Relational architectures and wearable space:

Smart schools and the politics of ubiquitous sensation

Abstract
This paper undertakes an analysis of the "smart school" as a building that both senses and manages bodies through sensory data. The authors argue that smart schools produce a situation of ubiquitous sensation, in which learning environments are continuously sensed, regulated, and controlled through complex sensory ecosystems and data infrastructures. This includes the consideration of ethical and political issues associated with the collection of biometric and environmental data in schools, and the implications for the design and operation of learning environments which are increasingly regulated through decentralised sensor networks. Working through a relational and adaptive theory of architecture, the authors explore ways of intervening in smart schools through the reconceptualization of sensor technologies as "atmospheric media" that operate within a distributed ecology of sensation that exceeds the limited bandwidth of the human senses. Drawing on recent projects in contemporary art, architecture, and interaction design, the authors discuss specific architectural interventions that foreground the atmospheric qualities and ethical problematics of sensor technologies in school buildings.

Key Words: school architecture; smart buildings; sensory technologies; biosocial research; ecology; atmospheric media

Introduction

Young people are growing up within a vastly expanded sensory ecology, as sensor technologies are increasingly emplaced within buildings, embedded in smart phones, worn on bodies, mounted on rooftops, orbiting in satellites, submerged in soil, and connected to plant and animal life. It is estimated that there are currently more automated sensors connected to the internet than human beings (Tironi, 2017: 2), as operations of sensing become increasingly "spread out and distributed across an array of devices, an array that is becoming more and more complex." (McCormack, 2018: 52). This redistribution of sensation through 21st century media technologies can be understood, following Gabrys (2016: 9-10), as a double movement. *Technologies are becoming environmental* as digital sensors become elemental components of everyday spaces and life processes. At the same time, *environments are becoming computational* to the extent that they can be affectively shaped and algorithmically programmed to serve particular interests, agendas, and imaginaries.

Growing up in this altered "mixed reality" makes for new challenges in developing sensibilities about place, environment, and belonging. Although sensing technologies are increasingly embedded in UK schools and worn by students and teachers, the social and political implications of these technologies for school communities have yet to be substantively explored. At present there are no existing methodological, theoretical, or ethical frameworks to guide the use of sensors and sensor data in UK schools. The rapid integration of sensor technologies into everyday educational life suggests that formal and informal learning environments are becoming critical sites for understanding the complex entanglements of biological, digital, sensory, and social milieus (de Freitas and Rousell, 2018).

This paper engages with the widespread development of smart schools across the UK, many of which are embedded with complex sensor networks that regulate learning environments through context-aware building management systems. These systems are capable of collecting and processing continuous streams of biometric and environmental data from school buildings and their inhabitants, including data collected from fingerprint scanners, facial recognition software, surveillance cameras, movement sensors, light sensors, and wearable biosensing technologies. Increasingly, biosensors are used to capture human gesture, movement, attention, facial expression, brain activity, galvanic skin response, heart rate, and breath. As anticipated in many ways by Deleuze (1992), the smart school shifts the very function of the school from one of disciplinary enclosure to one of modulation and distribution of data. Sensor technologies have the potential to render and influence "the position of any element within an open environment at any given instant" (7), enabling control to become a ubiquitous and atmospheric function of the environment itself. For Deleuze, this shift from disciplinary to environmental governance entails an associated dissembling of bodies into "dividuals" which can be ceaselessly divided into marketable and controllable "bits" or "data points".

In this paper we suggest that smart schools are producing a situation of "ubiquitous sensation", in which learning environments are continuously sensed, regulated, and controlled through complex sensory ecosystems and data infrastructures. We begin by discussing the history of UK smart schools as buildings that both sense and manage bodies through sensory data. This includes the consideration of ethical and political issues associated with the collection of biometric and environmental data in schools, and the implications for the design and operation of learning environments that are increasingly regulated through decentralised sensor networks (Gulson and Webb, 2018; Williamson, 2018). We then take up the concepts of "relational architecture" (Lozano-Hemmer, 2005) and "wearable space" (Hansen, 2006) in order to propose an alternative theoretical figuration of the smart school that departs from the typical technocratic one. We rethink sensor technologies as "atmospheric media" (Hansen, 2015) that operate through a "general ecology" of technics (Hörl, 2017).

While there is a growing body of research literature that critiques the environmental governance of sensation within smart schools (e.g. Williamson, 2014), we see an urgent need to investigate the potentials for political reclamation and redistribution of sensory data through architectural, artistic, and design-based interventions in schools (de Freitas, 2018a). Precisely because current applications serve neoliberal political agendas in the context of school architecture, we need to start thinking concretely about how to use sensor technologies differently for designing, modifying, and inventing learning environments that reclaim affective and somatic relationality (Coenen, Coorevitz, & Lievens, 2015). At the same time, we are wary that an uncritical embrace of 'relationality' is problematic if it functions to simply naturalize computation and support techno-governance in design and architecture (Parisi, 2017). Ours is not an attempt to dispel critiques of the computational logic informing smart schools, but to explore possible modes of intervention into the technical milieu. We discuss the example of *Cinder* (Umbrellium, 2018), a mixed-reality architectural interface that enables students to engage with the sensory infrastructure of a smart school in Cambridge, UK. *Cinder* takes the form of a virtual cat that "lives" in the building's sensory-digital networks and responds in real-time to the state of the building and its occupants. We selected this example because the school operates through an ecological sensibility, aiming for sustainability and the conservation of water and energy, and because the addition of Cinder intensifies the affective field, and draws attention to new kinds of biopower.

The Emergence of the Smart School

The figure of the smart school is increasingly used to describe educational buildings which are embedded with sensory and computational infrastructures capable of collecting and processing diverse forms of data and information (Williamson, 2015). In connection with the "smart cities" movement currently transforming urban environments and public space, the smart school is typically associated with the seamless integration of digital technology and architecture through efforts to improve the sustainability, adaptability, governance, and efficiency of learning environments (Montazami, Gaterell, & Nicol, 2015). As argued by Williamson (2014: 1), the smart school is being constituted as a "fabricated space" driven by a technocratic imaginary which aspires to govern and manage school buildings and their inhabitants through computational processing and algorithmic code. Recent constructions of the smart school within this technocratic imaginary often align with long-standing international initiatives for educational "optimization" through the improvement of school buildings, design, and technologies (see, for instance, Dudek, 2000; OECD, 2006; Hertzberger, 2008; Rivlin & Rothenberg, 1976; Willis, 2017). In the UK context, architecture has been a locus of policy hopes for improved educational futures at least since the open plan movement in the 1970s, through to ambitious programmes such as the Building Schools for the Future (BSF) in England, and similar initiatives elsewhere (Burke, Cunningham, & Grosvenor, 2010). Digital technology and new media have figured prominently within these future-oriented educational aspirations, as demonstrated through programmes such as FutureLab (NFER, 2017) and BECTA in the UK (Livingstone, 2012).

The recent uptake of technology-enhanced smart schools as a key engine of educational optimisation has been fueled by a series of significant policy initiatives in the UK context (Kraftl, 2012; Woolner et al 2007). As instantiated by the previous Labour government in 2003, the Building Schools for the Future (BFS) program proposed a £52 billion investment in the construction of technology-enhanced school buildings across England between 2005-2020 (Mahony, Hextall, & Richardson 2011). The BSF program was cancelled by the newly elected Coalition government in 2010, and has since been replaced by a drastically reduced initiative entitled the Priority School Building (PSB) program. To date the PSB program has strategically invested £4.4 billion in the refurbishment and technological enhancement of "schools in the worst condition across the country", with the explicit aim of "maximising every pound of the taxpayers' money" (Education Funding Agency, 2016). While the BSF and PSB programs reflect the centrality of smart schools in current policies for educational renewal across England, research into the lived experience of smart schools remains underdeveloped, and their potentials for educational transformation relatively unexplored (Daniels et al, 2018).

Despite the apparent gap between the future-reaching ambitions of Labour's BFS and the austerity measures of the PSB program that came to replace it, both initiatives reflect a neoliberal policy landscape that views smart schools as technology-enhanced "mechanisms" for the provision of 21st century education opportunities in the UK (Jacobs, 2015). Such mechanistic approaches to educational improvement and transformation are seen to operate as closed systems which impose predetermined design principles, imaginaries, and values on school communities from the outside (Woods, 2017). As such, both initiatives have suffered from a lack of research methods, theories, and evidence that adequately account for the interpenetrating factors of school building design, embodied educational practice, and 21st century media technologies (Gislason, 2010; Leiringer & Cardellino, 2011).

It's evident that the complex and increasingly dynamic relations between architecture, technology and education are under-theorised and overdetermined, such that smart schools are often positioned as both deterministically powerful and passively subservient: as visionary and transformative, yet also as mere vehicles of neoliberal policy and governance (Woods, 2017). This gap is further perpetuated by the lack of evidence as to how "smart" architectural visions and technologies are variously affirmed or disavowed by the vicissitudes of everyday life in schools (Cleveland and Fisher, 2014). Little is known about how smart buildings and technologies fit (or don't) with the lives, habits and expectations of students, families, school staff and local communities (Hall, 2017; Higgins et al 2005). There is also a need for studies focusing on the potentially transformative capacities of digital technologies in relation to school buildings and the everyday experiences of students and teachers (Burke, 2014).

Policy typically treats digital technologies as socially and educationally transformative instruments for optimising educational opportunity and fuelling future economic growth. As Gulson & Sellar (2019) note, in many cases education policy yoked to digital data infrastructures and computational systems of governance which are increasingly taking precedence over traditional educational objectives, such as quality pedagogy, curriculum, and assessment. In practice, digital technologies often remain circumscribed within mechanistic systems for 'delivering' the goals of predetermined objectives and reductive theories of learning, as coupled with the uncritical deployment of discourses associated with flexibility, optimisations, and personalisation (Dovey and Fisher, 2014). This is exemplified through current smart classroom initiatives by the Intel corporation which aim to personalise learning environments through the collection of facial, gestural, and behavioural data (Intel, 2019). The Intel system uses artificial intelligence to create personalised data profiles of students which can be immediately accessed by teachers, who are "armed with a dashboard providing real-time engagement analytics" (Intel, 2019). As described on Intel's website, the system uses "the computing power of Intel CPUs to support artificial intelligence innovations with deep learning capabilities that can now know users at a higher level – not merely interpreting user commands but also understanding user behaviours and emotions" (Intel, 2019). This example highlights the growing corporate investment in smart educational technologies capable of collecting and processing biometric data to support governmental agendas of optimisation and personalisation through distributed mechanisms of surveillance and control.

Relational Architectures

In attempting to think beyond predominant imaginaries of smart schools as mechanisms for technological optimisation and biopolitical governance, we take up the concept of "relational architecture" in re-orientating towards the experiential and speculative potentials of the built environment. The term "relational architecture" was coined by Mexican-Canadian artist Rafael Lozano-Hemmer in the mid-1990s to describe artworks "concerned with creating virtual openings in architecture, the city, the body, and technology" (Fernandez, 2007: p. 88). Relational architecture emphasizes how the built environment is both a means of controlling populations (keeping bodies in place) and a means of making bodies atmospheric – in other words, buildings can be made "to expose the body and society's receptivity to instability, fluctuation and re-imagining" (p. 87). Lozano-Hemmer (2005) describes how relational architecture involves a distinct shift from an imaginary of "interactivity" in which the building is meant to facilitate interaction amongst humans to an imaginary of "relationality" where that which is built is agentic and responsive.

Figure 1: *Articulated Intersect: Relational Architecture 18*, Rafael Lozano-Hemmer, Place des Festivals Montréal (2011). Source: Wikimedia Creative Commons

Whilst interactivity implies a vertical hierarchy of codes, commands, and controls that determine engagements between people, buildings, and technologies, relational architecture opens the very concept of architecture to a more lateral, ecological, and emergent series of relations that exceed predetermined intentions, designs, or mechanisms. Bodies, technologies, spaces, and times are understood as mutually affecting and co-constituting, as in the conceptual figure of the "architectural body" proposed by experimental architects Arakawa and Gins (2002). Examples of relational architectures designed by Lozano-Hemmer include *Body Movies: Relational Architecture 6* (2001), which projected large-scale shadows and portraits of moving participants onto cityscapes across North America and Europe; *Articulated Intersect: Relational Architecture 18* (2011-2014), which enabled participants to direct a canopy of searchlights over the cities of Hobart and Montreal using haptic levers (see Figure 1); and *Atmospheric Memory* (2019), an immersive exhibition of nine relational artworks at the Manchester International Festival exploring the confluence of digital, sensory, affective, and climatic atmospheres. Of particular relevance to our argument in this paper, *Atmospheric Memory* seeks to bring critical awareness to the ubiquitous capture of atmospheric data through sensory technologies, and attempts to offer more empowering and creative modes of relation with these technologies through immersive art experiences. Figure 2, for instance, shows a work from the exhibition entitled *Zoom Pavilion* which repurposed facial recognition technologies to elicit smiles from participants as their faces were remixed on the surfaces of the installation.

Figure 2: Detail from Lozano-Hemmer's *Zoom Pavilion*, part of the *Atmospheric Memory* exhibition at Manchester International Festival. Image Source: David Rousell.

These examples of relational architecture emphasize the scattered diffractive inhabiting of the environment, playing with surface, light and projection. We select these because they break with an all-engrossing computational logic – they open up the space rather than pay tribute to a technomediatic governance. The use of motion and facial sensors, projections and shadows seems to transform architectural surfaces into subtle but dynamic space of public intimacy, bringing the atmospheric qualities and capacities of digital sensing technologies up to the level of proprioceptive awareness, memory, and affective response. Projects like these avoid the crude materialism of smart architectural designs in which machinic matter is meant to flow naturally into the "becoming-environment of computation" (Parisi, 2017, p. 79). Instead, they emphasise the intricate entanglements between digital atmospheres and the technicities of the body and its massively distributed ecological networks.

Lozano-Hemmer's notion of relational architecture helps us to reconceptualise the possibilities of the smart school as a "distributed architecture of experience" (Massumi, 2011: 53) capable of generating complex and open-ended relations that re-animate the school. This shift from an interactive to a relational theory of architecture provokes a substantial revision of how learning environments might be conceived, constructed, experienced, and understood using 21st century media technologies and sensory data. In thinking beyond normative conceptions of the built environment as a physical container for managing human activity, we aim to consider the messy, contingent, and speculative dimensions of living and learning as dynamic and relational processes (de Freitas, 2011; Rousell, 2016). Thinking through a relational theory of bodies, technologies and buildings as mutually affecting, smart schools could become massively distributed ecological networks of people, data, places, times, buildings, concepts, thoughts, practices, technologies, materials, plants, feelings, interests, stories, desires, and more.

Ubiquitous sensation

The concept of relational architecture helps us to re-imagine the learning environment as an architectural *medium* and *milieu* that simultaneously constrains and affords the potentials for ecological growth, learning, and development (Rousell, 2019). And yet we are conscious of "the implicit moralism of this posthuman relationality" which often seems intent on rescuing a humanity through spreading its relations, finding itself again and again in its monstrous inventions and its alienated others (Colebrook, 2019, p.175). Celebrations of relationality can be rather self-serving ways of depoliticizing frictional encounters, failing to accept limits and incommensurables. Refusing to let being 'be' without relation is a way of colonizing the world with Humanist desire, part of the Kantian legacy of correlationism. The fruitful abstraction of a term like relationality often belies the ways in which it is lived in radically divergent ways. Such concerns are raised here especially in light of the new biopower at stake in sensor technology and smart architecture. This transformation emphasises the increasingly atmospheric "environmentality" of sensation, feeling, and thought through contemporary technological infrastructures and digital networks (Anderson and Ash, 2015; Hansen, 2015).

This reconceptualization of the learning environment becomes critical as 21st century media technologies such as WiFi, GPS, microsensing, and mobile computing become ubiquitous elements of everyday life in schools. Through these devices, architectural walls, screens, and objects become animate, increasingly sensitive and capable of mediating the molecular, biochemical, and semiotic "trafficking" of data across the porous membranes of human bodies and cells (Frost, 2016; Grönvall, Fritsch, and Vallgårda, 2016). WiFi signals, for instance, pass through the walls of buildings and human tissue alike, respecting no fixed boundary between body and environment. As Parisi (2009) argues, the environmental distribution of sensation between living bodies, buildings, and digital media is more than a computational network that simply processes 'information'. Rather, Parisi conceptualises these architectural networks as "technoecologies of sensation" which achieve a collective nexus of sensibility and dynamic response that moves seamlessly "between organic and inorganic matter" (p. 192). Dynamically mediated streams of sensory data become diffuse, elemental, and atmospheric, opening onto a massively distributed environmental sensibility rather than remaining tied to individual bodies as processers of information and perception (de Freitas, 2018b). We are no longer dealing with nodes and connections in a network, but rather with the atmospheric conditioning of a climate of thought, sensation, and technicity. Considered as complex sensory ecosystems that operate through the ubiquitous biomediation of life processes, smart schools have the potential to support the cultivation of an atmospheric "data-sense" that plugs directly into the "microtemporal qualities of experience" (Hansen, 2015, p. 132).

One of the drivers of such an atmospheric reading of 21st century learning environments is the recognition that digital sensing technologies do most of their work outside the narrow bandwidth of human perception. In many cases, the technical operations that digital technologies use to sense, calculate, and mediate our environments do not correspond with human sense perception or cognitive capacities at all. Hansen (2015) describes how 21st century media technologies operate at micro-temporal processing speeds that take place above and below the thresholds of human consciousness and sense perception. Rather than being prosthetic extensions of human embodiment and perception, digital media technologies physically and directly transform the environment by altering its "causal infrastructure" and reconfiguring the conditions under which human sense experience becomes possible (p. 38). This is because digital sensing technologies "impact the environment - including our bodily environment - before impacting … our higher-order sensory and perceptual faculties" (p. 38).

Digital sensing technologies are seen to mediate, reconfigure, and *co-produce* the sensible conditions under which learning takes shape in many contemporary environments. Sensors take on a new figuration as atmospheric, elemental, and distributed agential forces which are not reducible to anything that humans can directly sense, perceive, or know. As a hallmark of what many are terming a "posthuman" condition (Braidotti, 2013) and posthuman ecology (Braidotti & Bignall, 2018), this increasing depersonalisation of sensory data corresponds with a radically environmental account of human learning, sociality, experience, and subjectivity (Hansen, 2015), while also foregrounding the emergence of what we term a "politics of ubiquitous sensation". Such a politics seeks to describe the environmental redistribution of power relations through an ecology in which the technical is inextricable from the social, the biological, and the atmospheric. Hörl (2017: 4-5) describes this as the emergence of a "general ecology" that is denaturalised, technologized, and deterritorialised, aligning on the one hand with technocratic controlling surveillance and on the other with posthumanist aspirations for a radical ontology and ethics of relationality. Related to our points above, the term "general ecology" documents the spread of relationality across everything, emptying the term ecology of its distinctive access to natural processes. As Neyrat (2017) explains, ecological thinking of this kind seems incapable of imagining an 'outside' or something that might refuse to be in relation, something utterly alien and incommensurable.

Wearable Space

As a response to the biopolitics of this situation, we seek examples where affective computing and wearable sensors are used to break with conventions of control and prediction. How can we repurpose this data, which is presented as biological data produced in real time, including electro-dermal skin activity, heart rate, body temperature, and rates of motion and activity that are associated with changes in affective responses and emotional states (Pijeira-Diaz et al, 2016; Sano & Picard, 2013). The mobile and non-invasive nature of such technologies means that they can be somewhat easily integrated into everyday patterns of learning and behavior in schools, opening up a wide range of both controlling and *creative* possibilities for modulating and intervening in the environ/mentality of school life.

Responding to the increasingly dispersed and atmospheric nature of technology in the 21st century, Hansen (2006: 177) argues that "architecture must reconceive its function for the digital age … it must embrace its potential to bring space and body together in the creation of 'wearable space'". Wearable space is produced through the "interlacing of body and architectural space" in ways that enable reciprocal patterns of interaction and response between bodies, digital interfaces, and architectural surrounds (183). As an architectural space that is constructed through "the interaction of wearable and spatially embedded interfaces", wearable space enables the body to become "part of the architectural landscape, extending to digital dimensions" (Samdanis, Kim, and Lee, 2012: 2). Early examples of wearable space often include the construction of immersive environments associated with virtual and mixed reality interfaces, pervasive computational networks, wearable biotechnologies and environmental sensors that record and transmit biological data in real time.

While little research can be found that has applied wearable biosensors to intervene in school architectures, interfaces between biotechnologies and architectural environments are currently being developed in the emerging field of 'adaptive architecture' (Schnädelbach, Glover, & Irune, 2010). As described by Schnädelbach (2010: 1), the field of adaptive architecture is concerned with designing sensitive spaces that adapt to their surrounding environs, bodily inhabitants, and affective dimensions, less as a functional ideal that serves efficiency, and more as a way of opening up buildings for encounters and experiments. The field thus pushes away from the smart building paradigm, towards collaboration between disciplines such as architecture, art, engineering, computer science, cognitive psychology, and robotics (Schnädelbach et al, 2014; Schnädelbach, 2011).

Working in the Mixed Reality Lab at the University of Nottingham, Jäger et al (2017: 1) have designed a number of adaptive architectural experiments using 'real-time physiological data to respond directly to the bodily behaviours of their occupants'. These include prototype environments that kinetically respond to changing patterns of bodily movement, respiration, electrodermal skin response, and body temperature, among other biological variables, not for enhancing control and prediction but for the purposes of increasing sensitivities and awareness of how envelopment and inhabitation are sensed (Schnädelbach *et al*., 2012). *ExoBuilding*, for example, is an environment that enables complex biofeedback relationships between bodies and architectural space, an environment that quite literally incorporates its occupant's biodata into its physical structure, fabric, and behaviour. It's a small-scale experiment that involves various sensors and a tent-like structure. Breath sensors are used to modulate the environment through the shifting breathing patterns of occupants in real time. Inhalation makes the tent-like environment expand while exhalation contracts the environment, with additional sensors worn by the occupant also modulating atmospheric elements of lighting and sound. Drawing on 4EA (Embodied, Embedded, Enactive, Extended, and Affective) models of situated and distributed cognition (Jäger et al, 2017), *Exobuilding* aims to establish new forms of "interbodily resonance" between human bodies and architectural environments (see Figure 2). Interbodily resonance is typically used to describe the pre-cognitive modulation of sensorial relations between two or more people through micro-adjustments in bodily expression (Froese and Fuchs, 2012). *ExoBuilding* extends this concept to the relations between the body and architectural space, such that micro-adjustments in the pre-cognitive expression of the body enter into resonance with physical changes in the enveloping environment. The continuous adjustment and modulation of pre-cognitive relations between body and environment “eventually establishes an autonomous process” which neither the human nor the environment directly intend, program, or control (Jäger et al, 2017: 523).

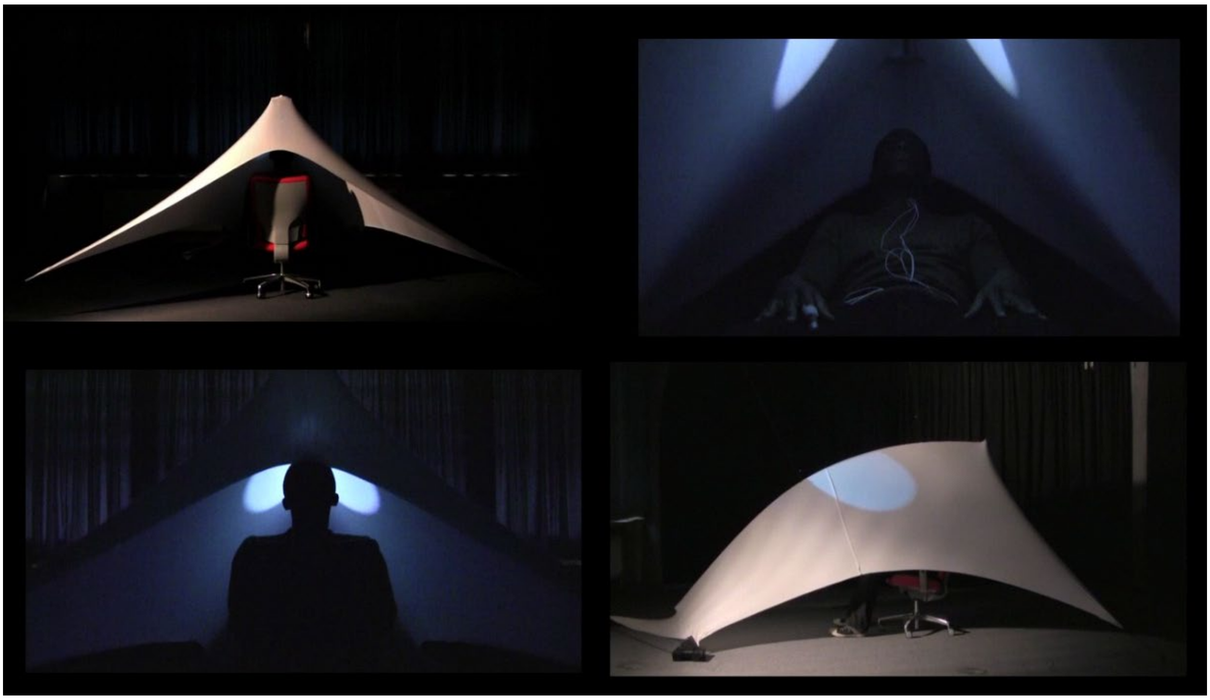

Figure 2: *Exobuilding*, a prototype architectural space that contracts and expands in response to breath sensors worn by occupants

More recently, Jäger et al (2019) have used the model of interbodily resonance to explore the potentials for two occupants to enhance interpersonal synchrony through adaptive environmental modulation. *WABI* is a prototype of an adaptive environment developed by Jäger et al that facilitates synchronized breath patterns between occupants collocated in adaptive environments (see Figure 3). WABI allows the same physiological interactions described above for *ExoBuilding*, however, it also enables each occupant to be immersed in the data of the co-present other, increasing pre-cognitive awareness and enabling occupants to synchronise behaviour and sustain complex patterns of interbodily resonance. Both *ExoBuilding* and *WABI* gesture towards new possibilities for learning environments that promote resonance between bodies and architectural space. Experimental evaluations performed by Jäger et al (2018; 2019) demonstrate that both prototype environments are capable of inducing meditative and relaxed physical states as occupants synchronise their breathing in relation to the adaptive fabric of the space.

Figure 3: (left) *WABI* interior with two facing chairs under a gently curved fabric structure; (right) exterior of *WABI*, showing two separate sections of the environment.

While we appreciate the ethical objectives of achieving resonance and relaxation through these inventive architectural prototypes, we also see some limitations with their underpinning phenomenological model, particularly the appeal to interbodily resonance as the basis for experimenting with the relations between bodies and environments. We can imagine how such experiments could all too easily be coopted by the control society, with interbodily resonance potentially used as a model to induce bodies into particular states and dispositions in service of externally-imposed agendas.

The concept of ubiquitous sensation offers a more atmospheric framing of body-environment relations that does not assume the phenomenological boundedness of sensory-percepto-motor functioning. Our argument is that sensing is not the preserve of human bodies, but is spread out across a relational and antagonistic ecology that is no less technical for being animate and agentic. For this reason, we see *Exobuilding* and *WABI* as initial forays into breathable space, but we worry that it simply affirms a desire for homogeneous resonance across bodies. In other words, it is not yet clear how these experiments might be scaled to cultivate pluralisms and diverse bodying processes, rather than convergence to a collective (human) norm through inter-bodily resonance induced via breath resonance. As we seek experiments that dig into the somatic and affective dimension of ecological relationality, it is important to attend to the *bodily struggle* of sympathetic coordination (de Freitas, 2018b). This shifts resonance away from a coming together in sameness, orienting instead toward the quivering differences that sustain complex social-material ecologies. We see a need to further pursue a relational and process-oriented philosophy of technology that shifts the ground significantly in how we might further develop these kinds of interventions (de Freitas & Rousell, 2018). Crucially, this approach understands technics as inherent to sensing (human and non-human), and therefore conceives sensing as a collectively distributed operation that enables agents of all kinds to endure, form relations, learn, and achieve different values. It is hard to contest the claim that this proliferation of linkages serves the interests of technocapital, by expanding connectivity and circuits of exchange. Wearable space is primed for technogovernance, opening up new paths for regulation and control, but these small-scale experiments in architectural space stand-alone as opportunities to think through and debate the uses of sensor technologies.

Cinder the sensitive cat

In this section we undertake a more detailed analysis of a mixed reality architectural intervention called *Cinder*, which was installed in a newly built smart school in Cambridge in 2016. The school has been designed and constructed using principles of open plan, sustainable, and adaptive design, including the use of natural ventilation and day lighting combined with photovoltaic panels and ground source heat pumps to maximise energy efficiency. The building's energy use is managed and regulated by a customised Building Management System (BMS), which also collects and archives data on the building's environmental functioning. Students are able to interact with the BMS through *Cinder*, a virtual cat created by London design firm Umbrellium (2018) that changes its size and behavior depending on the building's energy collection and consumption on a daily basis (see Figure 4).

Figure 4: Students interacting with Cinder through a mixed reality "mirror" installed in the atrium of the Cambridge school. Source: Umbrellium (2018).

The cat operates as a kind of interactive mascot or avatar who responds in real-time to the building's environmental conditions, which are in part modified by the collective data of the students as well as other aspects of the milieu, such as diurnal and seasonal patterns. She also responds to individual student interaction. Students can dance or engage with her in the school atrium, as reflected in the augmented reality mirror inserted into that space. She may shrink or seem lethargic if there is little energy being collected by the solar panels on the roof of the building, or if there is too much water being used throughout the day. The cat's behaviour becomes a signal of whether or not the building is using energy in a conservative and sustainable manner, while also operating as an affective interface enabling students to develop new forms of relation with the building through its sensory data.

We focus on this example here because of the ethical and political implications of the intervention, its capacity to cultivate affective bonds between students and the building, and its specific focus on sensitivity to the environment. This focus on sustainability was requested by the school leaders, as part of their commitment to educating students about conservation of energy, and more specifically about the energy-conserving aspects of the building. "We [wanted] to give students and staff an insight into, and understanding of, the building they work and play in," said Usman Haque, from the design company that created Cinder for the school (BBC, 2016). Because Cinder's behaviour and appearance is actually affected by real-time sensor data, and by how people interact with her, she is an example of a *digital life* trapped in the building or on student laptops. The students thus relate to her as a kind of virtual pet belonging to the augmented environment. She is friendly and purring on some occasions and at other times she scampers away, in search of "food" when the sustainable energy sources are sensed as diminished. Through consultations with the students and staff, Umbrellium designed something that achieves a certain *animacy* insofar as it is responsive to the environment and to human interaction. Cinder only intimates the appearance of organic life, and yet she takes on a powerful agentic quality in the school. As the designers explain, the cat is not a mere visualization of pre-existing data, nor just a daily report of progress:

> The thing we have created is quite complex – we can't make the cat 'go to this location' or 'behave like this' because it's programmed to respond almost with a personality. The building manifests itself through the cat and having a character means it's not just a bland visualization. (Cambridge News, 2016)

Moreover, Cinder was intended to cultivate a certain responsibility on the part of the students, as they were then partially responsible for her care. The ethical framing of Cinder is incredibly complex for these reasons. She is cute and cuddly, and plays with the affections of the students, precisely in order to induce particular kinds of behaviour. As a cat, she is both present and yet unavailable, vanishing into the network and then suddenly re-appearing, or disappearing into the materiality of the mirror when the power is shut down. Students bond with such pet avatars and become increasingly dependent on the interaction. The aims of the developer were linked to this interest in affective connection, and the possibility of transforming habits. As Umbrellium states:

> This project should stay in this junior high school for at least ten years. We don't want it to be a work of art in space, we don't want it either to be a game. We really want it to be a virtual animal, that the pupils embrace, take care of, make it grow. (Makery, 2016)

This is an example of an adaptive architectural intervention, attending to and indeed giving voice to the distributed agencies of an augmented reality. Cinder clearly aims to build new kinds of relationality with the built environment using sensor technology, and intensifies the affective field. She is not simply an art installation, as she joins the school community, quite literally. Nor is she presented as part of a gamification of school buildings, where one might imagine enticing student participation in ways that involved competing for cat attention. Cinder is a collectively mediated electric feline, responding to the *collective* socio-material achievements of the building. There is an ethics of care and an ethics of shared responsibility that she is meant to promote. Nevertheless, her influence on the students is effectively a kind of behavioural control, achieved via their desire to sustain a relationship with her. She acts as both an instrument and an instantiation of the school's sensor-driven Building Management System (BMS), extending the managerial hand of the BMS from the building to the bodies that inhabit it. Cinder expands the programmability of the school building through affective modulations that are designed to shape and modify human behaviour in very particular ways. Perhaps in this case, the sustainability objectives seem to trump concerns about how this kind of intervention aims to control behaviour through desire and affect.

Our analysis of Cinder demonstrates the importance of keeping ethical concerns front and centre when we consider ubiquitous sensing, and young people's vulnerability in an affect economy that is increasingly distributed through digital networks. Cinder works precisely because young people are already completely immersed in digital social networks, engaging with digital devices 24-7, and increasingly sensitive to the circulation of affect through these systems. Young people today labour in the affect economy, their biopower tapped and circulated through social networks. The use of digital characterisations like Cinder is a way of plugging into the potential affective intensity of the students, to access either their anxiety about sustainability or their affection for the cat. We are all too conscious of how Cinder is a controlling agent in the school, operating as a form of 21st century media, easily mobilized to serve the control society. On the other hand, we see Cinder as a positive intervention insofar as her activity represents a reasoned response to the accepted scientific consensus regarding climate change, energy use, and the role of human activity in altering planetary-scale processes. In other words, it matters that she is pursuing objectives for the building that are based in what are now established scientific perspectives and sustainability principles, rather than being based on nationalist values that contravene these principles. Of course science can be wrong (in fact, that is one of its operating principles), and often misguided and misapplied, but it is precisely by bringing science into the embodied and everyday experiences of students, through in this case sensor technologies and augmented reality, that smart schools can raise awareness of how science is a matter of tracking and mutating relationships and non-human agencies (Latour, 2017).

Relationality and the Outside

If we take a wider perspective, situating the smart school in a larger context, we also begin to see several limitations of Cinder's implementation of sensor technologies. The sensors through which she lives are linked to both urban energy networks and solar fluctuations, as well as archaic sewage and water systems in the nearby streets, and distant water supplies. Cinder is more than a cute little cat. She represents a powerful node in a complex political and material network of energy resources. If we trace the material links, we can see how she is connected to the community, the earth, and beyond to the sun, but not adequately to other less affluent communities. She is a contracted node of informatics and energetics. But she is programmed to enact the conditions of the school in terms of predetermined agendas and ideals, and her responsiveness to other nodes in these larger networks is essentially absent. In other words, her sensory capacities are programmed to serve the building exclusively, and do not extend into the wider networks of political association.

The current instantiation of Cinder is too inward-facing, and so the building achieves a limited kind of relationality associated with the self-maintenance of a closed system. A more expansive and open kind of relational architecture would involve a risky diplomacy with the outside. If the current version of Cinder gives back to these more expansive networks, it is only after the needs of the building have been met. We can imagine a second generation Cinder linked in with her feline siblings in other buildings, so that they might work collaboratively across the energy network (much like an Internet of Things). Not only would this help distribute resources across different schools, in a more equitable way, but it would help the students realize that their school building's sensory coordinates are linked to an outside that has divergent or contrasting demands. This would make the relational architecture more robust in an important sense, because the needs of the outside would become palpable within the building, in the form of other Cinders across the city. Another problem with the current Cinder is that she offers rather simple "causal stories" to the students about the environment. One of the primary aims of relational architecture is to play with the boundary of inside/outside, to better realize the ways in which envelopments of all kinds are carved out of atmospheric space replete with competing agencies. As Fernandez (2007: 83) suggests, Lozano-Hemmer's work opens the interiority of bodies and architectural spaces to the outside through a "logic of technologically facilitated relationality". This means that relational architectures play with the human need and tendency to envelop through architecture, but at the same time trouble the desire for such containments. In the case of Cinder, students are induced into a certain anxiety about whether they will be able to sustain the interior of the building, given limited exterior resources. This is consistent with conventional sustainability discourses aimed at inducing behavioural modifications in order to “improve” or “optimise” the management of a system. The challenge is to flip that feeling so that the palpable, tangible, and perceptible qualities of ecological relationality are felt not only as here and now, and for *us*, but for the “total environment” of an Earth and cosmos, in all its diversity.

Indeed, we can imagine a third generation Cinder, a more atmospheric object, that might not be so focused on sustaining the building through envelopment (sustaining its own inside). We are a species intent on enveloping ourselves in buildings, and no doubt human survival has depended on that. However, a more-than-human future may demand a more atmospheric and planetary approach (Clarke, 2018). We can envision a future Cinder immanent within networks well beyond the building and the city, a Cinder who channels the messages of rivers, compost sites, and interstellar sources linked through vast sensorial meshworks. We offer this here as a speculative thought experiment, and because we must continue to think about the technical capacities of sensor technologies as participating in “interface envelopes” where different agents and agencies are drawn into affective relation (Ash, 2013). We suggest that virtual mascots like Cinder enact a kind of “envelope-power” by drawing agents into affective and measured engagement, and cultivating a palpable atmosphere around them. McCormack (2018) describes this as the making of “new spacetimes of allure” (p.75). The history of smart buildings points to this intensifying envelope-power achieved by way of mixed-reality. The famous mirror dome erected in the Pepsi Pavilion in 1970 was an early example of a saturated technical and responsive environment, a “self-modulating ambient environment in which everything had the capacity to mediate everything else … an experiment in generating atmospheric allure by acting upon environmental infrastructures of sensing that operate outside and prior to conscious attention.” (McCormack, 2018: 69). Thus developments today in smart school designs and interventions can be seen as part of this recent history, exploring intersections between physiological capacities of human bodies and architectural spaces within an emerging political paradigm of ubiquitous sensation.

Concluding thoughts

This paper has worked to develop an alternative conceptual and practical vocabulary for analysing the ethical and political implications of ubiquitous sensory interfaces within smart schools. We suggest that relational ways of thinking about sensation and technics are necessary as we grapple with 21st century media within such environments. The concept of “relational architecture” has helped us to rethink 21st century learning environments, attending to the expansive sensitivities of bodies, technologies, and buildings. On the other hand, we’ve discussed how excessive advocacy for relationality serves technocapitalist interests and tends to see everything – no matter its refusal – as an opportunity for being in relation. We’ve used the emerging field of adaptive architecture to think differently about the technological couplings between bodies and architecture space. We have examined a few examples, discussing the degree to which these achieve a relational architecture. We've selected these examples because in our estimation they are creative and quite powerful, but ethically enigmatic. We've offered affirmative critique, pointing out limitations and possible paths for further development.

Most relevant to biosocial concerns, the examples underscore a new biopolitics of feeling whereby the sensitivities of the (white) civilized subject are enhanced and valorized as part of techno-capitalism. The "impressibility of the civilized body" is cultivated as part of the affective field (the capacity to affect and be affected), and reflects a growing interest in "general ecology" and epigenetics (Schuller, 2018: 4). These non-innocent developments track the body's differential capacity of feeling and emotional experience, as well as its physiological capacities to be responsive, recapitulating nineteenth century racist investments in the particularities of "impressible corporeality". Relevant to this debate is Deleuze's (1992) concept of *modulation* as a function of distributed environmental control, operating like a mold that continuously changes form, or "like a sieve whose mesh will transmute from point to point" (4). Both examples of Exo-Building and Cinder discussed in the paper operate through the fluid modulation, induction, and shaping of behaviour, sensation, and affective states, despite the clear direction of these modulations toward defendable goals of mindfulness and sustainability.

In concluding, we want to emphasize that analyses of biosensors and smart schools that stop at critique fail to produce a way out of the quagmire (de Freitas, 2016). Cinder for instance is extremely valuable as an example of an intervention developed in a small start up (Umbrellium, 2018) guided by social and ethical objectives to raise awareness of energy conservation. Our critique is affirmative in nature, in that we want to see such applications further developed. Exo-building is also an innovative experiment that plays creatively with the very ideas of building and envelopment. Our affirmative critique of these projects is meant to raise awareness of how affective resonance and pre-conscious coordination don't only entail a moduluation of sameness or stale mimicry (achieved through feedback), but can also entail a fundamental heterogeneity and transductive tension that is just as crucial (if not more crucial) in sustaining complex learning ecologies (Braidotti & Bignall, 2018; Simondon, 2017). We need to find ways to study the dynamics of that tension. These two examples are both artful methods for thinking differently about the use of sensors in the built environment. Since sensors are already widely deployed in schools, and there is every indication that this implementation will continue to accelerate according to neoliberal imaginaries of optimisation, we encourage similar kinds of innovative experiments. Critical analyses, re-imaginings, thought experiments, *and* physical interventions are required in order to materialise empowering learning environments.

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