Title
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ABSTRACT

"Smart city" narratives promise IoT data-driven innovations leveraging biosensing technologies. We argue this overlooks a potential benefit of city living: affirmation. We designed the Heart Sounds Bench, which listens to and amplifies the heart sounds of those sitting on it, as well as recording and playing back the heart sounds of previous sitters. We outline our design intent to invite rest, reflection, and recognition of others' lives in public space. We share results from a study with 19 participants. Participants expressed feeling connected to a shared life energy including others and the environment, and described heart sounds as feeling intimate yet anonymous. Finally, we elaborate the concept of *life-affirmation* in terms of *recognition* of others' lives, feeling *connection*, and respecting difference with *opacity*, as a way of helping "smart city" designs embrace a multiplicity of desires.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI);

KEYWORDS

Biosensing, affirmation, smart city, heart sounds, heartrate, public space, bench

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Figure 1: The Heart Sounds Bench amplifies the heart sounds of bench-sitters, inviting a moment of calm yet vibrant life-affirmation.

1 INTRODUCTION

Smart city narratives "aim to evoke positive change and innovation–at least as the proponents see it–via digital ICT; essentially, building an IoT at the city-scale by installing networked objects throughout the urban environment (and even human bodies) for a wide range of different purposes" [142]. These narratives promise improved efficiency, safety, fitness, sustainability, and civic participation, often relying on data [3, 19, 22, 50, 54, 55, 57, 102, 114, 142, 149, 166]. Biosensing technologies–sensors measuring humans and the accompany data, models, predictions, and insights–undergird many smart city IoT applications. For example, video surveillance can detect heartrate [131], correlated with future involvement in violent crime [108], or percentages of joy, contempt, and anger [1]. Wearable trackers promote individual workplace efficiency [9], physical fitness [6], emotional wellness [5, 14], and self-improvement through algorithmically suggested behavioral micro-nudges [148]. Sidewalk Labs plans to revamp citing living with smart city sensing and technology [12, 13, 68, 81, 112]. Knightscope robots patrol parking lots, and sometimes public space, using sensors to detect and report 'anomalies' as security risks that often conflate the existence of homeless people with criminal activity [8, 33, 73, 154, 172].

Critiquing this, Nissenbaum argues that such pervasive surveillance is unjust and tyrannical [124]. Regarding Sidewalk Labs, Crawford cautions against such in-depth intervention by a single company into civic infrastructure [36]. Sadowski and Pasquale critique the smart city ideal, tracing free market ideology that seeks to "spread market logics to all dimensions of human life" while "focusing on the narrow goals of promoting transparency and efficiency" [142]. Our work critiques and explores alternatives to these problematic smart city narratives through design research by engaging the heart sounds bench as a probe [26].

De Lange and de Waal outline a key tension in smart cities: "The challenge therefore in our view is to balance these stories of personalization and efficiency on the one hand and of building collectives based on differences and mutualism on the other hand" [42]. Urban sensing can be used for personalization and efficiency, smoothing over difference for sameness, but an alternative role for urban sensing could be more like visionary urban scholar Jacobs' call for cities to celebrate "a great and exuberant richness of differences and possibilities, many of these differences unique and unpredictable and all the more valuable because they are" [98, p. 220-1]. Shifting from 'smart cities' to 'social cities' [42], we contribute a design probing affective experiences of affirmation and connection while respectfully engaging difference.

Widespread biosensing in daily life makes data- and algorithmic judgments about people's physical un/fitness, mental un/wellness, and criminal/terrorist risk [91]. These categories are far from neutral: one side is 'normal' and one side is 'other'. The 'other' category is usually seen as suboptimal, in need of improvement, control, or discipline, or as something to be feared. This can contribute to *otherization*, a process whereby people come to be viewed as intrinsically different and alien [11, 143] (e.g., racism, Islamophobia). While data-driven approaches including biosensing often claim to escape social prejudice with objective insights, they can instead reify pre-existing stereotypes and bolster structural inequality with a false sheen of scientific authority [3, 17, 18, 29, 31, 32, 53, 125]. Our work engages biosensing in ways that challenge the need for data-driven categorization by presenting heart *sounds* without filtering or analysis.

Our work sits at the intersection of smart city narratives and affective computing, seeking to reconfigure both. Affective Computing seeks to automatically 'detect' human emotions in terms of discrete data-driven categories [15]. This risks flattening difference by claiming that such categories are universally generalized [26], and furthering otherization around emotional un/wellness [91]. At the same time, HCI is undergoing an affective turn whereby research seeks not only to support functional tasks, but also affective experiences, construed more broadly than Affective Computing's discrete categories of emotion, such as playfulness, reflection, or slowness [16, 63, 77, 128, 152]. Our work investigates how smart city sensing technologies may shape the affective experiences of city living while at the same time challenging the data-driven categorization prevalent in affective computing, by fostering a slow emotional experience with biosensory data that does not rely on data-driven categorization.

Being in public space can fulfill emotional desires not directly related to prevalent smart city narratives. Sometimes people want to get out and about, to see and be seen. As city planners and architects are well aware, the design of urban space influences the kinds of social interactions therein [171]. Contrasting the normative categorization of many urban sensing technologies, we focus on the particular affective experience of *affirmation* in public space.

2 AFFIRMATION

Affirmation, defined as "emotional support or encouragement" [2], has emerged as a design goal [91, 157, 173]. We outline how affirmation is lacking in prevalent smart city narratives, and contribute the Heart Sounds Bench as a design exploration of affirmation. Listening to one's own heart sounds, and those of another co-present bench-sitter, invites a quiet moment of listening, bodily awareness, and engagement with other(s). Analyzing the results of our study with 19 participants, we further contribute an elaboration of a concept we name *life-affirmation* in terms of *recognition*, *connection*, and *opacity*. Recognizing and feeling connected to the life and experience of others contributes to affirmation, while accepting the opacity of what we cannot know about others helps further recognize and affirm difference. We call for designers to continue exploring affective experiences of urban public space while embracing a multiplicity of desires.

Though perhaps not discussed in these terms, affirmation can occur in public space: The bus driver who stops because he sees someone running. The stranger on the bus who moves their bag to make room on the seat, or the one who provides directions. The shopkeeper who greets those entering, before a purchase has been made. Even walking on a crowded sidewalk requires sharing space, acknowledging one another's needs for passage. Of course, these daily affirmations of one's existence and needs are experienced unequally depending on privilege. As designers, we draw inspiration from mundane moments of affirmation, while remaining reflexive about our social position and social norms.

Smart city narratives often miss this notion of affirmation. The emphasis on economic exchange constructs its subjects in terms of their ability of to produce economic value by leveraging efficiency and fitness, affirming capital not people. Additionally, biosensing technologies' potential for otherization, especially regarding criminal risk, is not affirmative. The Heart Sounds Bench responds to what we feel is a lack of affirmation in prevalent smart city narratives.

The built environment can also feel affirmative. If not intentionally designed to be unpleasant [145], public benches affirm the needs of passerby to sit. Resting may not be not an efficient use of time or part of a fitness regime. Sitting on a bench might lead to being approached by strangers, which could be unsafe. A better economic exchange might require passerby to pay for a seat at a cafe. The Heart Sounds Bench celebrates and leverages the potential of public benches to contest the smart city emphasis on efficiency, fitness, safety, and economic exchange, instead affirming the existence and needs of passerby for a moment of rest.

3 RELATED WORK

Participatory sensing engages citizens in collecting data about civic issues such as air quality or for fostering curiosity, exploration, and discussion [106, 133, 134, 163, 164]. HCI is investigating fostering civic participation with smart city sensing [21, 22, 35, 37, 46, 48, 66, 74, 78, 101, 126, 135, 162]. Boehner and DiSalvo explored how civic tech is conceptualized by civic leaders [27]. Design artifacts can shape Deweyian publics [45] around political issues [49]. Public IoT is oriented toward communities, matters of concern, and matters of care [41, 47]. The Heart Sounds Bench is less about fostering discussion or participation in particular civic issues, and is more about the affective experience of being in public urban space.

Designers and city planners explore affective experiences of citing living. City Lab explores public interventions for building community [150]. Wallace et al. explored the hedonic pleasure of shopping on the high street with the Self-Reflector [168]. HCI has explored fostering community and curiosity in the smart city [24, 30, 132], exploring emotional reflection or emotional bonds with particular places [160, 161, 170], and supporting artistic critical interventions in urban space [60, 61, 105, 107]. Niemeyer's interactive urban lighting acknowledges passerby with colorful lights that follow them at night [123]. The Heart Sounds Bench builds on these explorations, looking particularly at the affective experience of affirmation.

Perhaps partly due to their affirmative potential, benches have been explored by designers and artists. Rogers' bold yellow benches provide comfortable seating [140]. Others design benches to encourage social interaction between strangers [43, 82, 104]. Grasso et al.'s interactive bench supports community emotional awareness [75]. Johnson's film documents the social life of benches [103]. Like other explorations, the Heart Sounds Bench has the potential to foster interactions between co-present strangers, because it can amplify the heart sounds of two sitters simultaneously. While this invitation exists, we also recognize that many might avoid sharing a bench with a stranger due to fear of harassment or violence. So, additionally, the Heart Sounds Bench records and later plays back heart sounds, suggesting a lingering presence to future sitters.

Somaesthetic design fosters directing attention inward for bodily awareness, often in a session set apart from daily life [88]. Somaesthetic design can leverage biosensors to help attune people to their bodies [87, 89, 120, 146]. Often a somatic connoisseur helps participants unpack and articulate their experiences after a session [147]. The Heart Sounds Bench in some ways builds on these practices, amplifying heart sounds to attune people to their own bodies. Yet, public space is immersed in daily life rather than separate from it, and lacks the guidance of a somatic connoisseur.

Listening can invite attention that we wanted to leverage to attune people to their bodies. Public sound art explores playful, critical, and expressive interactions in urban space. This includes mapping sensor input to audio output [62], collecting and looping snippets with a glove-based electret microphone [159], engaging cultural heritages through sound [58, 69, 70], or street art [76]. A variety of networked instruments support multi-person musical collaboration, (e.g., Ten-Hand Piano [23]). Transition Soundings is an interactive public sound installation built into a bus stop [25]. While these projects often explore social interactions or multisensory explorations with sound, the Heart Sounds Bench focuses on exploring the direct *sounds* of the heart, rather musical phrasings or the beats per minute typically used in self-tracking.

Biosensing is used to influence sound. Dancers wear biosensors on their bodies that translate their movements, heartrate, or other measures into parameters that are used to generate sound or influence the improvisation of musicians. For example, Jang outfitted a pair of dancers with strangely shaped bone-like back-worn sensors; the dancers gradually accept and explore one another's atypically shaped bodies [99, 100]. MacCallum and Naccarato explore issues of agency and control using dancers' heart rate to influence improvisation [110, 120]. Works such as these indicate the rich expressive possibilities of connecting bodies and sound. Our focus was to engage this expressive potential in a much more everyday setting with participants who may or may not have specialized movement or music training.

Oliveros' Heart Chant was a key inspiration for leveraging sound as a medium. In this participatory performance, people stand in a circle and sing long tones, with one hand on their chest and the other on the back of the adjacent person [127, 129]. The experience is slightly vulnerable because this close contact is atypical of the large personal space maintained in the U.S., and singing feels embarrassing for some. Through this structured, shared vulnerability emerges a feeling of affirmation as each person's voice and body are accepted as part of the co-performance.

Biosensing can influence interpersonal interactions. Heart rate has been engaged for physical games [111, 169], board games [56], gauging connectedness in conferencing systems [90], augmented mobile chat [80], or even broadcasting heart rate to online social networks [38]. Howell et al. found that an ambiguous clothing-based display of skin conductance had the potential to foster supportive social emotional reflection, but also to aggravate insecurities [93]. Eriksson et al. explored ritualized tangible representations of heartbeat for bereavement [52]. SlovÃąk et al. found that remote heart rate sharing between close pairs in daily life could foster a sense of connection [156]. ReactionBot automatically adds emoji to messages based on facial expressions [109], with the potential to prompt emotional reflection. Snyder et al. probed experiences and interpretations around a color-changing light composite display of a pair's skin conductance [158]. Engaging the expressive potential of sound, our design presents live unfiltered heart sounds for collocated strangers, not colors, metrics, haptics or visualizations as others do.

4 DESIGNING THE HEART SOUNDS BENCH

The Heart Sounds Bench is a reflective design [152] intended to provoke reflection in both users and us as designers. A reflective design strategy, engaging the bench as a probe [26, 64, 95] helps find experiential possibilities that may emerge with urban sensing. Probes can act as elicitation techniques by fostering alternative experiences with technology [26]. A reflective design output, these experiences and reflections generate concepts and directions for further research. Our approach draws from speculative and critical design that seek to challenge assumptions and spark discussion with provocative artifacts [51, 137, 141], and framings of data as enmeshed in social practices (e.g., [139]).

Interaction Design

The design provides a place to sit and rest, recognizing and supporting the needs of passerby like other benches. Yet, its vibrant color and unusual shape both invite the eye to notice it from afar while hinting at an unusual function.

Bench-sitters' live unfiltered heart sounds are amplified and played from speakers in the bench, inviting a quiet moment of listening and bodily awareness. We refer to 'heart sounds' rather than 'heartbeats' to call attention to the continuous *sounds* of the heart and body, rather than only the discrete beats per minute. Although not technologically novel, we chose to use stethoscopes instead of chair [20], phone [113], non-contact [138], or PPG heart sensors, because stethoscopes give rich heart *sounds* that provide a sense of unmediated immediacy. Furthermore, the familiar form factor of the stethoscope can help favor informed active consent in future public use. People readily understood the sensor and opted-in by holding it.

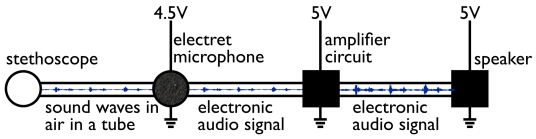

Figure 2: System diagram for each side of the bench.

With one stethoscope at each arm of the bench, two people can listen to their heart sounds simultaneously. The bench can also record heart sounds and later play these back to future sitters. We wanted to explore how listening to heart sounds could foster a sense of people affirming themselves and others. With two people on the bench simultaneously, we could explore the potential for affirming a co-present other. We relate this to moments of city living when we acknowledge the co-presence of a stranger, such as while sharing space on the bus. With the prerecorded playback, we could probe the potential for affirming an absent other. We related this to moments in city living when we acknowledge the presence of those who came before based on the traces they left behind, such as tags or stickers. This prerecorded audio also included a voice stating the date, time, and weather. The date and time were included to indicate that these heart sounds came from the past. The weather was included to give some sense of context and invite participants to reflect on the environment around the bench. While no voice is neutral, we asked a professional therapist to read these details in a calm tone, because we felt his voice was particularly well tailored for prompting open-ended emotional reflection.

System Design

At each side of the bench is a listening piece, an amplifier circuit, and a speaker. The listening piece is a modified stethoscope affixed to an electret microphone [96]. This connects to an audio amplifier [97]. The amplifier circuit connects to a speaker [7, 10]. The sounds from each stethoscope play through speakers on the corresponding side of the bench. The live real-time amplification of heart sounds is instantly responsive and recognizable as heart sounds. In addition to heart sounds, the stethoscopes are essentially a general-purpose microphone that also pick up rustling, tapping, and the vibration of people's bodies as they speak. The electret microphone receives a quiet steady DC voltage from 3 AA batteries in series. The amplifier circuit is powered by 5V DC from a wall adapter. Blankets folded on the arms of the bench reduce the medical feel of the stethoscopes and provide sound dampening between stethoscope and speaker to prevent feedback.

While bench-sitters' heart sounds were live via fully functional electronics, we used a Wizard of Oz technique to play back the heart sounds of a previous sitter. From a mobile

phone connected to a speaker [4], we played back the same prerecorded heart sound for all participants. This enabled us to probe participant experiences of hearing the playback and speculating on how they would feel about being recorded. Future work on the Heart Sounds Bench can implement recording and playback as well as designing an intuitive way to choose when to record and when to play back.

5 STUDY

Our goal with this study was to probe affective experiences of sensing and affirmation. For this first trial, we wanted to give a sense of public space and unstructured time experiencing the design, while ensuring ability to focus on heart sounds without distraction. So, although we are interested in public space with all its vibrancy and risk, for this first stage of the project we chose to study participants' experiences with the bench indoors. Conducting the study inside in a private room enabled us to more deeply probe how people interpreted and reacted to the design. The private setting ensured that audio and video recording did not capture any unsuspecting passerby, an important ethical consideration for us.

The study setting provides some sense of public space. On the bench, participants sat less than 1m away from a crowded pedestrian thoroughfare via large corner ground level windows through which squirrels and birds sometimes enter. Yet, they also had space to clearly hear their heart sounds. So, the room evokes a sense of having a quiet secluded corner viewing a larger outdoor space.

Participants came in pairs to probe how they experienced hearing their own heart sounds, those of a co-present other, and the prerecorded playback of an unseen other. After a few introductory questions by the researcher that began to build rapport between participants, the researcher left participants sitting on the bench alone together in the room for about 20 minutes. About halfway, the researcher played the prerecorded heart sounds of the absent other. Returning, the researcher conducted a semi-structured interview with the pair about their experiences and interpretations with the heart sounds for about 45-60 minutes. Recruitment was conducted over organizational and public-facing mailing lists and communication platforms. Audio and video recordings of participants were transcribed for analysis and coded to find emergent themes [34]. Participants are referred to by pseudonym.

Future work will study the system in public. The indoor study focused on in-depth emotional reflection 20 minutes of experiencing the bench without distraction and 45-60 minutes of emotional reflection afterward. In public the duration of participation and depth of reflection will likely be less, while the larger N study of public behavior can surface trends and unexpected uses.

6 FINDINGS

Nineteen people participated (9 women, 10 men, mid twenties to mid thirties). Pairs were strangers, coworkers, or friends. Three participated alone due to scheduling issues. Most participants alternated between quietly listening to their heart sounds and chatting with one another about the experience. Sometimes they took turns listening to their heart sounds one at a time. In describing their experiences, participants often cited nearby elements of public space such as passerby, trees, squirrels, sounds, and the sunset, indicating that the study setting did evoke some sense of public space for participants.

Life Energy

Several participants described feeling connected to a life energy or sense of being alive. Some focused on their own vitality, others on a sense of connection within the pair, while a few felt a sense of connection including themselves, others, and the environment.

Sally connected hearing her own and others' heartbeats to a sense of life pulsing through herself and others.

> *"**It's a nice reminder of what's pulsing through everybody**. It's nice to be able to hear somebody else's heartbeat, just makes you that much more aware of that you're around somebody else who's living and breathing." Later she added, "It just seems really sweet to me to hear that, **to hear somebody else's, the life pulsing through them**."*

She described first a growing awareness of her own body, then expanding her attention outward to an appreciation of the lives of others. While much HCI work with heart rate and the smart city focuses on fitness, participants' reflections on appreciating and feeling connected to the lives of others point to a distinct design opportunity.

In imagining public use of the bench in the future, Charlie envisioned feeling more involved in the moment, the environment, and the world.

> *"If it's outdoors, I think it would make me feel more involved in the moment, like involved with the environment. When I'm listening to my heart sounds, watching the gate [gestures to scenery through the window], it would make me feel more involved with the environment... Listening to the sound is like, **there's many metaphors about your heartbeat beating with the same thing around the world**... like **the heart beating with the world**... which makes me feel involved with this world, and more enjoy at that moment."*

He described feeling present in the moment with his own heart beating in connection with the world. This sense of

Figure 3: Participants often sat silently together listening to their heart sounds, or reflected on the experience together.

presence and connection suggests an affective experience that could be explored in designing for the smart city.

Jay built on his study partner Charlie's sense of involvement and reflected on a sense of connection with nature.

> *"**This seemed like I was more connected**, even if it was just in this room, I feel **it seemed like it was extending outside of myself**... I [felt connected to] the world around me. And that something so internal and personal could have an effect on others around me. Even though it was seemingly just you [gestures to his study partner], but perhaps maybe someone could hear it outside [through the windows], or I guess just in the way that [pause] **trees just moving and we can kind of tell other things in the earth are doing or making other sounds or other sensory messages. It seemed like I was doing that too... The fact that we're embedded within nature** and doing this [the Heart Sounds Bench] gave it kind of like an outside perspective of **seeing myself as one and the same as other beings or other objects** that also do that... **that also show their signs of life**."*

Jay traces a connection between his heartbeat and the lives of other people, trees, or even objects.

John focused more on a sense of connection with the other person on the bench. Reflecting on his experiences with the Heart Sounds Bench and imagining its future use in public space, described the experience of hearing a co-present other's heart sounds:

> *"Hearing another person's heartbeat feels like, not something that's super revealing but at the same time it's something that's very personal and inherent to who you are. **This is like the force of your life** or something."*

Like others, John draws a connection between heart sounds and life energy. Again, distinct from a prevalent focus on physical fitness, this sense of 'life force' was a remarkable affective experience for many participants.

Odile focused more on her own sense of being alive. *"I think the rhythm of my heart being so steady reminds me... that I am alive."* Odile went on to describe how this reminder helped calm her and make her feel like she could manage her stress. Again, the association between heart sounds and vitality came up for many participants.

The connection between heart sounds and being alive makes sense given that the heart is essential to our biological life. Though this is a basic fact, the affective dimensions of being reminded of this seemed to be a remarkable experience for many participants. Feeling more connected to oneself or one's study partner seems to have been meaningful and enjoyable for several participants. While heart rate sharing has been previously found to foster a sense of connection [156], what surprised us were the multiple instances where participants described a broader sense of connection extending to many other people, the environment, the world, even trees and objects. We speculate that what might have contributed to this sense of broader connection is the externalization of the heart sounds through the speakers, as well as the ground level view out the windows onto trees, sky, and passerby. The Heart Sounds Bench centers the individual by helping them attune to their own heart sounds, expands this to a dyad, and then further amplifies this awareness through the broader environment.

In contrast to smart city sensing technologies that construct people in terms of economic value, safety threat level, or other models and categories, our design called attention to a shared embodied experience of being alive. Participants seemed to find this sense of shared life energy to be a meaningful and compelling experience, pointing to future opportunities for designs exploring this.

Vulnerability of Life

The stethoscope reminded several participants of prior experiences with stethoscopes such as doctor or hospital visits. For example, Sheena said she was reminded of medical emergencies when stethoscopes have been used on her. She arrived at the study just after a frightening experience on the subway. The Heart Sounds Bench seems to have aggravated her stress by bringing back bad memories.

Jay also related the heart sounds to worrying about 'mortality', as he put it. Speculating future public uses of the bench, Jay imagined worrying about the deteriorating health of older relatives.

> *"As much as this can be an intimate experience, it could also a disturbing or scary experience because... hearing the heart sounds of someone else, or even your own... Say I were to go with my father or an older member of my family, and essentially we've walked or something, and I hear their heart beating really fast. That can be a really quick reminder of their mortality, or in many ways engaging with someone else's health in a way that might be kind of frightening, and it might change the relationship between you and that person."*

An unexpectedly fast heartbeat could indicate frightening health concerns in a loved one. Heart sounds served not only as a reminder of being alive, but also as a reminder of the vulnerability of life. This seems related to both the medical associations of the stethoscope and the heart's essential cardiovascular function.

Intimacy

Several participants described hearing their study partner's heart sounds as intimate. In describing listening to her study partner's heart sounds, Amanda said, ***"It's weirdly intimate, like I don't know this person but I've heard an organ that keeps them alive."*** Others were reminded of intimate moments with a romantic partner, with an ear to their chest listening to their heart sounds. The stethoscope's live unfiltered heart sounds are extremely similar to what one hears by pressing an ear to another's chest. Some products for long distance couples sonify heart rate (e.g., [118]), and SlovÃąk et al. found remote heart rate sharing to foster connection [156]. Yet, the unique richness of live unfiltered heart *sounds* rather than heart rate sonification could be more widely leveraged in designs.

Anonymity

Co-present study partner. Listening to the heart sounds of the co-present study partner seemed to feel both intimate and anonymous. While participants often expressed that it felt special or unique to hear such an essential sound from another person that they would not normally hear, at the same time they sometimes reflected on how this sound could also feel anonymous. Amanda, who described hearing her study partner's heart sounds as "weirdly intimate", also reflected, ***"I wouldn't know one heartbeat from another or from my own."*** Her study partner Nathan added, *"I sort of felt similarly that, any heartbeat, I didn't have like a clear distinction about which one was mine or what it meant about someone else...* ***kind of anonymous."*** Some participants speculated they would not be able to identify their own heart sounds or their study partner's from a selection.

Absent other. In addition to the live unfiltered heart sounds of study participants, we included playback of the heart sounds of an 'absent other' who previously sat on the bench. The playback began with a voice stating the time, date, and weather. Listening to the absent other's heart sounds was mostly experienced as anonymous and not intimate. Kusha reflected, ***"With the heart sounds that were prerecorded, I was trying to build a story and imagine a person."*** Her study partner John added, *"I was much more interested in hearing [Kusha's]... I think I could have felt more connected to [the absent other's playback] if instead of just the date and the time there was some explanation of what the person was going to be doing..."* Jay described it as *"disembodied"*. Participants often wondered what the absent other was feeling or doing, but struggled to build a narrative. They linked this lack of context to not feeling connected with the heart sounds of the absent other. Nathan summarized, ***"I didn't know anything about that person or their context. It just seemed like an anonymous recording."***

Calming

Many participants described the experience as calming. Odile used the word 'calm' repeatedly to describe her experience. Kusha said she began the study feeling stressed, but then the heart sounds help her calm down. Participants also linked their experience of calm with seeing trees or the sunset through the window, and often suggested placing the bench in a park to enhance its calming potential. Although the researcher stated they were free to take breaks, chat, and put down the stethoscope, many participants sat quietly listening to their heartbeats. For many this seemed to be a calming experience.

Other Themes

Estelle, an electroacoustic musician, explored the Heart Sounds Bench as a feedback instrument. Many electroacoustic instruments operate on this principle: A feedback instrument relies on feeding the output (in our case, speakers) back into the

input (stethoscope), often with amplification increasing intensity. The feedback loop is mediated by physical materials, so subtle adjustments (in location of stethoscope on bench) create nuanced expressive sounds. She described it in terms of cybernetics and how tools or musical instruments can serve as extensions of the body. Some participants playfully experimented with the system, tapping on the stethoscope or using it to amplify their voice. Energetically amplifying not only the heart but also whatever the stethoscope encounters may have contributed to the sense of shared life energy by fostering attentive listening to unexpected sounds of both humans and materials.

Almost all participants spent a few moments finding the right spot on their chest to listen to their heart sounds. For a few, this took several minutes and was frustrating. Yet, this searching could also contribute to growing one's bodily awareness, which was seen as valuable by some.

A few participants related the bench to meditation. Kusha described how she had been focusing on her heart during meditation, and the heart sounds helped her with that. Alan said he would want the system in his home so he could use it for daily meditation. Rohit said he has been trying to meditate more often and felt the system could be a helpful aid. Perhaps along a similar vein, many participants described the experience as calming, contemplative, centering, grounding, or talked about being in the moment.

When asked how they would feel about their own heart sounds being recorded and played back later after they were gone, almost all participants wondered whether heart sounds could be individually identifiable, citing this as a key consideration. They also expressed concerns about whether heart sounds in combination with other data such as video surveillance could become individually identifiable, or reveal unexpected insights about them. Deploying the bench in public space, it is essential to consider how the bench could potentially become an unwanted form of surveillance.

7 ELABORATING LIFE-AFFIRMATION

Synthesizing our findings and design intent, we elaborate on the concept of *life-affirmation* in terms of *recognition*, *connection*, and *opacity*. In accordance with designerly modes of knowledge production [65], this is not intended as a generalizable definition. Rather, by elaborating one particular conception situated around a particular design, we hope to open a path for others to continue exploring this concept. We do not claim that our bench currently supports life-affirmation in public because this is as yet untested; rather we contribute life-affirmation as a promising direction for future design exploration in public space.

The Heart Sounds Bench seems to have fostered a particular kind of affirmation we call *life-affirmation*. This life-affirmation can spread outward from self, to study partner, to other people and the natural environment. Participants described feeling reminded that they are alive, and feeling more drawn into themselves and connected with their body. They described being reminded that their study partner is living and breathing too, and the strange intimacy of hearing their heart sounds. They described feeling more connected to "what's pulsing through everyone" (Sally), "the heart beating with the world" (Charlie), and "seeing myself as one and the same as other beings or other objects that ... show their signs of life" (Jay). There is a sense of shared vitality, that multiple beings are partaking in a similar process of living. Though at some level this is an obvious observation, the affirmation of this shared vitality creates a particular feeling participants found remarkable. We call this *life-affirmation*.

Revisiting our initial critique of smart city narratives, we see life-affirmation as a key element often neglected by an emphasis on efficiency, fitness, and safety. Being in public can provide a joyful sense of shared vitality, of seeing others and being seen. There is a unique pleasure to being in the midst of the hustle and bustle of a crowded, chaotic city street. This affective experience is an important aspect of city living that should not be overlooked in the push for efficiency, fitness, and safety.

The life-affirmation experienced with the Heart Sounds Bench seems to stem from sitting outside the action rather than being immersed in it. For the study, participants sat inside looking through ground level windows at a campus thoroughfare crowded with people streaming by. They often gazed through the windows or gestured toward them during the interview. Participants often suggested putting the bench in a quiet area outdoors with a view of natural scenery. Taking a step back from the action seemed to facilitate centering on oneself, before expanding that sense of connection outward to other people and the environment.

Life-affirmation is a conceptual tool that helps address calls to build connection while respectfully engaging difference (e.g., [42]). We elaborate three key aspects of life-affirmation–recognition, connection, and opacity–that contribute to its conceptual potential.

Recognition

Much work 'recognizes' normative categories of a person, flattening difference into categories. Instead, we call for recognizing others' existence and feelings as valid. Life-affirmation involves a kind of *recognition* distinct from the recognition typically sought by biosensing technologies, which often seek to recognize discrete emotional categories (e.g., [28, 84, 136, 144]), or identify or authenticate an individual based on biosensory data they give off (e.g., [39, 40, 59, 83, 94, 116, 117, 155]).

In contrast to that kind of recognition, participants described being 'reminded' or being 'more aware' of something

they already knew: that they and others are alive. Recognizing this is technically trivial, but seemed to be a meaningful affective experience for participants. The biosensory data people give off, or "the signs of life" (Jay) that humans and plants alike give off, can contribute to life-affirmation. San Leandro Lights are anothe example of urban sensing that supports this notion of recognition: These street lamps create beautiful pools of light that follow pedestrians using sensors [123]. There is an opportunity for smart city biosensing to design for recognition. This recognition need not take the form of specific data-driven categories; rather, a focus on simply recognizing or acknowledging people's existence, feelings, and experiences could support life-affirmation.

Connection

Connection is not unique to our work. Yet, life-affirmation offers a unique way to build connection between strangers while respecting difference. Recognizing this shared vitality led to a greater sense of connection for many participants. Slovák et al. also found heart rate sharing to foster social connection [156]. There, a sense of connection emerged within pairs of colleagues and cohabitant couples. In our study, participants described feeling more connected to their study partner as well as to other people, the environment, or the world more broadly. This seemed to stem from a sense of going sharing a similar life process as others, providing a sense of commonality. As another example, Hein's Modified Social Benches encourage social interaction between strangers [82]. Smart city sensing technologies tend to frame people as atomized individuals [91, 122, 142]. Connection and life-affirmation point to an opportunity for biosensing designs to emphasize social interconnection, as some work with self-tracking has already begun to do (e.g., [121]).

Opacity

While we celebrate the sense of connection of feeling "one and the same as other beings or other objects" (Jay), it is essential to recognize not only our commonality with others but also our difference. Our adaptation of Glissant's notion of *opacity* can help respect difference and support other ways of knowing. Opacity resists a tendency to build connection by understanding the 'other' via reducing them to hegemonic categories. A contemporary of Fanon, Glissant was a postcolonial philosopher and poet who analyzed Caribbean Creole's complex relationship with the language of the colonizer. In his essay 'For Opacity', Glissant argues for the *right to opacity* as a way of acknowledging difference while avoiding the reductive problem of transparency [71].

> "If we examine the process of 'understanding' people and ideas from the perspective of Western thought, we discover that its basis is this requirement for transparency. In order to understand and thus accept you, I have to measure your solidity with the ideal scale providing me with grounds to make comparisons and, perhaps, judgments. I have to reduce... I relate it to my norm. I admit you to existence, within my system." [71, p.189-190].

Understanding is often approached via transparency, which requires reducing the other to predefined terms or categories. This route to recognition affirms only a reduced representation of the other in terms of hegemonic norms. Glissant further problematizes understanding (*comprendre*) as taking or appropriating and proposes gives-on-and-with (*donner-avec*) as an alternative [72], but here we focus on opacity.

For smart city sensing, transparency is often valued as a way to build trust in the smart city [57]. Perhaps if we could know more about each other, we could fear each other less and affirm each other more. Yet, smart city sensing is a particular way of knowing that privileges particular norms and categories. We should not have to make ourselves legible in terms of hegemonic data-driven categories in order to be affirmed. In that translation too much is lost or reduced. Opacity resists transparency.

Opacity is distinct from privacy. While "privacy is an essentially contested concept" [119], its conceptualization often foregrounds appropriate information flows or the right to not be bothered [124, 151, 167]. In contrast, Opacity foregrounds ways of knowing, problematizing the production of 'information' in terms of predefined categories. We call for smart city technologies to more critically and reflexively engage the knowledge politics of their sensing and inference.

Opacity is related to, but distinct from, *ambiguity of information* [67]. Since Gaver et al.'s foundational paper on ambiguity, many information displays have leveraged ambiguity to prompt open-ended reflection. A display's lack of clarity can prompt users to 'supplement' this with their own contextual knowledge for interpretation. We see ambiguity as a valuable approach, and indeed much of our prior work engages ambiguity in data display [44, 92, 93]. Opacity similarly presents the user with a lack of clarity, but for a different purpose of acknowledging the limitations of our own understanding. To those not trained in auscultation, heart sounds are somewhat opaque and users did not seem to form specific interpretations of this data.

A comparative example is Affector, which shows abstract ambient ambiguous video feed of a coworker in their office. Affector is framed around ambiguity. As described by the designers, "In order to support reflection on both emotion and the role technology plays in it, Affector is deliberately designed to communicate emotion obliquely and enigmatically.

It does not provide easy answers to how someone feels today; instead, it provides indirect evidence which users must interpret with reference to the data supplied by the system, as well as background knowledge of their friendship and contextual cues" [153, p. 351]. The ambiguity prompts users to supplement the data with their own contextual knowledge to form interpretations. Yet, the intended users likely can only guess at how their coworker feels. The 'oblique', 'enigmatic', or opaque design foregrounds the limits of our own ability to know others.

Data-driven insight is valorized in our current moment, but opacity argues for acknowledging the limitations of our knowledge of others. This joins our past work calling for humility in knowledge claims made with emotional biosensing [91] as well as related work calling for contestability in knowledge claims made with emotional biosnsing [85, 86].

Taken together, recognition, connection, and opacity contribute to life-affirmation, forming a novel conceptual tool to help reframe sensing's role in urban life, from smart cities to social cities. We reworked the concept of recognition away from recognizing data-driven categories toward recognizing others' lives, experiences, and feelings. This centers the affective experience of recognition rather than data-driven insight or predictive potential. We describe a sense of connection that can emanate outward from self-attunement, to a co-present other, to many others across the world and the natural environment. While celebrating this sense of shared vitality and commonality, we also introduce opacity as a way of respecting difference. Recognizing the opacity of others reminds us that we cannot know others entirely, and holds space for different ways of knowing that do not neatly translate.

8 LIMITATIONS

Conducting the study inside in a private room, though it enabled us to more deeply probe participants' experiences, hindered our ability to probe affective experiences of being in public. Most participants came from a similar age group and educational background, limiting our ability to engage questions of otherization woven throughout our argument. In future work deploying the bench in public, we hope to explore interactions where people might feel more 'other' to one another. Yet in public, two strangers sitting on the bench simultaneously listening to their heart sounds seems unlikely, given legitimate concerns around harassment. Future design iterations will continue to explore how the heart sounds of an absent other can be more evocative and engaging. Finally, life-affirmation does not solve problems. It does not address important issues such as sustainability or violent crime. Yet, it is still worthwhile to explore how urban sensing will shape affective experiences of city living.

9 FUTURE DESIGN DIRECTIONS

Future design directions should continue to explore affective experiences with smart city living, embracing a wide variety of alternative feelings and desires. These efforts at inclusivity and diversity have already begun (e.g., [115, 130, 165]). We contribute *life-affirmation* as one feeling to explore, elaborating this in terms of *recognition*, *connection*, and *opacity* for celebrating and respecting both commonality and difference. As anthropologist/geographer Harvey [79] puts it,

> "The question of what kind of city we want cannot be divorced from that of what kind of social ties, relationship to nature, lifestyles, technologies and aesthetic values we desire."

Rather than trying to converge on a common set of social ties, lifestyles, etc., urban sensing should explore a multiplicity of desires for vibrant social cities.

10 CONCLUSIONS

We contribute the design of the Heart Sounds Bench to explore an often-overlooked potential for affirmation in city living. Our key contribution is life-affirmation as a conceptual tool for reworking smart city narratives. We do not claim that our bench currently supports this in public (as yet untested); rather we contribute life-affirmation as a promising direction for future design exploration in public space. Nineteen participants' insightful articulations of their experiences help us elaborate *life-affirmation* in terms of *recognition*, *connection*, and *opacity*. Recognizing others' lives, feeling connected, and embracing difference with opacity can be a meaningful affective experience of life-affirmation. Future designs with public urban biosensing technologies should explore a wide variety of affective experiences and a multiplicity of desires.

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REFERENCES

[1] [n. d.]. Affectiva Developer Portal: Metrics. http://developer.affectiva.com/metrics/

[2] [n. d.]. affirmation. https://en.oxforddictionaries.com/definition/affirmation

[3] [n. d.]. The Algorithmic Justice League. https://www.ajlunited.org/

[4] [n. d.]. Amazon.com: Infinity One Premium Wireless Portable Speaker: Home Audio & Theater. https://www.amazon.com/Infinity-One-Premium-Wireless-Portable/dp/B00LOL7HDC

[5] [n. d.]. Feel. http://www.myfeel.co/

[6] [n. d.]. Fitbit. https://www.fitbit.com/

[7] [n. d.]. Harman Kardon Esquire. https://www.harmankardon.com/content?ContentID=esquire

[8] [n. d.]. Home. https://www.knightscope.com/

[9] [n. d.]. Humanyze Products. https://www.humanyze.com/products/

[10] [n. d.]. JBL Pulse | Wireless Bluetooth Speaker with LED Light Show. https://www.harmanaudio.com/JBL+PULSE.html

[11] [n. d.]. otherize. https://en.oxforddictionaries.com/definition/otherize

[12] [n. d.]. Sidewalk Labs. https://www.sidewalklabs.com/

[13] [n. d.]. Sidewalk Toronto. https://sidewalktoronto.ca/wp-content/themes/sidewalktoronto

[14] [n. d.]. Spire Mindfulness. http://www.spire.io

[15] Rafael Calvo, Sidney D'Mello, Jonathan Gratch, and Arvid Kappas (Eds.). 2015. *The Oxford Handbook of Affective Computing* (2015-01-01). Oxford University Press. http://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199942237.001.0001/oxfordhb-9780199942237

[16] Anton Nijholt (Ed.). 2017. *Playable Cities: The City as a Digital Playground* (2017). Springer Singapore. //www.springer.com/us/book/9789811019616

[17] Sara Ahmed. 2004. Affective Economies. 22, 2 (2004), 117–139. https://muse.jhu.edu/article/55780

[18] Sara Ahmed. 2014. *The cultural politics of emotion* (2 ed.). Edinburgh University Press. OCLC: 884113266.

[19] Hamed S. Alavi, Denis Lalanne, Julien Nembrini, Elizabeth Churchill, David Kirk, and Wendy Moncur. 2016. Future of Human-Building Interaction. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016) *(CHI EA '16)*. ACM, 3408–3414. https://doi.org/10.1145/2851581.2856502

[20] Jenni Anttonen and Veikko Surakka. 2005. Emotions and Heart Rate While Sitting on a Chair. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2005) *(CHI '05)*. ACM, 491–499. https://doi.org/10.1145/1054972.1055040

[21] Mariam Asad and Christopher A. Le Dantec. 2017. Tap the "Make This Public" Button: A Design-Based Inquiry into Issue Advocacy and Digital Civics. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (2017) *(CHI '17)*. ACM, 6304–6316. https://doi.org/10.1145/3025453.3026034

[22] Mara Balestrini, Yvonne Rogers, Carolyn Hassan, Javi Creus, Martha King, and Paul Marshall. 2017. A City in Common: A Framework to Orchestrate Large-scale Citizen Engagement Around Urban Issues. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (2017) *(CHI '17)*. ACM, 2282–2294. https://doi.org/10.1145/3025453.3025915

[23] Ivaro Barbosa. 2008. Ten-Hand Piano : A Networked Music Installation. In *Proceedings of the International Conference on New Interfaces for Musical Expression* (2008-06-01). https://doi.org/10.5281/zenodo.1179487

[24] Katja Battarbee, Nik Baerten, Martijn Hinfelaar, Paul Irvine, Susanne Loeber, Alan Munro, and Thomas Pederson. 2002. Pools and Satellites: Intimacy in the City. In *Proceedings of the 4th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques* (2002) *(DIS '02)*. ACM, 237–245. https://doi.org/10.1145/778712.778746

[25] David Birchfield, Kelly Phillips, Assegid Kidan, and David Lorig. 2006. Interactive Public Sound Art: a case study. In *Proceedings of the International Conference on New Interfaces for Musical Expression* (2006-06-01). https://doi.org/10.5281/zenodo.1176873

[26] Kirsten Boehner, Rogrio DePaula, Paul Dourish, and Phoebe Sengers. 2007. How emotion is made and measured. 65, 4 (2007), 275–291. https://doi.org/10.1016/j.ijhcs.2006.11.016

[27] Kirsten Boehner and Carl DiSalvo. 2016. Data, Design and Civics: An Exploratory Study of Civic Tech. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16* (2016). ACM Press, 2970–2981. https://doi.org/10.1145/2858036.2858326

[28] Andrey Bogomolov, Bruno Lepri, and Fabio Pianesi. 2013. Happiness Recognition from Mobile Phone Data. In *Proceedings of the 2013 International Conference on Social Computing* (2013) *(SOCIALCOM '13)*. IEEE Computer Society, 790–795. https://doi.org/10.1109/SocialCom.2013.118

[29] Simone Browne. 2015. *Dark matters: on the surveillance of blackness*. Duke University Press.

[30] Andre de Oliveira Bueno. 2016. From Smart Cities to Social Cities: Technology to Support Community Life. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016) *(CHI EA '16)*. ACM, 198–202. https://doi.org/10.1145/2851581.2859020

[31] Joy Buolamwini. 2016. The Algorithmic Justice League. https://medium.com/mit-media-lab/the-algorithmic-justice-league-3cc4131c5148

[32] J. Buolamwini and T. Gebru. 2018. Gender Shades: Intersectional Accuracy Disparities in Commercial Gender Classification. In *Proceedings of Machine Learning Research* (2018), Vol. 81. 77–91.

[33] Patrick Caughill. 2017. The SPCA has removed its controversial security robot. https://futurism.com/spca-removed-controversial-security-robot/

[34] Kathy Charmaz. 2006. *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. Pine Forge Press.

[35] Eric Corbett and Christopher A. Le Dantec. 2018. Exploring Trust in Digital Civics. In *Proceedings of the 2018 Designing Interactive Systems Conference* (2018) *(DIS '18)*. ACM, 9–20. https://doi.org/10.1145/3196709.3196715

[36] Susan Crawford. 2018. Beware of Google's Intentions. (2018). https://www.wired.com/story/sidewalk-labs-toronto-google-risks/

[37] Clara Crivellaro, Rob Comber, Martyn Dade-Robertson, Simon J. Bowen, Peter C. Wright, and Patrick Olivier. 2015. Contesting the City: Enacting the Political Through Digitally Supported Urban Walks. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (2015) *(CHI '15)*. ACM, 2853–2862. https://doi.org/10.1145/2702123.2702176

[38] Franco Curmi, Maria Angela Ferrario, Jen Southern, and Jon Whittle. 2013. HeartLink: Open Broadcast of Live Biometric Data to Social Networks. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2013) *(CHI '13)*. ACM, 1749–1758. https://doi.org/10.1145/2470654.2466231

[39] Max T. Curran, Nick Merrill, John Chuang, and Swapan Gandhi. 2017. One-step, Three-factor Authentication in a Single Earpiece. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers* (2017) *(UbiComp '17)*. ACM, 21–24. https://doi.org/10.1145/3123024.3123087

[40] M. T. Curran, J. Yang, N. Merrill, and J. Chuang. 2016. Passthoughts authentication with low cost EarEEG. In *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology*

Society (EMBC) (2016-08). 1979–1982. https://doi.org/10.1109/EMBC.2016.7591112

[41] Maria Puig de la Bellacasa. 2011. Matters of care in technoscience: Assembling neglected things. 41, 1 (2011), 85–106. https://doi.org/10.1177/0306312710380301

[42] Michiel de Lange and Martijn de Waal. 2013. Owning the city: New media and citizen engagement in urban design. 18, 11 (2013). https://doi.org/10.5210/fm.v18i11.4954

[43] Amnon Dekel, Yitzhak Simon, Hila Dar, Ezri Tarazi, Oren Rabinowitz, and Yoav Sterman. 2005. Adding Playful Interaction to Public Spaces. In *Proceedings of the First International Conference on Intelligent Technologies for Interactive Entertainment* (2005) *(INTETAIN'05)*. Springer-Verlag, 225–229. https://doi.org/10.1007/11590323_24 Sonic Waterfall Musical Chairs Intimate Bench - lights that try to get people to sit closer together.

[44] Laura Devendorf, Joanne Lo, Noura Howell, Lin Lee Jung, Nan-Wei Gong, M. Emre Karagozler, Shiho Fukuhara, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. I dont want to wear a screen: Probing perceptions of and possibilities for dynamic displays on clothing. In *Proceedings of the 34th Annual ACM Conference on Human Factors in Computing Systems (CHI'16)* (2016).

[45] John Dewey. 2012. *The Public and Its Problems: An Essay in Political Inquiry*. Pennsylvania State University Press. https://www.jstor.org/stable/10.5325/j.ctt7v1gh

[46] Jessa Dickinson, Sheena Erete, Mark Diaz, and Denise Linn Riedl. 2018. Inclusion of Underserved Residents in City Technology Planning. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (2018) *(CHI EA '18)*. ACM, LBW530:1–LBW530:6. https://doi.org/10.1145/3170427.3188583

[47] Carl DiSalvo and Tom Jenkins. 2017. Fruit Are Heavy: A Prototype Public IoT System to Support Urban Foraging. In *Proceedings of the 2017 Conference on Designing Interactive Systems - DIS '17* (2017). ACM Press, 541–553. https://doi.org/10.1145/3064663.3064748

[48] Carl DiSalvo, Tom Jenkins, and Thomas Lodato. 2016. Designing Speculative Civics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016) *(CHI '16)*. ACM, 4979–4990. https://doi.org/10.1145/2858036.2858505

[49] Carl DiSalvo, Jonathan Lukens, Thomas Lodato, Tom Jenkins, and Tanyoung Kim. 2014. Making public things: how HCI design can express matters of concern. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14* (2014). ACM Press, 2397–2406. https://doi.org/10.1145/2556288.2557359

[50] Carl DiSalvo, Phoebe Sengers, and Hrnn Brynjarsdttir. 2010. Mapping the Landscape of Sustainable HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2010) *(CHI '10)*. ACM, 1975–1984. https://doi.org/10.1145/1753326.1753625

[51] Anthony Dunne and Fiona Raby. 2013. *Speculative everything: design, fiction, and social dreaming*. The MIT Press.

[52] Sara Eriksson and Preben Hansen. 2017. HeartBeats: A Speculative Proposal For Ritualization of Digital Objects. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems - DIS '17 Companion* (2017). ACM Press, 218–222. https://doi.org/10.1145/3064857.3079149

[53] Virginia Eubanks. 2017. *Automating inequality: how high-tech tools profile, police, and punish the poor* (first edition ed.). St. Martin's Press.

[54] F. S. Ferraz and C. A. G. Ferraz. 2014. More than Meets the Eye in Smart City Information Security: Exploring Security Issues Far beyond Privacy Concerns. In *2014 IEEE 11th Intl Conf on Ubiquitous Intelligence and Computing and 2014 IEEE 11th Intl Conf on Autonomic and Trusted Computing and 2014 IEEE 14th Intl Conf on Scalable Computing and Communications and Its Associated Workshops* (2014-12). 677–685. https://doi.org/10.1109/UIC-ATC-ScalCom.2014.143

[55] Marcus Foth, Jaz Hee-jeong Choi, and Christine Satchell. 2011. Urban Informatics. In *Proceedings of the ACM 2011 Conference on Computer Supported Cooperative Work* (2011) *(CSCW '11)*. ACM, 1–8. https://doi.org/10.1145/1958824.1958826

[56] Jrmy Frey. 2016. Remote Heart Rate Sensing and Projection to Renew Traditional Board Games and Foster Social Interactions. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016) *(CHI EA '16)*. ACM, 1865–1871. https://doi.org/10.1145/2851581.2892391

[57] Ester Fritsch, Irina Shklovski, and Rachel Douglas-Jones. 2018. Calling for a Revolution: An Analysis of IoT Manifestos. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (2018) *(CHI '18)*. ACM, 302:1–302:13. https://doi.org/10.1145/3173574.3173876

[58] Jonas Fritsch, Morten Breinbjerg, and Tue S. Jensen. 2014. Designing interactive listening situations. In *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures the Future of Design - OzCHI '14* (2014). ACM Press, 31–40. https://doi.org/10.1145/2686612.2686618

[59] D. Gafurov, E. Snekkenes, and P. Bours. 2007. Gait Authentication and Identification Using Wearable Accelerometer Sensor. In *2007 IEEE Workshop on Automatic Identification Advanced Technologies* (2007-06). 220–225. https://doi.org/10.1109/AUTOID.2007.380623

[60] Cally Gatehouse. 2016. Critical Design As Networked Counter Public. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems* (2016) *(DIS '16 Companion)*. ACM, 29–30. https://doi.org/10.1145/2908805.2909421

[61] Cally Gatehouse. 2016. Feral Screens: Queering Urban Networked Publics. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems* (2016) *(DIS '16 Companion)*. ACM, 99–104. https://doi.org/10.1145/2908805.2913014

[62] Benjamin Gaulon. 2012. L.S.D Light to Sound Device. http://www.recyclism.com/lsd.php

[63] Bill Gaver. 2002. Designing for Homo Ludens. (2002).

[64] Bill Gaver, Tony Dunne, and Elena Pacenti. 1999. Design: Cultural Probes. 6, 1 (1999), 21–29. https://doi.org/10.1145/291224.291235

[65] William Gaver. 2012. What Should We Expect from Research Through Design?. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2012) *(CHI '12)*. ACM, 937–946. https://doi.org/10.1145/2207676.2208538

[66] William Gaver, Liliana Ovalle, Andy Boucher, Nadine Jarvis, David Cameron, Mark Hauenstein, Sarah Pennington, John Bowers, James Pike, and Robin Beitra. 2016. The Datacatcher: Batch Deployment and Documentation of 130 Location-Aware, Mobile Devices That Put Sociopolitically-Relevant Big Data in People's Hands: Polyphonic Interpretation at Scale. ACM Press, 1597–1607. https://doi.org/10.1145/2858036.2858472

[67] William W. Gaver, Jacob Beaver, and Steve Benford. 2003. Ambiguity As a Resource for Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003) *(CHI '03)*. ACM, 233–240. https://doi.org/10.1145/642611.642653

[68] David George-Cosh and Eliot Brown. 2017. Google Parent Nears Deal to Build Its Vision of a City in Toronto. (2017). https://www.wsj.com/articles/alphabets-city-building-unit-nears-development-deal-in-toronto-1507142561

[69] Elisa Giaccardi, Hal Eden, and Gerhard Fischer. 2006. The Silence of the Lands. In *Proceedings of the New Heritage Forum* (2006).

[70] Elisa Giaccardi, Hal Eden, and Gianluca Sabena. 2005. The Silence of the Lands: Interactive soundscapes for the continuous rebirth of cultural heritage, Vol. 303. 163–168.

[71] douard Glissant. 1997. For Opacity. In *Poetics of Relation*. The University of Michigan Press, 189–194.

[72] douard Glissant. 1997. *Poetics of relation*. University of Michigan Press.

[73] Chelsea Gohd. 2017. In a dystopian move, the SPCA is using a robot to scare off homeless people. https://futurism.com/dystopian-move-spca-using-robot-scare-off-homeless-people/

[74] Daniel Gooch, Annika Wolff, Gerd Kortuem, and Rebecca Brown. 2015. Reimagining the Role of Citizens in Smart City Projects. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers* (2015) *(UbiComp/ISWC'15 Adjunct)*. ACM, 1587–1594. https://doi.org/10.1145/2800835.2801622

[75] Antonietta Grasso, Alain Karsenty, and Dave Snowdon. 2000. A Bench for All Moods. In *CHI '00 Extended Abstracts on Human Factors in Computing Systems* (2000) *(CHI EA '00)*. ACM, 197–198. https://doi.org/10.1145/633292.633400

[76] Reinhard Gupfinger and Martin Kaltenbrunner. 2014. SOUND TOSSING Audio Devices in the Context of Street Art. In *Proceedings of the International Conference on New Interfaces for Musical Expression* (2014-06-01). https://doi.org/10.5281/zenodo.1178778

[77] Lars Hallns and Johan Redstrm. 2001. Slow Technology Designing for Reflection. 5, 3 (2001), 201–212. https://doi.org/10.1007/PL00000019

[78] Mike Harding, Bran Knowles, Nigel Davies, and Mark Rouncefield. 2015. HCI, Civic Engagement & Trust. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (2015) *(CHI '15)*. ACM, 2833–2842. https://doi.org/10.1145/2702123.2702255

[79] David Harvey. 2008. The Right to the City. 53 (2008), 23–40.

[80] Mariam Hassib, Daniel Buschek, Pawe?W. Wozniak, and Florian Alt. 2017. HeartChat: Heart Rate Augmented Mobile Chat to Support Empathy and Awareness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (2017) *(CHI '17)*. ACM, 2239–2251. https://doi.org/10.1145/3025453.3025758

[81] Andrew J. Hawkins. 2017. Alphabets Sidewalk Labs strikes deal to turn 800 acres of Toronto into an internet city. (2017). https://www.theverge.com/2017/10/17/16488942/alphabet-sidewalk-labs-toronto-quayside

[82] Jeppe Hein. 2008. Modified Social Benches L-U. http://www.jeppehein.net/pages/project_id.php?path=works&id=102

[83] J. Hernandez, D. J. McDuff, and R. W. Picard. 2015. BioInsights: Extracting personal data from wearable motion sensors. In *2015 IEEE 12th International Conference on Wearable and Implantable Body Sensor Networks (BSN)* (2015-06). 1–6. https://doi.org/10.1109/BSN.2015.7299354

[84] Javier Hernandez, Rob R. Morris, and Rosalind W. Picard. 2011. Call Center Stress Recognition with Person-specific Models. In *Proceedings of the 4th International Conference on Affective Computing and Intelligent Interaction* (2011) *(ACII'11)*, Vol. 1. Springer-Verlag, 125–134. http://dl.acm.org/citation.cfm?id=2062780.2062798

[85] Tad Hirsch, Kritzia Merced, Shrikanth Narayanan, Zac E. Imel, and David C. Atkins. 2017. Designing Contestability: Interaction Design, Machine Learning, and Mental Health. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (2017) *(DIS '17)*. ACM, 95–99. https://doi.org/10.1145/3064663.3064703

[86] Tad Hirsch, Christina Soma, Kritzia Merced, Patty Kuo, Aaron Dembe, Derek D. Caperton, David C. Atkins, and Zac E. Imel. 2018. "It's Hard to Argue with a Computer": Investigating Psychotherapists' Attitudes Towards Automated Evaluation. In *Proceedings of the 2018 Designing Interactive Systems Conference* (2018) *(DIS '18)*. ACM, 559–571. https://doi.org/10.1145/3196709.3196776

[87] Kristina Hk, Martin Jonsson, Anna St{\textbackslash}a ahl, Jakob Tholander, Toni Robertson, Patrizia Marti, Dag Svanaes, Marianne Graves Petersen, Jodi Forlizzi, Thecla Schiphorst, Katherine Isbister, Caroline Hummels, Sietske Klooster, Lian Loke, and George Poonkhin Khut. 2016. Move to Be Moved. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016) *(CHI EA '16)*. ACM, 3301–3308. https://doi.org/10.1145/2851581.2856470

[88] Kristina Hk, Martin P. Jonsson, Anna Sthl, and Johanna Mercurio. 2016. Somaesthetic Appreciation Design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016) *(CHI '16)*. ACM, 3131–3142. https://doi.org/10.1145/2858036.2858583

[89] Kristina Hk, Phoebe Sengers, and Gerd Andersson. 2003. Sense and Sensibility: Evaluation and Interactive Art. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003) *(CHI '03)*. ACM, 241–248. https://doi.org/10.1145/642611.642654

[90] Masamichi Hosoda, Akira Nakayama, Minoru Kobayashi, and Satoshi Iwaki. 2004. Conference State Estimation by Biosignal Processing: Observation of Heart Rate Resonance. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems* (2004) *(CHI EA '04)*. ACM, 1187–1190. https://doi.org/10.1145/985921.986020

[91] Noura Howell, John Chuang, Abigail De Kosnik, Greg Niemeyer, and Kimiko Ryokai. 2018. Emotional Biosensing: Exploring Critical Alternatives. 2 (2018), 69:1–69:25. Issue CSCW. https://doi.org/10.1145/3274338

[92] Noura Howell, Laura Devendorf, Rundong (Kevin) Tian, Toms Vega, Nan-Wei Gong, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. Biosignals as social cues: Ambiguity and emotional interpretation in social displays of skin conductance. In *Designing Interactive Systems (DIS)* (2016).

[93] Noura Howell, Laura Devendorf, Toms Vega Glvez, Rundong Tian, and Kimiko Ryokai. 2018. Tensions of data-driven reflection: A case study of real-time emotional biosensing. In *SIGCHI Conference on Human Factors in Computing Systems* (2018).

[94] Chen-Yu Hsu, Yuchen Liu, Zachary Kabelac, Rumen Hristov, Dina Katabi, and Christine Liu. 2017. Extracting Gait Velocity and Stride Length from Surrounding Radio Signals. ACM Press, 2116–2126. https://doi.org/10.1145/3025453.3025937

[95] Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B. Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stphane Conversy, Helen Evans, Heiko Hansen, Nicolas Roussel, and Bjrn Eiderbck. 2003. Technology Probes: Inspiring Design for and with Families. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2003) *(CHI '03)*. ACM, 17–24. https://doi.org/10.1145/642611.642616

[96] Adafruit Industries. [n. d.]. Electret Microphone Amplifier - MAX4466 with Adjustable Gain. https://www.adafruit.com/product/1063

[97] Adafruit Industries. [n. d.]. Stereo 3.7W Class D Audio Amplifier - MAX98306. https://www.adafruit.com/product/987

[98] Jane Jacobs. 1961. *The Death and Life of Great American Cities*. Vintage Books.

[99] Seiyoung Jang. 2018. Alata. http://www.seiyoungjang.com/music.html

[100] Seiyoung Jang. 2018. The Embodied Instrument: From Wearable Instruments to the Idealized Form.

[101] Tom Jenkins, Christopher A. Le Dantec, Carl DiSalvo, Thomas Lodato, and Mariam Asad. 2016. Object-Oriented Publics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016) *(CHI '16)*. ACM, 827–839. https://doi.org/10.1145/2858036.2858565

[102] Natalie Jeremijenko. 2016. Creative Agency and the Space Race of the 21st Century: Towards a Museum of Natural Futures. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (2016)

(DIS '16). ACM, 3–4. https://doi.org/10.1145/2901790.2915254

[103] Esther Johnson. 2015. Alone Together (The Social Life of Benches). https://www.nowness.com/story/alone-together-the-social-life-of-park-benches-esther-johnson

[104] Sofie Kinch, Erik Grnvall, Marianne Graves Petersen, and Majken Kirkegaard Rasmussen. 2013. Encounters on a Shape-changing Bench: Exploring Atmospheres and Social Behaviour in Situ. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction* (2013) *(TEI '14)*. ACM, 233–240. https://doi.org/10.1145/2540930.2540947

[105] Susan Kozel. 2012. AffeXity: performing affect using augmented reality. 21 (2012), 72–96.

[106] Stacey Kuznetsov and Eric Paulos. 2010. Participatory Sensing in Public Spaces: Activating Urban Surfaces with Sensor Probes. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (2010) *(DIS '10)*. ACM, 21–30. https://doi.org/10.1145/1858171.1858175

[107] Stacey Kuznetsov, Eric Paulos, and Mark D. Gross. 2010. WallBots: Interactive Wall-crawling Robots in the Hands of Public Artists and Political Activists. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (2010) *(DIS '10)*. ACM, 208–217. https://doi.org/10.1145/1858171.1858208

[108] Antti Latvala, Ralf Kuja-Halkola, Catarina Almqvist, Henrik Larsson, and Paul Lichtenstein. 2015. A Longitudinal Study of Resting Heart Rate and Violent Criminality in More Than 700 000 Men. 72, 10 (2015), 971–978. https://doi.org/10.1001/jamapsychiatry.2015.1165

[109] Miki Liu, Austin Wong, Ruhi Pudipeddi, Betty Hou, David Wang, and Gary Hsieh. 2018. ReactionBot: Exploring the Effects of Expression-Triggered Emoji in Text Messages. 2 (2018), 1–16. Issue CSCW. https://doi.org/10.1145/3274379

[110] John MacCallum and Teoma Naccarato. 2015. The Impossibility of Control: Real-time Negotiations with the Heart. In *Proceedings of the Conference on Electronic Visualisation and the Arts* (2015) *(EVA '15)*. BCS Learning & Development Ltd., 184–191. https://doi.org/10.14236/ewic/eva2015.19

[111] Remco Magielse and Panos Markopoulos. 2009. HeartBeat: An Outdoor Pervasive Game for Children. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2009) *(CHI '09)*. ACM, 2181–2184. https://doi.org/10.1145/1518701.1519033

[112] Aarian Marshall. 2017. Alphabet, Google, and Sidewalk Labs Start Their City-Building Venture in Toronto. (2017). https://www.wired.com/story/google-sidewalk-labs-toronto-quayside/?mbid=BottomRelatedStories

[113] Kenta Matsumura, Peter Rolfe, and Takehiro Yamakoshi. 2015. iPhysioMeter: a smartphone photoplethysmograph for measuring various physiological indices. 1256 (2015), 305–326. https://doi.org/10.1007/978-1-4939-2172-0_21

[114] Donald McMillan, Arvid Engstrm, Airi Lampinen, and Barry Brown. 2016. Data and the City. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016) *(CHI '16)*. ACM, 2933–2944. https://doi.org/10.1145/2858036.2858434

[115] Maureen Meadows and Matthijs Kouw. 2017. Future-making: inclusive design and smart cities. 24, 2 (2017), 52–56. https://doi.org/10.1145/3046429

[116] Nick Merrill, Max T Curran, and John Chuang. 2017. Is the Future of Authenticity All In Our Heads? Moving passthoughts from the lab to the world. In *NSPW* (2017).

[117] Nick Merrill, Max T Curran, Jong-Kai Yang, and John Chuang. 2016. Classifying mental gestures with in-ear EEG. 130–135.

[118] Joanna Montgomery. [n. d.]. Pillow Talk. http://www.littleriot.com/pillow-talk/

[119] Deirdre K. Mulligan, Colin Koopman, and Nick Doty. 2016. Privacy is an essentially contested concept: a multi-dimensional analytic for mapping privacy. 374, 2083 (2016). https://doi.org/10.1098/rsta.2016.0118

[120] Teoma Jackson Naccarato and John MacCallum. 2016. From representation to relationality: Bodies, biosensors and mediated environments. 8, 1 (2016), 57–72. https://doi.org/10.1386/jdsp.8.1.57_1

[121] Dawn Nafus. 2018. Exploration or Algorithm? The Undone Science Before the Algorithms. 33, 3 (2018), 368–374. https://doi.org/10.14506/ca33.3.03

[122] Gina Neff and Dawn Nafus. 2016. *Self-tracking*. MIT Press. OCLC: 952572176.

[123] Greg Niemeyer. 2016. Waves of Data: Illuminating pathways with San Leandro Lights. 6, 3 (2016), 80–83. https://doi.org/10.1525/boom.2016.6.3.80

[124] Helen Nissenbaum. 2004. Privacy as Contextual Integrity. 79 (2004).

[125] Safiya Umoja Noble. 2018. *Algorithms of oppression: how search engines reinforce racism*. New York University Press.

[126] Christian Nold. 2015. Micro/macro prototyping. 81 (2015), 72–80. https://doi.org/10.1016/j.ijhcs.2015.02.004

[127] Kerry OBrien. 2016. Listening as Activism: The Sonic Meditations of Pauline Oliveros. (2016). https://www.newyorker.com/culture/culture-desk/listening-as-activism-the-sonic-meditations-of-pauline-oliveros

[128] William Odom, Sin Lindley, Larissa Pschetz, Vasiliki Tsaknaki, Anna Vallgrda, Mikael Wiberg, and Daisy Yoo. 2018. Time, Temporality, and Slowness: Future Directions for Design Research. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility - DIS '18* (2018). ACM Press, 383–386. https://doi.org/10.1145/3197391.3197392

[129] Pauline Oliveros. 2007. My "American Music": Soundscape, Politics, Technology, Community. 25, 4 (2007), 389–404. https://doi.org/10.2307/40071676

[130] Doenja Oogjes, William Odom, and Pete Fung. 2018. Designing for an Other Home: Expanding and Speculating on Different Forms of Domestic Life. In *Proceedings of the 2018 Designing Interactive Systems Conference* (2018) *(DIS '18)*. ACM, 313–326. https://doi.org/10.1145/3196709.3196810

[131] A. Osman, J. Turcot, and R. E. Kaliouby. 2015. Supervised learning approach to remote heart rate estimation from facial videos. In *2015 11th IEEE International Conference and Workshops on Automatic Face and Gesture Recognition (FG)* (2015-05), Vol. 1. 1–6. https://doi.org/10.1109/FG.2015.7163150

[132] Eric Paulos and Chris Beckmann. 2006. Sashay: Designing for Wonderment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2006) *(CHI '06)*. ACM, 881–884. https://doi.org/10.1145/1124772.1124901

[133] Eric Paulos and Tom Jenkins. 2005. Urban Probes: Encountering Our Emerging Urban Atmospheres. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2005) *(CHI '05)*. ACM, 341–350. https://doi.org/10.1145/1054972.1055020

[134] Eric Paulos, Chris Myers, Rundong Tian, and Paxton Paulos. 2014. Sensory triptych: here, near, out there. ACM Press, 491–496. https://doi.org/10.1145/2642918.2647410

[135] Jonas Frich Pedersen and Marie Louise Juul Sndergaard. 2015. CityMockUp Co-Creating the Urban Space. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (2015) *(CHI EA '15)*. ACM, 43–48. https://doi.org/10.1145/2702613.2726957

[136] Rosalind W. Picard. 2015. Recognizing Stress, Engagement, and Positive Emotion. ACM Press, 3–4. https://doi.org/10.1145/2678025.2700999

[137] James Pierce, Phoebe Sengers, Tad Hirsch, Tom Jenkins, William Gaver, and Carl DiSalvo. 2015. Expanding and Refining Design and

Criticality in HCI. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (2015) *(CHI '15)*. ACM, 2083–2092. https://doi.org/10.1145/2702123.2702438

[138] Ming-Zher Poh, Daniel McDuff, and Rosalind Picard. 2011. A Medical Mirror for Non-contact Health Monitoring. In *ACM SIGGRAPH 2011 Emerging Technologies* (2011) *(SIGGRAPH '11)*. ACM, 2:1–2:1. https://doi.org/10.1145/2048259.2048261

[139] David Ribes. 2018. STS, Meet Data Science, Once Again. (2018), 0162243918798899. https://doi.org/10.1177/0162243918798899

[140] SA Rogers. 2012. Street Seats for the People: Bold Guerrilla Furniture. https://weburbanist.com/2012/03/06/street-seats-for-the-people-bold-guerrilla-furniture/

[141] Daniela Rosner. 2018. *Critical fabulations: reworking the methods and margins of design.* The MIT Press.

[142] Jathan Sadowski and Frank Pasquale. 2015. The spectrum of control: A social theory of the smart city. 20, 7 (2015). http://firstmonday.org/ojs/index.php/fm/article/view/5903

[143] Edward W. Said. 1978. *Orientalism* (1st ed ed.). Pantheon Books.

[144] A. Sano, A. J. Phillips, A. Z. Yu, A. W. McHill, S. Taylor, N. Jaques, C. A. Czeisler, E. B. Klerman, and R. W. Picard. 2015. Recognizing academic performance, sleep quality, stress level, and mental health using personality traits, wearable sensors and mobile phones. In *2015 IEEE 12th International Conference on Wearable and Implantable Body Sensor Networks (BSN)* (2015-06). 1–6. https://doi.org/10.1109/BSN.2015.7299420

[145] Gordan Savicic and Selena Savic. 2013. *Unpleasant Design.* G.O.R.I.A.

[146] Thecla Schiphorst. 2009. Soft(N): Toward a Somaesthetics of Touch. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (2009) *(CHI EA '09)*. ACM, 2427–2438. https://doi.org/10.1145/1520340.1520345

[147] Thecla Schiphorst. 2011. Self-evidence: Applying Somatic Connoisseurship to Experience Design. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (2011) *(CHI EA '11)*. ACM, 145–160. https://doi.org/10.1145/1979742.1979640

[148] Natasha Dow Schll. 2016. Data for life: Wearable technology and the design of self-care. 11, 3 (2016), 317–333. https://doi.org/10.1057/biosoc.2015.47

[149] Holger Schndelbach, Nils Jger, Sara Nabil, Nick Dalton, David Kirk, and Elizabeth Churchill. 2017. People, Personal Data and the Built Environment. In *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems* (2017) *(DIS '17 Companion)*. ACM, 360–363. https://doi.org/10.1145/3064857.3064864

[150] Benjamin Schneider. [n. d.]. How Park(ing) Day Sparked a Global Parklet Movement. https://www.citylab.com/life/2017/09/from-parking-to-parklet/539952/

[151] Elaine Sedenberg, Richmond Wong, and John Chuang. 2018. A Window into the Soul: Biosensing in Public. In *Surveillance, Privacy and Public Space*. 87–110. https://www.taylorfrancis.com/books/e/9781351780193/chapters/10.4324%2F9781315200811-15

[152] Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph 'Jofish' Kaye. 2005. Reflective Design. In *Proceedings of the 4th Decennial Conference on Critical Computing* (2005) *(CC '05)*. 49–58. https://doi.org/10.1145/1094562.1094569

[153] Phoebe Sengers, Kirsten Boehner, Michael Mateas, and Geri Gay. 2008. The disenchantment of affect. 12, 5 (2008), 347–358. https://doi.org/10.1007/s00779-007-0161-4

[154] Matt Simon. [n. d.]. The Tricky Ethics of Knightscope's Crime-Fighting Robots. https://www.wired.com/story/the-tricky-ethics-of-knightscopes-crime-fighting-robots/

[155] M. Sivarathinabala and S. Abirami. 2014. Automatic identification of person using fusion of gait features. In *2014 International Conference on Science Engineering and Management Research (ICSEMR)* (2014-11). 1–5. https://doi.org/10.1109/ICSEMR.2014.7043628

[156] Petr Slovk, Joris Janssen, and Geraldine Fitzpatrick. 2012. Understanding Heart Rate Sharing: Towards Unpacking Physiosocial Space. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2012) *(CHI '12)*. ACM, 859–868. https://doi.org/10.1145/2207676.2208526

[157] Petr Slovk, Greg Wadley, David Coyle, Anja Thieme, Naomi Yamashita, Reeva Lederman, Stefan schutt, and Mia Doces. 2015. Developing Skills for Social and Emotional Wellbeing. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (2015) *(CHI EA '15)*. ACM, 2397–2400. https://doi.org/10.1145/2702613.2702654

[158] Jaime Snyder, Mark Matthews, Jacqueline Chien, Pamara F. Chang, Emily Sun, Saeed Abdullah, and Geri Gay. 2015. MoodLight: Exploring Personal and Social Implications of Ambient Display of Biosensor Data. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing (CSCW'15)* (2015). ACM Press, 143–153. https://doi.org/10.1145/2675133.2675191

[159] Beomjune Son, Conner Hunihan, and Soravis Prakkamakul. 2018. SoundGlove: Multisensory Exploration of Everyday Objects for Creative Purposes. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (2018) *(CHI EA '18)*. ACM, LBW628:1–LBW628:6. https://doi.org/10.1145/3170427.3188554

[160] Shenando Stals. 2017. Exploring Emotion, Affect and Technology in the Urban Environment. In *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems* (2017) *(DIS '17 Companion)*. ACM, 404–406. https://doi.org/10.1145/3064857.3079172

[161] Shenando Stals, Michael Smyth, and Oli Mival. 2017. Exploring People's Emotional Bond with Places in the City: A Pilot Study. In *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems* (2017) *(DIS '17 Companion)*. ACM, 207–212. https://doi.org/10.1145/3064857.3079147

[162] Franziska Maria Tachtler. 2017. Best Way to Go?: Intriguing Citizens to Investigate What Is Behind Smart City Technologies. In *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems* (2017) *(DIS '17 Companion)*. ACM, 28–33. https://doi.org/10.1145/3064857.3079113

[163] Evangelos Theodoridis, Georgios Mylonas, Veronica Gutierrez Polidura, and Luis Munoz. 2014. Large-scale Participatory Sensing Experimentation Using Smartphones Within a Smart City. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services* (2014) *(MOBIQUITOUS '14)*. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 178–187. https://doi.org/10.4108/icst.mobiquitous.2014.258016

[164] Rundong Tian, Christine Dierk, Christopher Myers, and Eric Paulos. 2016. MyPart: Personal, Portable, Accurate, Airborne Particle Counting. ACM Press, 1338–1348. https://doi.org/10.1145/2858036.2858571

[165] Peter van Waart, Eva Visser, and Maaike Harbers. 2015. How to Design for Diversity in Smart Cities?. In *Cultural Diversity and Technology Design Workshop at the 7th International Communities and Technologies Conference* (2015).

[166] F. J. Villanueva, M. J. Santofimia, D. Villa, J. Barba, and J. C. Lpez. 2013. Civitas: The Smart City Middleware, from Sensors to Big Data. In *2013 Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing* (2013-07). 445–450. https://doi.org/10.1109/IMIS.2013.80

[167] Carissa Vliz. 2018. In the privacy of our streets. In *Surveillance, Privacy, and Public Space*, Bryce Clayton Newell, Tjerk Timan, and Bert-Jaap Koops (Eds.). Routledge, 16–32.

[168] Jayne Wallace, Jon Rogers, Michael Shorter, Pete Thomas, Martin Skelly, and Richard Cook. 2018. The SelfReflector: Design, IoT and the High Street. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (2018). ACM Press, 1–12. https://doi.org/10.1145/3173574.3173997

[169] Wouter Walmink, Alan Chatham, and Florian Mueller. 2013. Duel Reality. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (2013) *(CHI EA '13)*. ACM, 2849–2850. https://doi.org/10.1145/2468356.2479543

[170] Tom White and David Small. 1998. An Interactive Poetic Garden. In *CHI 98 Conference Summary on Human Factors in Computing Systems* (1998) *(CHI '98)*. ACM, 335–336. https://doi.org/10.1145/286498.286804

[171] William H. Whyte. 1979. Social Life of Small Urban Spaces. http://www.imdb.com/title/tt1778327/ IMDb ID: tt1778327.

[172] Kyle Wiggers. 2017. Meet the 400-pound robots that will soon patrol parking lots, offices, and malls. https://www.digitaltrends.com/cool-tech/knightscope-robots-interview/

[173] Donghee Yvette Wohn and Wei Peng. 2015. Understanding Perceived Social Support Through Communication Time, Frequency, and Media Multiplexity. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (2015) *(CHI EA '15)*. ACM, 1911–1916. https://doi.org/10.1145/2702613.2732866