Mapping the Landscape of Sustainable HCI

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ABSTRACT
With the recent growth in sustainable HCI, now is a good time to map out the approaches being taken and the intellectual commitments that underlie the area, to allow for community discussion about where the field should go. Here, we provide an empirical analysis of how sustainable HCI is defining itself as a research field. Based on a corpus of published works, we identify (1) established genres in the area, (2) key unrecognized intellectual differences, and (3) emerging issues, including urgent avenues for further exploration, opportunities for interdisciplinary engagement, and key topics for debate.

Author Keywords
Sustainable HCI, sustainability, reflective HCI

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g.,HCI): Miscellaneous.

ACM General Terms
Human Factors

INTRODUCTION

From the first appearance of two landmarks at CHI 2007 of what became the nascent subfield of "sustainable HCI" [11,49] – the area has exploded. In early 2009, Goodman [29] found 120 papers and grant abstracts related to the topic of the environment in HCI, while in our more tightly scoped initial survey in August 2009 we found 157 papers related to sustainability. In our initial review of papers in this area, we were struck by the remarkable heterogeneity of methods, orientations, and approaches, which have contributed to the rubric of sustainable HCI. With the explosive growth that has happened in this area, now is an opportune time to step back and catalog the approaches and orientations that are being taken and to map out the differing intellectual commitments that underlie the area. This will allow for community discussion about the pros and cons of different approaches and the assumptions that they entail about design, use, sustainability, and the role that HCI should play in it.

In this paper we present a map of the current landscape of sustainable HCI that differentiates and organizes the approaches that have emerged in the field. Our goal is not to present a single definitive clustering, since any clustering of work in the field depends heavily on the criteria one uses for differentiation. Instead, we provide 3 lenses for understanding the structure of current work: we will describe (1) the primary emerging *genres* of work, or common frameworks that structure how researchers define the problem of sustainable HCI and structure what is an appropriate solution; (2) the (often implicit) *axes of difference* among works, or substantially differing commitments to issues around sustainability and the role HCI should play in it, which underlie work in different genres and often even in the same genre; and (3) emerging issues: areas where there is already substantial agreement on methods and outcomes, areas where (perhaps even despite such agreement) there are major avenues for exploration that have been relatively untouched, subfields that should be put into contact with each other or with sustainable HCI as a whole, and key issues on which researchers appear to unknowingly disagree, and would be worth more explicit debate and discussion. Our goal is to provide a reflective lens for practitioners of sustainable HCI which will allow for principled, reflective discussion of how we have, until now, defined sustainable HCI, and how we might best choose to do so in going forward.

RELATED WORK

Our work was informed firstly by programmatic statements in sustainable HCI, which set out what people think the field should be or might be, and aim to recruit work in the area. Most prominently cited is Blevis [11], who draws on product and critical design. He argues for a need to alter the role that HCI currently plays within rapid product obsolescence cycles, and for a research agenda based on reducing the material effects of technology both directly (e.g., through making products that can be replaced modularly rather than wholesale) and indirectly (e.g., through making products with heirloom quality so that they will not be so quickly discarded). Mankoff et al. [49] offer a now widely adopted categorization of sustainable HCI into two orientations: sustainability *in* design (mitigating material effects of software/hardware), and sustainability

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CHI 2010, April 10–15, 2010, Atlanta, Georgia, USA.
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through design (influencing sustainable lifestyles or decision-making). Mankoff, Kravets and Blevis [50] identify ways computer scientists can help reduce energy usage: by reducing computers' energy consumption and electronic waste through, for example, control systems or educational applications, and by supporting climate data collection and science. Tscheligi, Reitberger, de Ruyter, and Markopoulos [68,74] argue that persuasive technology can be a key ingredient of sustainable HCI by giving users information about the environmental impact of their actions, and by increasing the desirability of pro-environmental behavior.

In pervasive sustainability, Jain and Wullert [42] look at sustainability *in* design. They address the material effects of pervasive systems by improving performance per unit of material or energy, by making computational devices longer-lasting, and through better recycling and disposal. In their presentation of example projects in pervasive sustainability, Cardenas-Tamayo et al. [18] focus on sustainability *through* design; most of the projects are based on sensor networks, with a wide range of applicable areas, from participatory design to sensor networks for building energy modeling. Woodruff and Mankoff [79] include both kinds of projects; they see the core challenges of sustainability as including "monitoring the state of the physical world; managing the direct and indirect impacts of large-scale human enterprises such as agriculture, transport, and manufacturing; and informing individuals' personal choices in consumption and behavior." Foth, Paulos, Satchell and Dourish [26] argue that pervasive sustainability should shift focus from the individual scale to sustainability at larger scales and within broader social frameworks.

Unlike most of these previous papers, our primary goal here is not to describe what sustainable HCI should be but to identify empirically what it has already become and to identify structural features and trade-offs in the research landscape. In that sense, our work is most similar to critical analyses of sustainable HCI, such as those provided by Pierce, Roedl, Odom, and Blevis [63,64,65]. These papers provide frameworks for understanding the design decisions made and the trade-offs among different factors which emerge from a comparison of different approaches to the same problem. Because our focus is on the research literature as a whole, rather than on specific designs, our work is most indebted to Goodman [29], who seeks to clarify differences in orientation and methodology that underlie work which self-identifies as "environmental" HCI. Goodman clusters work in environmental HCI according to its implicit theory of human action through technology [Goodman, personal communication, 8/18/2009], which leads to three broad clusters of work: "sustainable interaction design, revisioning consumption and citizen sensing." In this paper, we build on Goodman's analysis by providing multiple orienting principles which allow for several clusterings of work and show how contributions in apparently different subareas of sustainable HCI in some ways conflicts and in some ways relate to each other.

Like these analyses, our work in this area is intended not only to further the state of sustainable HCI but also to provide an exemplar of rigorous humanities research in HCI. In this we build on prior work drawing on critical theory such as Bardzell's interaction criticism [8,9,13,69] by moving criticism from a focus on particular interaction designs to the state of the field overall. In the vein of epistemological analyses such as [14,35,45], we aim to show how careful, critical analysis of differing perspectives on research in the field and their relationship to deeper underlying intellectual commitments and trends can benefit HCI by providing reflective scaffolding for future research.

METHODOLOGY

We began our analysis by constructing a corpus of papers on sustainable HCI by searching the ACM Guide to Computing Literature on the term "sustainable HCI." Each paper returned, and any paper it cited, was examined to see if it was a sustainable HCI paper; if so, it was added to our corpus. The criteria for a "sustainable HCI" paper were: (1) Was a primary goal of the work sustainability-related? For example, papers on carpooling without a discussion of environmental effects were excluded. (2) Was the intended audience the HCI community? This second criterion was used to exclude papers that were about environmental IT but published for other audiences, such as in environmental psychology. We then split the corpus into two subsets: (1) 25 programmatic statements (for example, panel and workshop abstracts promoting sustainable HCI) and analyses of sustainable HCI, used to inform our rubric; and (2) 58 peer-reviewed journal or conference papers, notes and works in progress, the topic of our analysis.

Next, we developed a rubric of questions to ask about each paper. We read the programmatic statements and analyses, looking for issues that appeared to recur or that would illuminate differences between different sustainable HCI approaches. This resulted in the following questions: (1) how does the paper define and justify attention to sustainable HCI? (2) what disciplinary orientation is used? (3) how is the problem of sustainability and its solution framed? Goodman and DiSalvo, Boehner, Knouf and Sengers [21,29] served as inspiration for the following questions. (4) How is the role of the researcher framed? (5) Who takes action, or is supposed to take action? (6) Who is considered the 'expert,' and whose point of view is questionable? (7) How do the authors deal with political disagreements about the environment? (8) Does the paper aim to establish a definitive truth, or does it leave open the possibility of serious differences of opinion about its subject matter? (9) What constitutes success?

For each paper in the corpus, we wrote a summary and a narrative answer to each of these questions. As we did so, we discussed patterns that emerged – methodologies and

frameworks that were frequently repeated, issues that were discussed (or surprisingly not discussed), areas where there seemed to be substantial agreement or disagreement – as well as flagging papers that appeared to march to the beat of a different drummer. After finishing this review, we developed a spreadsheet with coded answers for each question to further identify patterns. Based on our review, we developed three forms of analysis: (1) genres, or clusters of papers which share problem formulations; (2) axes of difference, or major differences among papers from the same or different genres; (3) emerging issues, including areas that are over or underexplored, potential interdisciplinary connections, and key topics for debate. The rest of the paper describes these results.

GENRES

Genres are emergent clusters of research that draw from similar sources, share a general problem formulation, and have similar ideas of how to approach solving those problems. They tend to share key citations and to cross-cite each other. We expect that authors would generally recognize our analysis of their genre. Identifying these genres and how they work may be useful for researchers who are looking for how to make a well-defined sustainable HCI contribution, or to seek new ground within the space of sustainable HCI by avoiding areas already substantially covered. These genres cover most but not all papers in our corpus, since some contributions are novel in their formulation. The genres are not necessarily mutually exclusive, as papers may speak to multiple literatures.

Persuasive technology

Persuasion is a major theme in the sustainable HCI literature, comprising about 45% of our corpus (Woodruff, Hasbrouck and Augustin found a similar preponderance [78]). About 45% of these trace their theoretical rationale to BJ Fogg's theory of persuasive technology [25]. Many of these papers come from a psychology or CMC orientation, although some are more design-oriented. Within this genre, the standard approach is to design systems that attempt to convince users to behave in a more sustainable way. The design strategies employed can be generally divided into (1) strong persuasion, in which information is provided about the extent to which a user's behavior is or is not sustainable [e.g.,7], and (2) passive persuasion, in which information about consumption, waste or other broad impact effects are presented to the users, usually implicitly contextualized within the topic of sustainability [e.g.,1,30,31]. Relatively few papers employ design strategies that prescriptively enforce particular behavior patterns [e.g.,43,55]. Papers vary in whether the user is intended to be consciously aware of the persuasion [e.g.,1,2] or not [e.g.,33,71].

Within this approach, what constitutes "sustainable behavior" is usually determined by designers. Few papers cite an empirical external basis for the desired behavior. Rather, in most cases, the constitution of sustainable behavior is fairly general, often revolving around themes of resource usage and conservation [e.g.,2,5,24,30,31,44,52, 53,73]. What counts as success — the basis of evaluation — is behavior change or decision-making that aligns with the predetermined desired behaviors. However, not all of the papers within this genre evaluate the sustainability effects of the design — many such papers are design descriptions [e.g.,30], while others use sustainability applications primarily as a target domain to test theories of persuasion, rather than aiming to enhance sustainability per se [e.g.,33,54,70,73].

Ambient awareness

Ambient awareness systems draw upon the histories of calm computing and ambient displays to construct systems intended to make users aware of some aspect of the sustainability of their behavior, or qualities of the environment associated with issues of sustainability (about 25% of our corpus). The forms of these systems range dramatically, from devices and physical artifacts [e.g.,30,31] to visualizations [e.g.,37] to instrumented environments [e.g.,5,16] and intelligent agents [e.g.,1]. For example, the Static! project (http://www.tii.se/static/) included the Power Aware Cord that glows in response to energy consumption, and the Flower Lamp that blooms as energy consumption in a household decreases over time. These projects demonstrate two primary design tactics employed in this genre: the former makes consumption visible in order to prompt awareness of use [e.g.,5], while the latter makes visible (and aesthetically rewarding) desirable consumption patterns [e.g.,31]. There is a large overlap between ambient awareness and persuasive technology: many persuasive systems are ambient, based on the idea that the ambiently provided information will persuade the user to behave sustainably.

Sustainable interaction design

Sustainable interaction design (SID)[11] describes papers oriented around using sustainability as a "critical lens" [34] to rethink the role and outcomes of design (ca. 10% in our corpus). These works come out of and often speak to the design research literature, and are frequently philosophically and critically oriented. While the previous two genres take known approaches in HCI and apply them to sustainability as a problem domain, SID works tend to see a need to fundamentally rethink the methods of HCI in order address sustainability. Many of the papers in this area see designers as complicit in the unsustainability of current interactive products, aiming to change design to encourage more sustainable effects. The work is often focused on material effects, i.e. reducing resource wastage and pollution, especially due to the rapid obsolescence of current technologies [e.g.,80]. Some papers address other issues such as encouraging mass transportation [67]. Methodologies in this genre vary, including conceptual design [e.g.,67], critical design [e.g.,31], thought pieces [e.g.,11], and design criticism [e.g.,64].

Formative user studies

This genre consists of studies to understand users' attitudes to the environment or to (un)sustainable design (ca. 15%). In contrast to the prior genres, which tend to focus on how *designers* conceive of sustainability, this work aims to understand how *users* think about and approach sustainability as a first step to new design. Methodologies vary from large-scale quantitative studies [e.g.,34] to qualitative interviews [e.g.,40] and ethnography [e.g.,20,78] Unlike persuasive and (to a lesser degree) ambient works, which tend to be based on notions of right and wrong behavior and to see individuals as responsible for changing behaviors for the better, these works tend to legitimize differences in attitude towards sustainability and to show how individuals are embedded in social and cultural systems which constrain the potential sustainability of their behavior. Huang, et al., [40], for example, show how differences in mobile-phone contracts in North America, Germany, and Japan lead to differing opportunities in practice for mobile phone reuse. Most of these works focus on users as consumers; Aoki et al. [4] is a notable exception looking at a variety of stakeholder groups.

Pervasive and Participatory Sensing

A significant emerging strand of work uses sensors to monitor and report on (usually adverse) environmental conditions, with the implicit goal of using the data collected to change these conditions (ca 22% of our corpus). Some of this work uses sensing as an embedded component in larger semi-automated systems, such as to measure the perishability of food in distribution networks [41] or to trigger feedback to steer cattle away from environmentally-sensitive regions [76]; these works are part of a sensing literature that extends beyond HCI into engineering. Within HCI, many of these papers focus on *participatory sensing*, which generally means the involvement of non-experts in collecting data from sensing platforms. Participants are non-experts in that they do not have advanced knowledge of sensing technologies and/or methods of data collection, however, the participants may be experts in the context being sensed. For example, in the Cyclesense pilot project Biketastic (http://biketastic.com/), bicyclists are enrolled to collect data concerning road surface conditions in Los Angeles, using the built-in accelerometers and GPS services in mobile phones. As experts in context, bicyclists dynamically select varied routes through city and in the process collectively contribute a rich set of data; ostensibly richer, more varied, and thus more representative to that context than if the data was collected by the engineers, computer scientists or designers developing the Biketastic system. One catchphrase used in the literature for such work is "citizen science" [27,62]; work under this label tends to emphasize the democratic potential of involving end users in data collection, a theme shared with community environmental information systems [e.g.,32,51].

Limitations of genre analysis

There are a variety of genres which could have been part of our analysis but were not. Some genres, such as sustainable games [e.g.,6,7] and critical analysis of sustainability [21,23,29], had too few exemplars to sustain a full analysis. Other genres unexpectedly did not appear in the corpus; the implications will be discussed in Emerging Issues.

AXES OF DIFFERENCE

In the previous section, we described clusters of work that largely share commitments to how the problems of sustainable HCI should be formulated and how a researcher should approach finding a solution. In this section, we shift focus to major differences or disagreements which underlie works in our corpus, often even works in the same genre. Our goal is not to adjudicate these disagreements but to demonstrate that, despite the relative lack of debate about these issues within the field, there are real differences of commitment between these works, which would be worthwhile for sustainable HCI researchers to discuss.

Sustainability as research focus vs. application area.

Many of the works in our corpus take sustainability as the central focus of interest, with tools and methods chosen or adapted as appropriate to address concerns about sustainability [e.g.,11,37,57, 50]. Other works start with an interest in particular tools and methods, and use sustainability as an application domain to test out those tools and methods [e.g.,3, 5,22]; this is particularly common in the persuasive technology genre. On the one hand, work that takes sustainability as its focus more strongly integrates notions of sustainability within research methods, while taking sustainability as a convenient application domain may address sustainability more superficially or even misaddress some issues (for example, by not considering the possible wastefulness of energy used by a game to teach people not to waste energy). On the other hand, papers grounded in other literatures that use sustainability as an application area may add novel perspectives and techniques to sustainable HCI. It is also important to recognize that no HCI researcher comes to sustainability without pre-existing concepts, methods, and approaches; hence, this axis is more a relative scale of commitment to the area than a binary opposition.

Individual consumers vs. other users, groups, or scales.

We found that the bulk of papers in the corpus (about 70%) target users conceived of as individual consumers, either directly (e.g., by understanding them, educating them or changing their behavior) or indirectly (e.g., by altering design practice in order to provide consumers with more sustainable options for purchasing or reuse). Foth, Paulos, Satchell and Dourish [23,26] argue for the need to design for other 'scales' such as building affiliative groups or at the level of the nation-state, like designing for activist groups [29,61,66,78] or multiple stakeholders [4,57]. A few researchers target food production and distribution systems [41,76]. Another option is to keep the focus on individuals,

but see them through the lens of other social roles. For example, participatory sensing and other community-oriented work [17,22,32,58] tend to see individuals as members of a democratic public, as citizens rather than as consumers, while Bohlen and Tan and Kobayashi, Ueoka and Hirose [15,47] design to increase affective links to nature without reference to consumption.

Users as the problem vs. solving users' problems.
Many of the papers in our corpus see user behavior as causing environmental problems and therefore in need of change. This orientation frequently arises in persuasive and ambient works, which aim to let users know which aspects of their behavior are environmentally problematic and/or prod them to change. An extreme example is Wark et al. [76], who manipulate their cattle 'users' with mild electrical shocks in order to keep them out of environmentally sensitive areas. Other papers, notably the formative studies, aim to drive design primarily from needs and opportunities raised by users, rather than seeing them as the problem. On this axis, there are many boundary cases that aim to balance recognizing the unsustainability of user behavior with user-centered design. In sustainable interaction design for example, unsustainable behavior is often seen as a problem caused not by bad users but by bad design, with the solution being better design options that will enable more positive behavior. Yun [81] evaluates persuasive technologies designed to promote a particular behavioral change, but evaluates with respect to how the technology is appropriated by users in unexpected ways. Strengers [72] looks to reduce resource use in cleaning and climate control, while detailing the challenges and cultural constraints to changing behavior that users uncover in daily life and that make a simple focus on awareness of resource use inadequate. Wash [77] aimed to encourage the use of public transportation but found through user-centered design techniques that the best match between designer aims and user wants was to increase the efficiency of car usage instead.

Improving vs. fundamentally changing lifestyles.
Some of the papers in our corpus support current lifestyles while increasing their sustainability, for example by supporting existing activities while reducing their resource usage [e.g.,42]. Others, notably many in sustainable interaction design, emphasize the need for fundamental cultural change, rather than simply increasing the efficiency of current lifestyles [34]. There are trade-offs between these approaches; Goodman [29] argues that works aiming for cultural change address a more fundamental aspect of sustainability, but because of their long-term orientation tend to be speculative and difficult to evaluate. Chetty et al. [19] similarly argue that while changing user behavior is indirect and difficult, engineering away underlying inefficiencies may lead to a faster short-term win.

Technology as an adequate vs. inadequate solution.
Unsurprisingly, given that a major activity of HCI researchers is building technologies, many of the papers in our corpus focus on technological solutions to the problems of sustainability, for example by improving the material design of technologies [36], encouraging sustainable behavior [28], or improving the efficiency of our everyday activities [43]. Yet some researchers question the ability of technology alone to provide a solution for sustainability. Some point to a need for tying in to broader efforts in sustainability [e.g.,37], such as policy reform [32,38,40, 79], business practices [40], or consumer education [40]. Others see a need for technology design to be contextualized within broader cultural issues in the use of technology [48] public debates [58], and the politics of information access [32]. Yet others take a broader view of design involving not only the technology but also awareness of, and space for, non-technological or contextual issues: Wakkary and Wash [75,76] argue for designing for openness and reappropriation, Bohlen and Tan [15] limit their technology to leave space for more direct interaction with nature, and DiSalvo et al. [22] emphasize the importance of participatory, communal aspects of design over the 'final product.' A few question whether technical solutions to sustainability are even possible [e.g., 56]. Kobayashi et al. [47], for example, point out the inherent contradiction in attempting to use technology to create more intimate connections with nature.

HCI as usual vs. HCI must be rethought.
The majority of papers in our corpus use existing HCI methods and orientations to approach problems of sustainability, but others argue that the structure of HCI as a field itself contributes to the problems of unsustainability. A common argument [e.g.,11,56,75,80] is that HCI supports a wasteful rapid obsolescence cycle of IT products, requiring rethinking the relationship between HCI research practice and industry. A few authors point to specific methodological issues raised by sustainability, suggesting for instance that the packageable methods popular in HCI map poorly to sustainability because they fail to take into account the complexity of the problem [11], that design driven by formal models of user needs leads to rapid obsolescence when new needs are found [75], or that evaluation of long-term and systemic effects is a blind spot for HCI [39,57]. DiSalvo et al. [21] suggest that disciplines with a longer history of engagement with the environment – in their case eco-arts – provide useful lenses for rethinking how sustainable HCI should be constituted.

Political differences are relevant vs. irrelevant.
Issues around the environment are a source of great political debate in society. The overwhelming majority of research and design in sustainable HCI does not acknowledge or address such differences as part of the research. Persuasive technologies, for example, generally start from the idea that there are known, right and wrong ways to relate to the environment, and technology should

help users relate in the right way. There is however, a growing contingent of research that reports on and, in some cases, engages the politics of sustainability and the environment in a variety of ways [e.g.,21]. Some researchers look at varying politics among users; for example, Aoki et al. [4] discuss differences in politics within the environmental movement, while Woodruff et al. and Hank et al. [34,78] differentiate users' orientations to sustainability and highlight how this leads to a need for different forms of design. Several researchers argue for the need to design systems to support political activism [29,61,66,78,]. Other researchers focus on how political differences may directly affect HCI research itself. Aoki et al.'s research on environmental sensing [4] looks at how data collection and use is a political issue concerning questions of expertise and participation, aiming through this discussion to make HCI researchers aware of the political landscape of environmental sensing. Nathan et al. [57] likewise recognize the politics inherent in design and planning, and propose a method for HCI researchers to work within the politics of a situation through the development of value-driven scenarios. Blevis [10] notes that the discourses and practice of design have political impact beyond the fields of interaction design and HCI. Similarly, Dourish [23] discusses how apparently 'external' politics play a role in shaping our ideas of sustainable HCI.

EMERGING ISSUES

Throughout the genres and axes of difference, our cataloging and categorization of sustainable HCI has been descriptive, with an emphasis on reporting on the current state of the field. In this section, we will describe issues that emerge from this analysis, providing key topics for future research and reflective discussion in sustainable HCI.

Knowns and Unknowns

In the sizable subgenres of HCI there is a noticeable redundancy, with researchers frequently devising similar approaches and coming to similar conclusions. Such redundancy does not advance us towards the objectives of sustainability, in fact it can hinder progress. To avoid reinventing the wheel, there is a need for the field to take stock of what is known and to identify major unknown questions or issues, which arise from what has been established, as a basis for future work. While during early development of a field, any exploratory work can make a substantial contribution, it is imperative now for the field to recognize that well-defined subgenres of sustainable HCI have become established and that in those areas work should be required to clearly extend, rather than replicate, already-published works. For example, a significant body of research has documented the need to design products and services to which users develop greater attachments, so as to intervene in the cycle of rapid obsolescence [12,59,80]. This leads to unaddressed challenges, such as how we might support users attached to software and hardware that has been declared obsolete by the industry. Similarly, it is widely established as a design concept that ambient displays may support environmental behavior change, but there are few studies that demonstrate actual changes in resource usage and none we found do so beyond a few-week sample deployment. Other authors have suggested that we frequently address individual consumers, but now need to find ways to address collectives and regional and national contexts [26,29,23]; that we frequently rely on users' moral conscience, but need to find other ways to engage users [26,23]; that we frequently address sustainability through technology design, but need to find ways to address policy issues [29,78]; or that we frequently design from a position of experts, but we need to find ways to help users become experts on sustainability on their own terms [72,78]. What is needed now is not the repetition of these insights, but rather the use of this knowledge as the basis for discovering new problems for inquiry and shaping design endeavors.

Open Areas, Potential Connections

Despite the interdisciplinary nature of sustainability as a topic and the vast amount of related research in many fields, connections to these fields by works in sustainable HCI are fairly ad hoc. The literatures drawn on within HCI depend primarily on the disciplinary orientation of the authors, which corresponds to some degree to the genres identified previously. Ethnographic approaches, for example, frequently draw on anthropological and critical studies of the environment; while within persuasive technology, which has a strong social psychology component, many authors draw on environmental psychology. While these individual connections have demonstrated the practical value of drawing on the broader literatures of sustainability, it is important that we now step back and systematically survey which areas have not yet been drawn on and what they could do for us. For example, although there is a significant body of literature on rhetorical communication and persuasion on environmental issues and behavior, this is largely absent from the persuasive research. Likewise, there is a significant body of literature in Science and Technology Studies (STS) that has addressed the role of technology with respect to the environment, the politics of environmental information, and the history and problematics of various stances to environmentalism, but this is insufficiently addressed in sustainable HCI. As Aoki et al. [4] discuss, it is well known in STS that environmental sensing is a contentious political issue, but relatively unknown by HCI. Other potential connections exist, for example, to the eco-arts [21], environmental history, or ecological economics.

Another area where connections wait to be built is to professional design. Although sustainable interaction design is building strong ties to the design *research* community, there is a significant gap between the *professional* fields of industrial and interaction design and design research in sustainable HCI. One could argue that this is not specific to sustainable HCI; the disconnect with the professional design community is systemic throughout HCI. However,

given the interest in sustainability within contemporary design, this lack of connection is problematic. For example, there are initiatives within most professional design organizations to foster sustainable design practices, relevant exhibitions and monographs, trade publications featuring sustainable products and practices, and popular design press and scholarly design journals that have taken up this topic through articles and online media. And yet, with few exceptions, this work is unaddressed in sustainable HCI literature. This situation is not limited to industrial and interaction design; such a disconnect is also present between sustainable HCI and architecture and urban design.

There is even a noticeable lack of connection between sustainable HCI and other technical fields, as revealed by the redundancy of research across engineering and computer science. Although one might expect a fair amount of connection between these fields, in our review we found the opposite to be the case. For example, with the exception of the genre of participatory sensing, there are few papers that span references across ACM and IEEE, even when topics clearly overlap. We found papers on designing technologies for domestic and consumer use in the IEEE with no references to the bulk of research on this topic from the CHI community [e.g.,24]. Similarly, we found numerous examples of persuasive systems in both the ACM and IEEE, which conceptually replicate one another. Such redundancy is illustrative of a severely problematic disconnect with related disciplines, resulting in the over-production of knowledge and missed opportunities for advancing the contribution of technology design and development to sustainability.

These issues prompt the question "What are, or should be, the boundaries of sustainable HCI?" We were forced to tackle this question in developing our corpus, and chose to include only papers that were concerned with sustainability or the environment, and oriented to the HCI audience. An unexpected consequence was that several genres which we expected to be relevant were poorly represented in our corpus because of these exclusion criteria. For example, works on low-power displays [e.g.,36] are generally focused on maximizing mobile battery use rather than on sustainability, while publications on environmental information systems [e.g.,32] tend to be focused towards non-HCI audiences. That this disconnect is not simply an artifact of our analysis but an unfortunate fact of life is suggested by papers like Orthofer and Loibl's [60], which describes a novel environmental information system and concludes that attention to the user interface would have been helpful to make it work. There is a clear need for sustainable HCI to draw on the expertise of researchers in areas such as hardware, environmental information systems, and community information systems, and there is also a clear need for HCI expertise in those areas; the question for us as a field is how to set up those conversations, given that we cannot expect their practitioners to show up at CHI.

One example of how such connections can be built comes from the participatory sensing genre. This genre not only spans disciplinary lines, but also weaves multiple disciplines together into forms of transdisciplinary research. This is evident in publication and citation patterns; in contrast to many other strands of sustainable HCI work, within participatory sensing, there tends to be significant referencing of engineering research. In part, this cross-referencing appears to be due to the centrality of a single organization (Center for Embedded Network Sensing at UCLA) and the fact that this organization itself is transdisciplinary, publishing across engineering, participatory design, and HCI conferences and journals.

Fostering Debate

A striking characteristic of the sustainable HCI literature is the relative lack of debate between different orientations. This is not because there are no potential *topics* of debate; each axis of difference presents subjects and positions about which there is substantial disagreement. In some instances it makes sense to simply pursue different approaches in parallel. But in others, different commitments reveal deeper issues which are important for the community to grapple with and discuss.

For example, we have documented that for many within HCI, the design and development of technological solutions for social issues such as sustainability is a fundamental objective. But some within sustainable HCI and many in the broader discourses of sustainability and the environment raise serious issues about how belief in technology as a neutral solution *itself* may be implicated in the problems of sustainability. However, a move away from an emphasis on technology design, or even from research aimed primarily at informing such design, presents challenges to HCI as a field — if technology is not the point, then what becomes the work of sustainable H"C"I? As another example, as previously discussed, most persuasive technologies seem to imply that users' behaviors are problematic, and that systems should direct them towards more desirable behaviors. We found that in many scenarios, the persuasion begins to border on coercion, to the point of some designs evoking Skinner-esque modification techniques [e.g.,55]. This is a serious issue of ethical concern for HCI and in particular for proponents of user-centered design. As scholarship in STS has articulated, questions of "the user" quickly become issues of expertise and hegemony: if we agree that fundamental change is needed and it might be change that users don't want, who gets to decide what change should happen and how, whose needs are met and whose values matter in the end? There are, of course, many other topics of sustainable HCI around which debate would be helpful and healthy. The question is, why is this debate not occurring?

CONCLUSION

The goal of this paper was to provide an analysis of the current landscape of sustainable HCI and to differentiate

and organize the diversity that comprises this field. To do so, we categorized sustainable HCI work into genres, which represent major clusters of work, and then identified axes of difference, which span genres and give shape to the landscape of sustainable HCI. The genres and axes are neither fixed nor final; rather, they serve as descriptors for what has been done and provide themes around which ongoing research can be structured. Based on the genres and axes, we identified emerging issues, which present significant challenges to the definition, scope, and practice of sustainable HCI research but also provide opportunities for expanding the scope of what is known, productively connecting to other disciplines and subfields, and fostering reflective debate on important issues of the field. Addressing these issues is a vital next step in our collective endeavor to shape and advance HCI's contribution towards a more sustainable society.

ACKNOWLEDGMENTS

This work was supported in part by NSF grant 0847293. Thanks to Francois Guimbretiere and Nicholas Knouf for comments and discussion on earlier versions of this paper.

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