaviour of the flowers to the memorized choreography of the virtual landscape. Multiple pathways of motion (dancer, flowers, audience) are thus set in correspondence with each other, traced, memorized and actuated, each time controlled by servo-motor actuators. Each time new movement is mapped onto the experiential space of the spectator, cognitive behaviour is affected while passing through the choreographed space.

## DISCUSSION

Both prototypes of the *Black Project* employ components designed to work together seamlessly to support a performance setting, in which the notion of 'becoming part' with the (digitally manufactured, programmed and animated) environment through a 'sensate machining' acts as focus. In both installations, behaviour is explored through an interdisciplinary, iterative and collaborative exchange between the disciplines of computational architectural design, human-computer interaction and choreography. Table 3 contains a summary comparison of both prototypes within the 4EA design framework.

*Black Spring* is generated as a complex, open arrangement of different component groups (topography, flowers, audience) that are partially autonomous, and partially interactive. Swarm behaviour is here extended to a maximum of component parameters that invests in complexity, temporality and asynchronicity. Beyond maintaining a geometrical position, characteristics, or assignment, the flowers move to an invisible code, a dancer bends and twists, establishing a second layer of audience engagement through subversive behaviour.

| **4EA design strategy - dimension** | **Black Spring** | **Black Shroud** |
|---|---|---|
| Space | Complex, hybrid topography as reference landscape. Topography contains vestiges of industrial references, such as aeroplane wings. | Uniform grid topography to highlight patterns of behaviours. |
| Material | Swarm of hybrid flower components. Multiple variations of mutant flowers. Actuation provides kinetic behaviour. | Uniform swarm of flowers. Single form of mutant flower. Actuation provides kinetic behaviour. |
| Code | The swarm takes on varying expressive qualities in relation to where the performer is positioned, through a choreographic collaboration between interaction designer, programmer and choreographer. | The quality of the swarm of flowers takes on energetic states ranging from trembling to convulsing, in relation to where the performer is positioned, through a choreographic collaboration between interaction designer, programmer and choreographer. |
| Interaction | Choreographed performance leaves potential traces for audience to discover. The choreography is informed by the notion of the human 'becoming part of' – a merging with the apocalyptic landscape. | Choreographed performance leaves potential traces for audience to discover. The choreography is informed by the notion of a meditative shroud, which shifts from a relation of refuge to something more menacing. |
| Body | The performer's experience is utilised in the choreographic process, in an iterative manner to find the balance between what the performer does (in terms of movement), what the performer perceives and feels, and the expressive quality of the swarm. Note that future research will include audience experience in this process, as a vital component of understanding the cognitive and somatic affect produced by the designed environment. | |

**Table 3. Comparison of Black Spring and Black Shroud prototypes within the 4EA design framework**

The prosthetic/parasitic flowers refuse support function and demonstrate a life and will of their own; the dancer registers as a hybrid between topography and device; thus affecting practice and progression of the choreography. The procession of the installation is terminated through dissipation, the exhaustion point of animated system members. *Black Shroud* refines the complex parameters of the previous system towards a semi-closed set made of one serial component, and movement interaction. Its flowers form in response to gestural invitation of the choreographed movement (dancer), and encapsulate the human in embrace.

Both prototypes aim to create new environments for creative engagement by audience, in which choreographed traces provide a set of patterns of potential interaction and behaviour that can be enacted and result in emergent patterns yielding novel cognitive experiences. It is important to note that through the development of a series of related prototypes, we are building up an archive of patterns of potential interaction and behaviour. As we develop more prototypes investigating varying dimensions of this 4EA approach, we add to the archive in a systematic manner.

An important point of difference in the making of the two prototypes is in the discourse that guided their process of creative collaboration and design development. *Black Spring* deployed interdisciplinary dialogue in a linear manner to engage creativity: from parametric virtual topography through computational design, to digital fabrication, to additional sensor implementation, to programming response, and finally programming interactivity. *Black Shroud,* in contrast, is founded on a dialogue that collaboratively engaged interdisciplinary expertise from the very start. The sensate machine and its autonomous/interactive behaviour is the first consideration, from which all other design activities flow. This is significant because with a change in thematic drivers, a shift in research takes place from prototype to later prototype. Whereas in *Black Spring* the 3D model acted as a springboard for program implementation, in *Black Shroud* the programmed behaviour itself became the shared language by which embodiment, embeddedness, enactment, extensions and affect can be brought forward, and in doing so promotes the previously discussed 4EA approach towards cognitive engagement. Our next move is to continue this experimentation by re-introducing a more complex topography, while maintaining a focus on programming behaviours so that the interactive and relational potentials for engagement are primary.

Specifically for the research, the recognition of this shift from programmed material to programmed behaviour leads to a major rethinking of how to rewire cognitive patterns for audience engagement from our perspective: the potential for creative engagement increases with the connectivity and flexibility of diverse components (bodies, movement, objects, trajectories). Our sensate machines extend the programmed machine that behaves in predetermined ways, towards a multiple complex behaviour of the unexpected; the machine inside the machine [19] that is capable of stimulating new relationships. True to von Foerster's discussion of non-trivial machines (whereby the output continuously varies), here the audience find their bodies as part of an ongoing equation of events, that is, the expected behaviour is informed by individual input that translates into asynchronous behaviour, enclosing each new body in a newly formed topography, whereby each new 'dancer' contributes to the choreography: Not what you think – but what you create.

## CONCLUSION

This paper has presented a first approach towards establishing a 4EA design framework, combining strategies of computational architectural design, human-computer interaction and choreography. The cognitive architecture 4EA approach to understanding human cognition as embodied, embedded, enacted, extended and affected – that is, as fundamentally constituted through interaction with the world – provides a theoretical foundation for our proposed design approach. Based on the premise that the environments we shape in turn shape our brains, our position is that the creation of programmed spatio-material environments – or sensate (cognitive, stimulative) machines – offers new stimuli for human interaction, experience and potentially, cognitive rewiring. We demonstrated the application of our design framework through the presentation of two prototype sensate machines that investigated networks of component parts and relationships between a manufactured topography, human bodies and animate material objects, combined with programming and processing through digital data.

One of the objectives of our research is to experiment with the application and sequencing of methods in the design process, in order to understand the effects of design process variables upon the produced environment. Through this permutation, we can generate variants of sensate machines informed by the 4EA approach, resulting in a corpus of works that demonstrate what is possible by conceptualising interactive, spatio-material environments as networks shaping and stimulating human cognition. The prototypes are an early demonstration of the recognition that a shift from programmed material towards programmed behaviour advances interaction as the key to a 4EA approach for rewiring cognition. While a more in-depth research is yet to be conducted, these initial sensate machines allowed us explore open behaviour for the implementation and response to a wider range of cognition and experience, thus approaching the enhancing and rewiring of human cognition through creative engagement.

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