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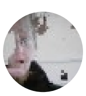

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Anticipated environmental sustainability of personal fabrication

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ABSTRACT

Distributed manufacturing is rapidly proliferating to citizen level via the use of digital fabrication equipment, especially in dedicated "makerspaces". The sustainability benefits of citizens' personal fabrication are commonly endorsed. However, to assess how these maker practitioners actually deal with environmental issues, these practitioners and their practices need to be studied. Moreover research on the environmental issues in personal fabrication is nascent despite the common perception that the digital technologies can become disruptive. The present paper is the first to report on how practitioners assess the environmental sustainability of future practices in this rapidly changing field. It does so through an envisioning workshop with leading-edge makers. The findings show that these makers are well able to envision the future of their field. Roughly 25% of the issues covered had clear environmental implications. Within these, issues of energy use, recycling, reusing and reducing materials were covered widely by environmentally-oriented participants. In contrast, issues related to emerging technologies, materials and practices were covered by other participants, but their environmental implications remained unaddressed. The authors concluded there is a gap between different maker subcultures in their sustainability orientations and competences. Further research on the environmental aspects of real-life maker practices and personal fabrication technologies now could help avert negative impacts later, as the maker phenomenon spreads. This knowledge should also be directed to developing targeted environmental guidelines and solutions for personal fabrication users, which are currently lacking. Potential also lies in seeking to enhance dialogue between pro-environmental and new-technology-oriented practitioners through shared spaces, workshops and conferences.

1. Introduction

Certain groups of end-users, often called "makers", are increasingly involved in the design and production of their own products (Raasch and von Hippel, 2012; Anderson, 2012). This transition is enabled by greater access to digital manufacturing technologies at home, through services or in dedicated spaces (i.e. "makerspaces"). Such access is regarded by many as a disruptive alternative to mass production and consumption through material "peer production" (Benkler, 2006; Bauwens et al., 2012) or "personal fabrication" (Gershenfeld, 2005). There are potential environmental benefits, and harms, to distributing production in this way, but these have been little studied to date (Kohtala, in press).

If these personal fabrication practices diffuse into wider society, it is important to clarify the direct environmental impacts of technologies and materials, but also their indirect effects on society and consumption patterns. For instance, the "maker movement" is often promoted as more environmentally benign than mass production, by enhancing skills to build and repair, answering one's own needs as opposed to "satisficing" through passive consumption, and distributing production within local networks as opposed to long, large-volume supply chains (Diegel et al., 2010; Niinimäki and Hassi, 2011; van Abel et al., 2011). How maker practitioners organise their activities may provide a leverage point for more sustainable practices, depending on the makers' own knowledge of environmental impacts and how they enact sustainability-oriented values.

These hypotheses about the current and future sustainability of making are, however, currently based on limited scientific evidence, and maker practitioners tackle these questions of environmental sustainability based on their professional skills. This raises the question of maker practitioners' knowledge: how wide and

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deep is their own awareness of the environmental implications of making, and do they operationalise it in their current practices as well as planning for future activities?

The authors have earlier investigated these topics through long-term ethnographic research, examining the daily practices of setting up new makerspaces and organising and conducting making activities. This appears helpful in discerning the gaps between actors' pro-environmental attitudes and their concrete practices (e.g. Kohtala and Bosqué, 2014). However, making is a rapidly changing phenomenon where environmental implications may change and evolve as new technologies and interests emerge. The research question in the present paper is therefore:

What issues do competent maker practitioners foresee in the environmental sustainability of near future makerspaces?

To assess this, a workshop was organised with leading-edge practitioners in Finland. It was designed carefully so the practitioners were working on a real project, but also to offer a clear view on if and how they would consider issues related to the environmental sustainability of makerspaces in 2020. The year 2020 was a target date close enough for the practitioners to voice reasoned propositions about, but also far enough in the future to push them to envision likely future developments in this rapidly changing field and indicate any related environmental effects. The reasoning behind the workshop structure and its context is explained in section 3, as well as the methods for analysing the results. The findings and their implications are summarised in sections 4–6. Section 2 provides more background on the maker movement and personal fabrication, with special emphasis on shared makerspaces and the knowledge on sustainability issues to date.

2. Background

Although "making" builds on a tradition of handicraft and "DIY" (do-it-yourself), it today also includes (and more commonly refers to) use of digital tools in hands-on fabrication of material artefacts, including electronics and physical computing experiments, stickers and marketing items for small businesses, furniture and items for the home or body, and prototypes of all kinds. Shared makerspaces are workshops with low-cost digital fabrication equipment, typically milling machines for making circuits or casting moulds (using wood, silicon, wax and plaster); vinyl cutters; desktop 3D printers (typically using ABS and PLA plastics); laser cutters (for usually plywood, cardboard and acrylic); and often electronics workstations for microprocessor programming and project prototyping.[1] Product designs (often shared digitally) are realised by the users themselves and, due to their digital form, can be designed together with peers in other locations.

Makerspaces include fab labs, which are workshops in MIT Center for Bits and Atom's network (Gershenfeld, 2005); hacklabs or hackerspaces for exploring electronics (Maxigas, 2012); commercial machine shops offering paid access to members; and a variety of other spaces that may be independent or associated with a library or museum, typically having less of the heaviest equipment such as large CNC machines (Troxler, 2011). The number of makerspaces worldwide is growing rapidly: to date there are over 450 fab labs and 1000 active hackerspaces (FabLabs, 2015; HackerspaceWiki, 2015), listings that do not account for independent spaces. There is currently scant research on who uses makerspaces and how exactly (e.g. Ghalim, 2013; Maldini, 2013), but the practitioner view is that there is considerable variation, from students in university fab labs to entrepreneurs to hobbyists who dominate hackerspace-type facilities (e.g. Eychenne, 2012; Toombs et al., 2014).

Reports on the sustainability of personal fabrication are emerging as the phenomenon spreads, often appearing as grey literature (De Decker, 2014; Olson, 2013). The few empirical studies that exist mainly focus on additive manufacturing, relevant to some digital fabrication equipment, such as studies on energy consumption and Life Cycle Analyses (e.g. Baumers et al., 2013; Faludi et al., 2015). When compared to mass production processes, digital manufacturing has the potential to reduce material, waste and energy, at least for small batches (ATKINS Project, 2007), and may mitigate negative impacts connected to supply chains (Huang et al., 2013). However toxicity of especially additive manufacturing materials remains a concern (Drizo and Pegna, 2006; Short et al., 2015), as well as the high energy consumption of digital fabrication.

In addition new DIY strands are exploring areas such as citizen science and urban agriculture, activities conducted in their own communities and spaces or included in the repertoire of already established makerspaces (Tocchetti, 2012). The environmental and human impacts of Do-It-Yourself Biology ("DIYbio", "biohacking" or "DIY-pharma") (Delfanti, 2013) are as yet unknown, but these practices are increasing in uptake and variety.

These environmental issues are summarised in Fig. 1. Given all these uncertainties, affecting how personal fabrication develops from early on appears preferable to simply having to face whatever negative impacts materialise later.

3. Data and methods

The data for this study were drawn from a collaborative design experiment where thirteen leading Finnish maker experts were recruited to elaborate the future of makerspaces for the year 2020. The stakes of the workshop were real: the host was Helsinki library services, who will build a public makerspace for its flagship city centre library that will open its doors in 2018, as well as a small-scale pilot space that opened a few months after the workshop. The local maker communities would be among the prime users of such facilities.

The workshop was designed to combine elements from lead user workshops (Herstatt and von Hippel, 1992; Churchill et al., 2009) and participatory design (Greenbaum and Kyng, 1991; Bødker et al., 2004; Hyysalo et al., 2014). Both the library personnel and the researchers sought practical information about future makerspaces but also raised discussion on sustainability, which was then highlighted in further analysis.

Similar futuring exercises have been conducted using, for example, participatory backcasting (Mont et al., 2014). Stakeholder collaboration was also seen as integral to learning and transition in urban transformation processes (McCormick et al., 2013). Furthermore peer-to-peer making practices are among the "grassroots innovations" that are rarely included in foresight exercises and innovation programmes but would have much to contribute (Smith et al., 2014; Hyysalo et al., 2013a,b, 2014).

The desired participants were identified by first listing the relevant maker communities, sectors and fields of expertise that would provide a diverse set of perspectives on the present and future of personal fabrication and makerspaces. The sectors, commercial, academic, third sector and local authorities, were further sub-divided into fields such as ICT, engineering, digital fabrication, "hacking", "crafts" and "support organisations". Both organisations and individuals were identified in the authors' contact networks (having been embedded in the Finnish maker scene for several years), in discussion with the library personnel and through snowball sampling. This resulted in a list of 32 individuals, many of

[1] For MIT's recommended Fab Lab inventory list, see Fab Foundation (2015).

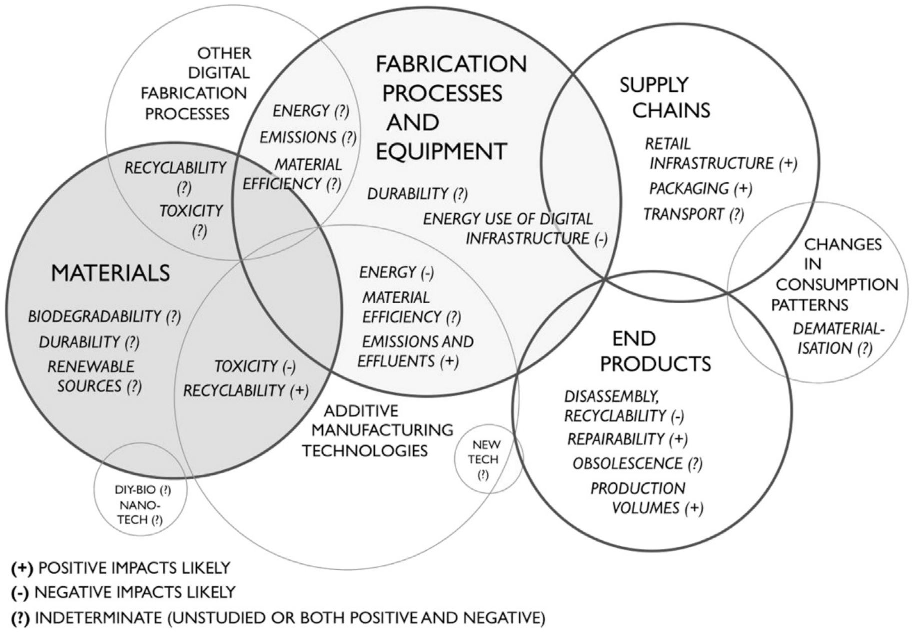

Fig. 1. Broad overview of the environmental issues in personal fabrication and makerspaces. Most empirical research to date appears in the grey coloured topics.

whom were involved in more than one relevant field or sector. The list was compiled so that each of the competences sought after for the workshop would be held by at least two invited individuals. The workshop date suited 13 participants, who upon a further check presented a balance of male and female and most importantly represented all the competencies desired. Taken together they held wide and deep knowledge on different facets of digital fabrication, shared workshops, open innovation and peer-to-peer dynamics, as well as experience in organising and facilitating participatory events, including making-related events, environmental activism and urban gardening, and peer learning.

In the workshop the first three hours concentrated on trend identification and final three hours on solution concretisation. Both parts relied on participants writing their statements on pre-categorised post-it notes, drawing from participatory design ideas of representing work through prefilled cards (Muller, 1993) and inspiration cards (Halskov and Dalsgaard, 2006). The categories on the cards reflected the issues most likely to be salient in considerations about the future of making and makerspaces based on prior research: “Technology”, “Activities”, “Sharing/Organizing/IPR”, “Safety & Risks”, “Other” and in the last three parts of the workshop “Sustainability”.

In the first phase of the workshop the participants had 30minutes to list the most important trends in making for the year 2020 and were then asked to share the three most important trends they had written. This was followed by an exercise where all participants starred which of the “top three” trends they felt were most important (not their own) to ensure an explicit understanding of which issues the participants themselves wished to emphasise.

The afternoon part of the workshop was designed to identify which trends could be concretised and were not merely the proposers' wishful, fantastic or ideological expressions of the future, lacking notions of what they could mean. These exercises were conducted in the same-sized makerspace (Aalto Fablab, Helsinki, Finland) that was to be built in the central library, and the participants were instructed to start adding post-it notes directly onto its machines and surfaces to make it the future 2020 makerspace. This phase drew from experience in “participatory full scale modelling” (Hornyanszky Dalholm, 1998) to help people achieve a “hands-on future” (Ehn and Kyng, 1991).

This workshop set-up was arranged to produce several types of data. A continuous audio recording with four separate recorders and two video recorders covered most talk and interaction taking place in both settings. As the number of people in these set-ups was relatively high (22, i.e. 13 participants, 4 facilitators, 6 library planners following the event), and particularly for the afternoon sessions when the participants dispersed to parallel actions and talk sequences, the audio and video data became challenging to transcribe and was rather used as a back-up repository, to verify issues that remained unclear with less intensive documentation methods.

The next layer of the documentation was photographs, which facilitators and library personnel shot continuously of the process and outcomes of the workshop. Altogether 691 photographs record every post-it written and the sequence in which they emerged, providing a still picture trace of the workshop flow. The written post-it notes, 495 in total, were the next layer of outcomes. Finally, each of the facilitators made fieldnotes after the day to record their observations of the dynamics between participants and participant reactions to the processes, materials and outcomes during the workshop.

The analysis of the data proceeded in several phases. The statements on post-it notes, codes therein, the author of each statement and their placement and sequence in the events were tabulated for the 188 trend statements and the 307 solution statements, along with if they had been ranked among the three most important and those voted by others. Seven trend statements were reclassified as solutions and three solutions were discarded as too abstract and ambiguous. Several statements were remarkably similar, and these exact matches were combined to form one statement.

The next analysis phase focused on how explicitly practitioners dealt with sustainability issues in makerspaces and personal fabrication. The statements were examined to determine which ones related to a positive or negative sustainability issue and which ones had no clear relevance to environmental impact. The

Table 1
Examples of "Top 3" Technology trends and their sustainability coding.

Category	Post-it contents	Location 0 = other wall, 1 = top wall (Top 3), no. of stars given by other participants	Sustainability 0 = No obvious sustainability implication 1 = Implicit sustainability (researchers' interpretation) 2 = THEY express sustainability
Technology	Big data + open data + co-creation = new opportunities	1 (*)	0
Technology	Nano material will arise in making	1	1
Technology	Waste management sites: sorting stations will scan all the waste and scanned items will be "networked", directed to X by request	1 (***)	2

sustainability-related statements were further coded according to if the participant had directly expressed the environmental concern, for instance, on a Sustainability post-it or in terms related to environment, waste, energy or other clear, unambiguous expressions. Several statements, however, had a clear environmental implication (Fig. 1) that was not expressed by the participants, and these statements were also marked (see Table 1). To ensure a robust discussion on what entailed a clear sustainability implication as well as a clear expression of sustainability concern by the participants, the two authors coded all the statements independently and then compared the coding in three consequent discussions. Most codings were uniform but twelve borderline items required the three rounds of deliberation. In the end five statements were discarded from further analysis as too ambiguous.

Finally, the trends and solutions were grouped respectively in thematic clusters, first general themes and then themes according to sustainability relevance. The sustainability-relevant statements were isolated and were placed into a logical property space, matching trends and solutions, an analysis that will be described further in section 5 and where the main findings of the current study reside.

4. Findings: the distribution of identified trends and solutions

The final data set yielded 177 trend statements and 262 solution statements. This section will briefly present the overview of workshop outcomes as necessary background information to discussing the results of the deeper analysis in section 5.

4.1. Trends

The themes addressed by the trend statements are illustrated in Fig. 2. The trends were distributed among the pre-determined categories quite evenly (16–23% falling to each category), as can be seen in Fig. 3 (left). When the participants were asked to rank them, the most important trends to the participants tended to fall in the Other and Technology categories (Fig. 3, right).

To illustrate the type of trends the participants contributed and their sustainability coding, three examples are presented in Table 1. The suggestion that nano-technology, for instance, will become more relevant in future making was regarded by the authors as

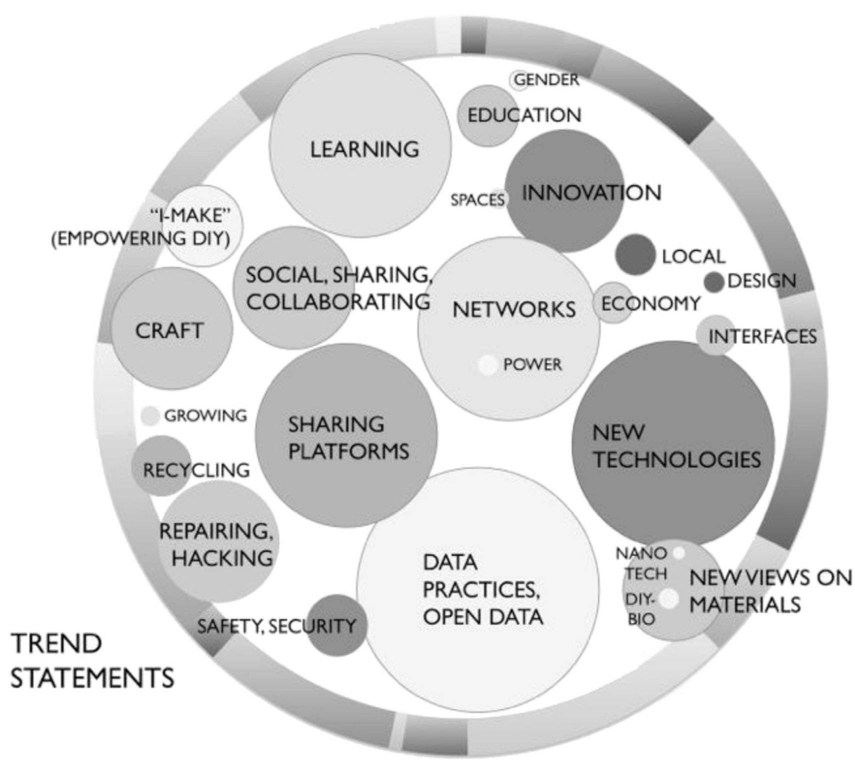

Fig. 2. Trend statement themes.

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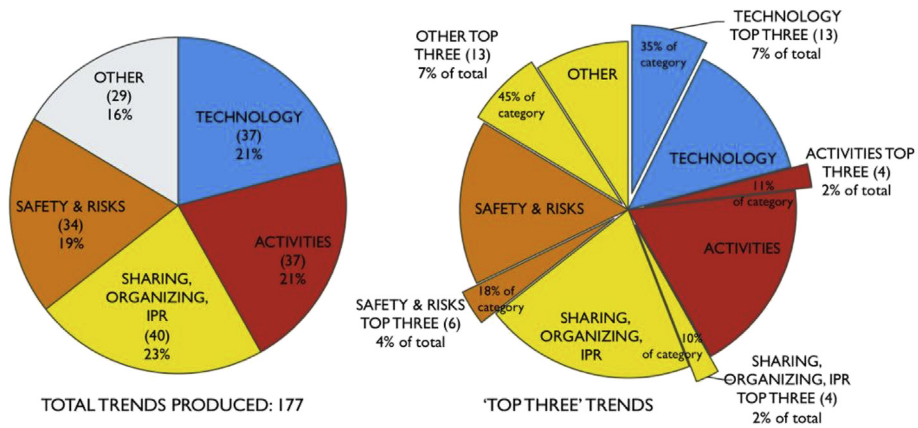

Fig. 3. Breakdown of trend categories.

having environmental implications, but none clearly expressed by the participants themselves.

Environmental implications related mainly to Technology trends, as seen in Fig. 4 (left). Participants directly expressed environmental concerns more in the Safety & Risks, Activities and Sharing/Organizing/IPR categories, while there were more unexpressed implications in the Technology category (Fig. 4, centre). Taken together, trends involving sustainability issues were in the clear minority: of the 177 trends produced, only 48 involved an environmental concern, whether expressed directly or not (Fig. 4, right).

4.2. Solutions

The afternoon's session yielded 262 solution proposals placed directly on the fab lab surfaces, indicating the exact location of the solution (Fig. 5), as well as on a "miscellaneous wall" created in the space. In total 37% of all solution proposals were posted on the miscellaneous wall, indicating that participants did not see future solutions for the library makerspace confined to the current fab lab environment.

The thematic clustering of solution proposals is illustrated in Fig. 6, showing wide variation in how specific the solutions were as well as the topics they addressed. The solutions' distribution among the pre-given categories differed from the trend distribution, as the "Other" category was used in 38% of the solutions and the second biggest category was Technology at 22% (Fig. 7, left). Between 1 and 4% of the solutions in each category had sustainability implications, the highest proportions being in the Other and Technology categories (Fig. 7, centre).

To ensure participants were not merely forgetting to express sustainability issues, they were asked to focus on sustainability solutions and implications for ten minutes at the end of the exercise, using the specific Sustainability post-it notes as well as "marking" existing solutions around the room for their sustainability relevance (Fig. 8). The results after this prompt are seen in Fig. 9, where Sustainability category solutions accounted for 8% of the total. As with the trends, overall the Technology category had the highest percentage of sustainability-relevant solution proposals (Fig. 9, centre).

The overall proportion of sustainability-relevant solutions compared to the total is comparable to the trend ratios, with 75% of solutions having no sustainability issues (Fig. 9, right). However, in comparison to trends, a notably larger ratio of these solutions expressed sustainability relevance directly, compared to those with environmental implications that were not expressed (both before and particularly after prompting). This indicates that practitioners may find it easier to identify implications for environmental sustainability when concretising solutions.

4.3. The sustainability faction

The workshop structure and subsequent analysis aimed especially at identifying whether environmental considerations

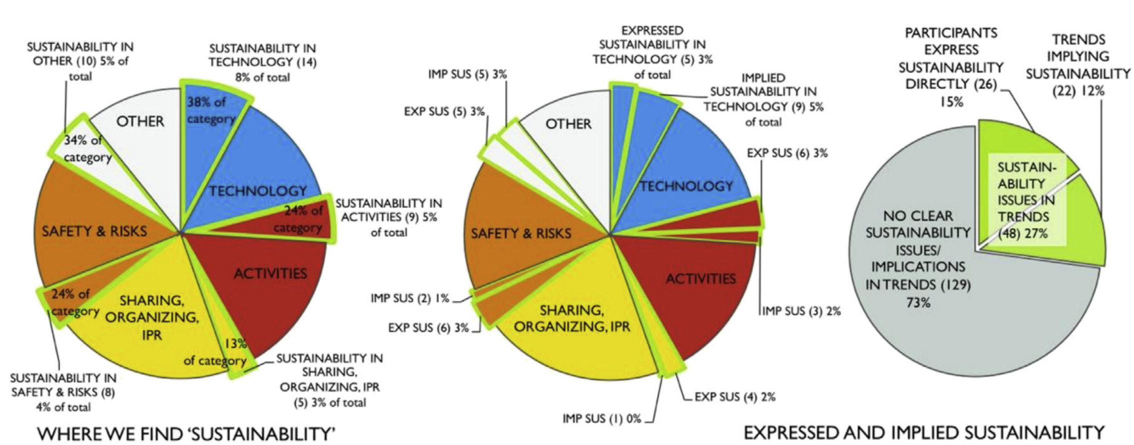

Fig. 4. Environmental sustainability in the trend statements.

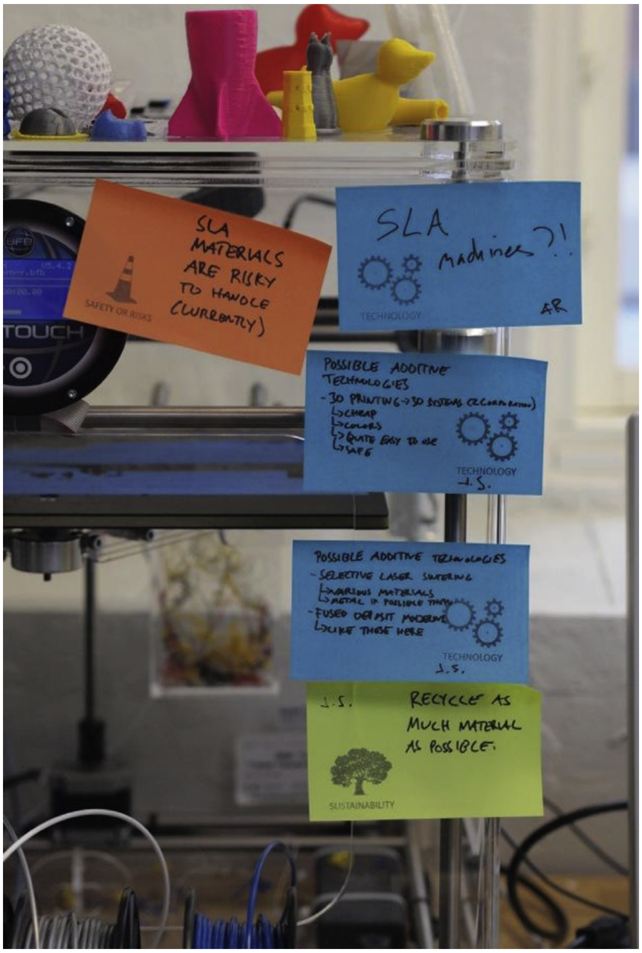

Fig. 5. Participant solution statements.

emerged naturally in the identification and expression of trends and concrete solutions. This allowed assessment of how salient or latent these issues may be for these practitioners, as well as what particular types of practitioners raise which issues. Three of the participants were known to be explicitly ecologically oriented in their own practice and self-identified environmental sustainability as a key concern for them in the introduction round of the workshop. These three participants formed a "sustainability faction", who consistently raised sustainability-related concerns throughout the workshop. It thus became interesting to compare the proposals made by this group to the others.

Fig. 10 (left) illustrates where this group expressed environmental concerns directly in their trends and where the authors identified unexpressed environmental implications. This is compared against the other participants' sustainability-related trends. Unsurprisingly, the sustainability faction directly expressed sustainability concerns more often than the other participants (10% of the total, compared to the others' 5%), but the other participants still generated trends that have sustainability implications (11% of the total, compared to the sustainability group's 1%). The solutions differ, as the other participants expressed sustainability concerns in 11% of all solutions while the sustainability faction did so in 6%. This seems to imply a comfort the sustainability group felt with expressing their environmental concerns in general trends but less certainty when it came to actual solutions in a makerspace. This will be discussed further in the following sections.

5. Findings: property space analysis of trend and solution interrelations

Sustainable Consumption and Production research has long shown a high discrepancy between pro-environmental attitudes and actual behaviours: the "behaviour-attitude gap" (e.g. Kollmuss and Agyeman, 2002). The gap may stem from sustainability being a "good" that is evoked for reasons of self-identity, an inability to realise pro-environmental intentions within the structural constraints of current society, or sustainability forming an ideology that lacks concretisation in some areas (Shove et al., 2012).

The phenomenon is also likely to feature in how sustainability is represented in a given futures exercise. This potential discrepancy was taken into account in the design of the present experiment, by asking the participants to produce two qualitatively different ways to address future sustainability: through trends and through

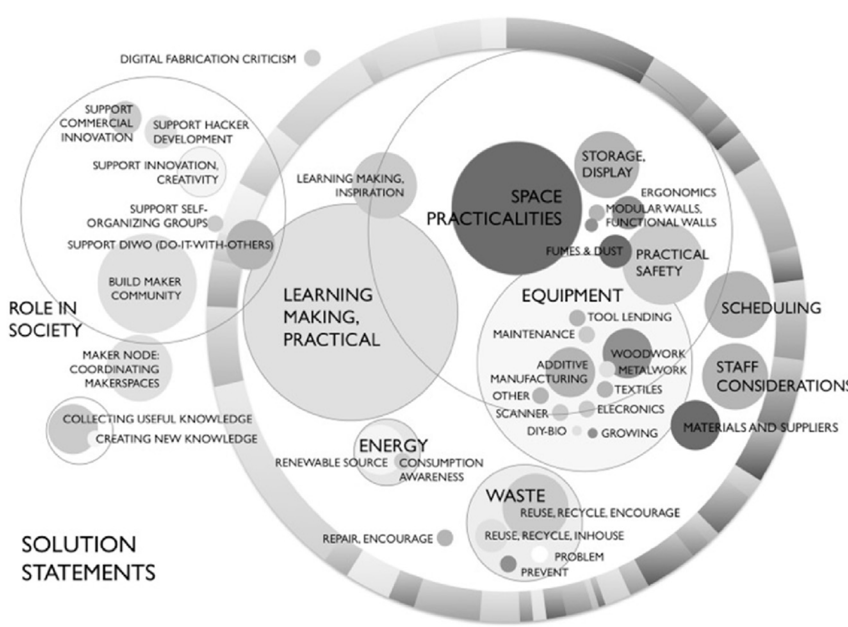

Fig. 6. Solution statement themes.

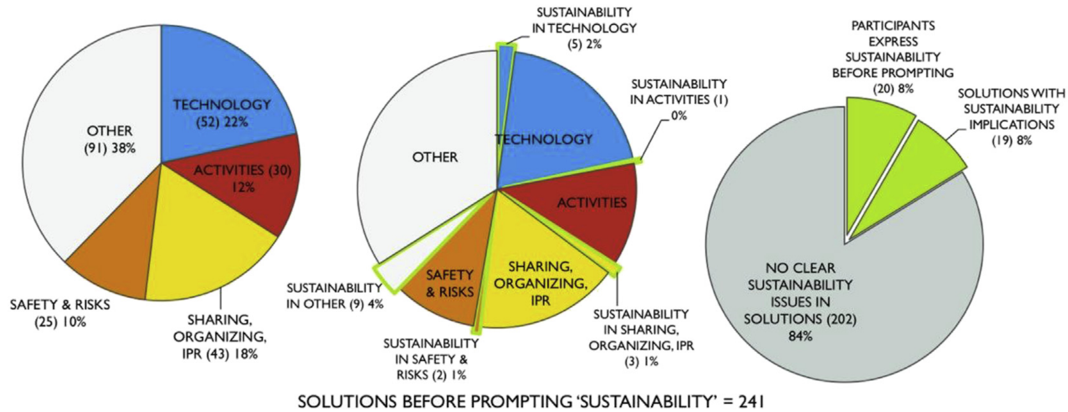

Fig. 7. Breakdown of solution proposals by category and environmental sustainability in each category (before the sustainability prompt).

concrete solutions. The pairing between the two should provide cues as to which trends find concretisation in solutions, or otherwise.

The analysis identified three types of relations to sustainability in the issues raised by participants: no relation, expressed sustainability implication, and clear unrecognised sustainability implication as judged by the researchers. These three categories form a logical property space (Becker, 1998; Rihoux and Ragin, 2009), exhibited in Table 2.[2]

This property space allows a closer examination of the issues raised as relevant for makerspaces in 2020 by making salient three types of comparisons. Firstly, there are the issues that have no clear sustainability relevance (in Table 3 in white): 326 items, or 72.9%. Thus, also as trend-solution pairs, the bulk of issues regarding future maker facilities and practices are in no clear way connected to environmental sustainability. Secondly, the paired issues that have some unrecognised sustainability implications ("implied") appear in light grey in Table 3: 37 items, or 8.3%. Thirdly, there are those future issues that the participants themselves expressed as relating to environmental sustainability (in Table 3 in dark grey): 84 items, or 18.8%. These latter proportions call for more detailed examination.

The main themes in each property space category are listed in Table 4. In the dark grey sections of the table, where participants were most active in identifying environmental issues, the largest clusters addressed material cycles, product and material longevity and energy. A noteworthy number of trend statements referred generically to recycling and reusing materials and repairing products. These matched with many solutions supporting these activities within a makerspace by lay citizens. Several repair-related trends also aimed to normatively mainstream repair through more significant cultural changes, whether by government policy, communications campaigns or formal education, but they could not be matched with any concrete solutions.

Many themes in the upper rows of the table pointed inward to personal fabrication itself. With these trend-solution pairs, the participants were less systematic in identifying environmental issues. Such issues included reused, easily updated and easily maintained equipment for makerspaces or the hacker ideology where even consumer products can be easily opened up, modified and customised, and repaired. Surprisingly, only one solution expressed concern about how the makerspace receives its materials: "*Logistics of supplies*" on a Sustainability post-it.

Some trends could not be matched with solutions but were nevertheless compelling for future consideration. One theme, for instance, addressed how current mass production will change: whether in altered supply chains or transformations in the production system itself. Another proposed that production will become localised and factories will move back into cities. This may indicate the emerging nature of a desired new paradigm where radical abstract transformations can be envisioned but not as yet the concrete steps to these visions.

There are thus differences (asymmetries) in how environmental sustainability was recognised and addressed in the trend-solution pairs. This is the reason to operate with the property space: not all items are equally comparable or even amenable to thematic clustering with regards to sustainability. The asymmetries in sustainability expression are likely to have resulted from difficulties to concretise some visionary trends or conversely connect practical solutions to larger trends. They may also be artefacts of the setting: participants may have failed to consider one or the other side thoroughly in the flurry of the workshop.

For this reason the next level in detailed analysis compares only the trend-solution pairs in "fully unrecognised sustainability implications" and "clear sustainability expression". This was done to

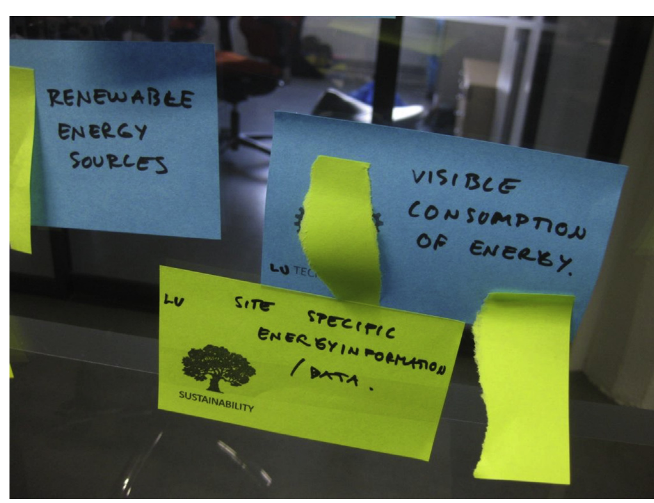

Fig. 8. Participants responded to the sustainability prompt by "tagging" others' post-its with pieces of a green Sustainability post-it.

[2] All the solution and trend expressions were also examined as possible false expressions of sustainability: "participants' false positives", where either solutions or trends claimed to have clear sustainability implication but are proven by research not to have one. No such statements were found. These categories were thus redacted out of the analysis (Rihoux and Ragin, 2009).

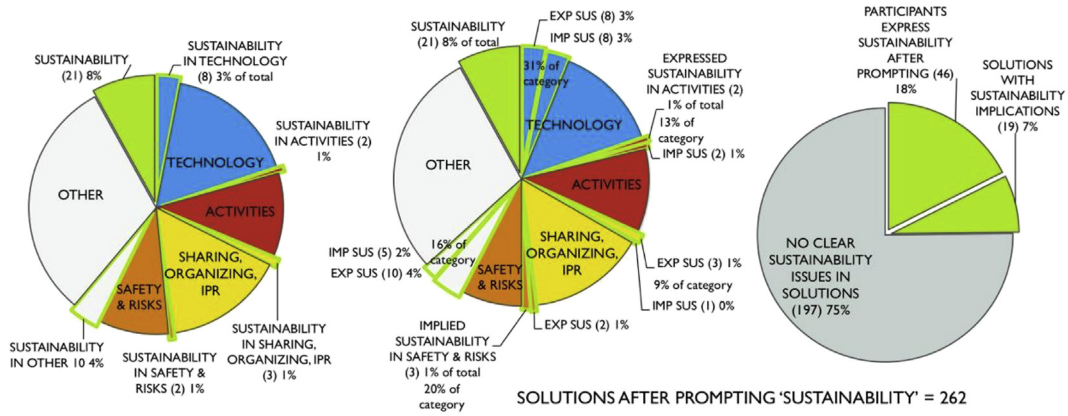

Fig. 9. Breakdown of solutions by category and sustainability in each category after the sustainability prompt.

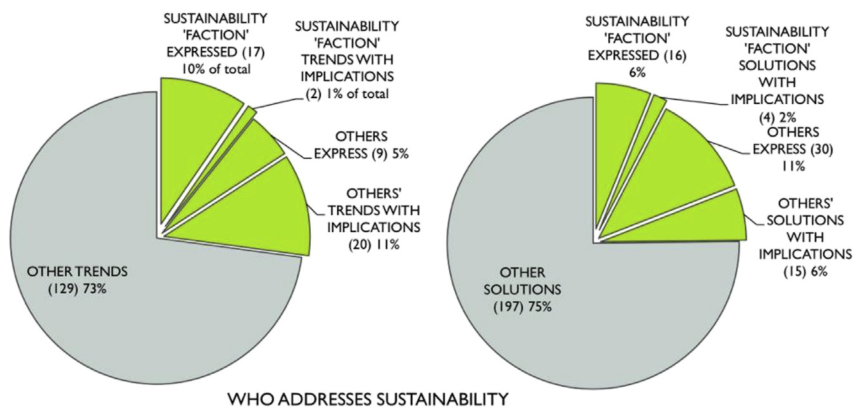

Fig. 10. Comparing the "sustainability faction" to the other participants.

identify if there were qualitative differences between these categories that are symmetric with respect to the interrelation between solutions and trends.

The trend-solution pairs in the Fully Unrecognised case indicated issues worth monitoring for future making, especially regarding technology development or combinations of elements enabled by new technologies such as disparate materials or embedded electronics. DIYbio is a novel and likely unfamiliar phenomenon, and it appears likely that participants ignored its sustainability implications. Another set of trend-solution pairs suggested growth of shared makerspaces, as opposed to digital fabrication at home. These solutions prompted more functional coordination among the spaces around the city and especially the role of a city library makerspace in this coordination. Finally, the issues of tool lending in a library makerspace and product design hospitable to hacking were not noted as having sustainability implications by the participants. They may simply have evaded participants' attention in the workshop and were easily passed over.

Table 2
Logical categories "property space" of interrelations between trends, solutions and whether sustainability is expressed or not expressed (implied).

Trends Solutions	S0 = solutions with no sustainability expression or implication	S1 = solutions with no sustainability expression but clear sustainability implication	S2 = solutions with sustainability expression
T0 = Trends with no Sustainability expression or implication	T0S0 Issues with no clear sustainability relevance.	T0S1 Unrecognised sustainability solutions not connected to any sustainability trends.	T0S2 Expressed sustainability solutions that may have been difficult to trend.
T1 = Trends with no Sustainability expression but clear sustainability implication	T1S0 Unrecognised sustainability trends, not concretised by any sustainability solutions.	T1S1 Trends connected to solutions where both have clear sustainability implication not recognised by participants: Fully unrecognised sustainability implications.	T1S2 Trends with unrecognised sustainability implication, concretised by expressed sustainability solutions.
T2 = Trends with Sustainability expression	T2S0 Expressed sustainability trends that do not find any concretisation.	T2S1 Expressed sustainability trends concretised only by solutions with non-recognised sustainability implication.	T2S2 Clear sustainability expression.

Table 3
Pairing solutions and trends in the property space.

Solutions / Trends	S0	S1 ("implied" sustainability solution)	S2 ("expressed" sustainability solution)
T0	**T0S0** 129 no sus. trends 197 no sus. solutions	**T0S1** 5 solutions not connected to trends.	**T0S2** 5 solutions not connected to trends.
T1 ("implied" sustainability trend)	**T1S0** 12 trends not connected to solutions.	**T1S1** 9 trends connected with 11 solutions.	**T1S2** 4 trends connected with 7 solutions.
T2 ("expressed" sustainability trend)	**T2S0** 7 trends not connected to solutions.	**T2S1** 3 trends connected with 5 solutions.	**T2S2** 18 trends connected with 35 solutions.

Nonetheless both had direct relevance for the set-up of the library maker facility.

The Clearly Expressed case pointed especially to issues of material eco-efficiency: reduce, reuse, recycle and repair. The trend-solution pairs addressed the personal level, i.e. waste reuse and product repair within the makerspace, as well as the municipal level, in particular the relationship between individual makers and existing recycling infrastructure in the spirit of a circular economy. Only a few solutions addressed *prevention* of waste from the outset, as preferable to reuse, an issue the authors had expected would be discussed more.

There were also a significant number of solutions dedicated to energy issues among the Clearly Expressed issues: the deployment of renewable energy sources, the desire to make electricity consumption more visible and other solutions to reduce overall energy consumption.[3] The environmental attributes (or dangers) of the materials themselves, beyond dust and fumes, were little addressed by the participants. An exception was the solution reading: "*hierarchy of good-bad materials on display (critical material thinking)*", which also alluded to the library's potential role in sustainability education.

The differences between the expressed and unrecognised became most apparent when the differences between issues the "sustainability faction" voiced and those voiced by the other ten participants were examined, as shown in Table 5. The proportions of the sustainability faction's contributions varied in the logical spaces that contain asymmetric trend-solution pairs, but their role becomes visible in the symmetric pairs of Fully Unrecognised and Clear Expression cases.

In the Clear Expression case, the sustainability faction seemed to be concerned with engaging the wider society in maker culture via repair activities, as well as engaging maker activists in "sustainability" via recycling infrastructures. The other participants showed more interest in the environmental issues in making activities themselves: dealing with the materials and the equipment, suggesting better fabbing processes and considering energy consumption. In waste prevention the sustainability group tended to focus on reuse, while the other participants offered solutions to combat waste and mistakes within the fabbing process itself, as well as pointing out the need for better (cleaner) materials in personal fabrication.

In the Fully Unrecognised case, the role of the sustainability faction was much smaller, contributing only two solutions (18% of solution proposals in the category) and no trends. This indicates the group was capable of identifying sustainability implications in trends and solutions that they themselves raised. This left a suite of trend-solution pairs raised by other participants with unrecognised environmental implications. These included DIYbio as well new equipment developments that may enable environmentally problematic products (where disassembly becomes more challenging, for instance). The two solutions raised by the sustainability group related to shared and common-pool resources, i.e. tool lending and sharing resources among city makerspaces.

The pro-environmental makers thus had limited engagement with unrecognised issues, and their engagement was also highly selective within this category: new materials and emerging technologies did not draw their attention. Also elsewhere in the trend-solution mapping space, trends with clear sustainability implications such as nano-technology, new material toxicity and changes in mass production were not addressed by the sustainability-oriented faction.

6. Discussion

The present study is part of the first line of research on how environmental sustainability is enacted in real-life personal fabrication settings. This line of research is important because the scientific evidence from which maker practitioners could draw remains scant, and much of the environmental impact of the potentially disruptive technologies rests on practitioners' shoulders.

To complement ethnographic research on present-day maker practices, the present study set-up was designed to assess how practitioners envision the future facilities and activities in this

[3] An "outlier" theme in the property space was represented in a trend-solution pair devoted to urban gardening or agriculture, arguing for its inclusion in making activities.

Table 4
Key themes in the property space.

Trends \ Solutions	S0	S1 ("implied" sustainability solution)	S2 ("expressed" sustainability solution)
T0	**Everything else** no sus trends no sus solutions	**Implied solution isolates** FLOSS[a] HANDICRAFT	**Difficult to trend** SPACE PLANNING OBSOLESCENCE SUPPLY CHAINS EXPERTISE
T1 ("implied" sustainability trend)	**Not recognised, not concretised trends** CHANGES TO MASS PRODUCTION LOCAL PRODUCTION NANO-TECH ALTERNATIVE ECONOMY	**Fully unrecognised** DIY-BIOLOGY LIBRARY TOOL LENDING SHARED MAKERSPACES NEW EQUIPMENT (TECHNOLOGIES)	**Expressed only in solution** OPEN EQUIPMENT SHARED CRAFTSPACES
T2 ("expressed" sustainability trend)	**Not concretised trends** BICYCLES REPAIR CULTURE ALTERNATIVE URBAN ALTERNATIVE CONSUMERISM	**Unrecognised expression** BIO-REGIONS TOXICITY	**Clear expression** URBAN AGRICULTURE REDUCTION IN ELECTRICITY CONSUMPTION RENEWABLE ENERGY SOURCES BETTER MATERIALS RECYCLE REPAIR REUSE WASTE REDUCE WASTE

[a] i.e. "free/libre/open source software".

rapidly moving field. The envisioning workshop for a real maker facility that will be set up in 2020 was used to avoid mere pro-environmental discourse without real-life anchoring. The participants, their peers and peer communities would be among the prime users and benefactors of this space. The study also provided indications of how maker practitioners address environmental issues when envisioning this future.

6.1. The workshop set-up and its validity for assessing practitioner views about future making

The workshop design allowed the authors to assess whether and which environmental sustainability issues would arise on their own accord, as well as whether and which issues would arise if environmental sustainability was brought in as a specific topic of attention. The participants worked on both trends and solutions for the year 2020, which further allowed the authors to centre on those issues that were consistently and symmetrically voiced both as trends and solutions. The set-up was thus geared in three ways to anchor participants to concrete practices and not their espoused views about environmental sustainability (Kollmuss and Agyeman, 2002; Shove et al., 2012).

The output of almost 500 trends and solutions indicates the practitioners faced no difficulty envisioning the future of making, even as they took the work seriously and worked carefully. There was good coverage of specific areas of making in both trends and solutions, and the participants also converged on several topics of mutual relevance to the different kinds of making in which they were involved. This was further ascertained through the prioritisation ("Top 3") exercises.

6.2. Participant perceptions of environmental sustainability of making in 2020

The majority of the expressed issues did not have a clear environmental implication. Environmental sustainability thus does not appear to be an overarching aspect of all or even the majority of issues the makers consider relevant in future makerspaces. This is in line

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Table 5
Sustainability faction representation in trend-solution pairs.

Solutions / Trends	S0	S1 ("implied" sustainability solution)	S2 ("expressed" sustainability solution)
T0	**Everything else** no sus trends no sus solutions	**Implied solution isolates** 0 trends. SF solutions 3/5 = 60%.	**Difficult to trend** 0 trends. SF solutions 0/5 = 0%.
T1 ("implied" sustainability solution)	**Difficult to trend** 0 trends. SF solutions 0/5 = 0%.	**Fully unrecognised** SF trends 0/9 = 0%. SF solutions 2/11 = 18%.	**Expressed only in solution** SF trends 0/4 = 0%. SF solutions 1/7 = 14%.
T2 ("expressed" sustainability trend)	**Not concretised trends** SF trends 5/7 = 71%. 0 solutions.	**Unrecognised expression** SF trends 1/3 = 33%. SF solutions 1/5 = 20%.	**Clear expression** SF trends 11/18 = 62%. SF solutions 14/35 = 40%.

with our ethnographic research on daily practices in setting up and running maker facilities (Kohtala, 2013; Kohtala and Bosqué, 2014).

The topics that participants expressed as relating to sustainability focused especially on repair, reducing, reusing and recycling of materials, electricity consumption and possibilities for more sustainable materials and energy. In these topics the sustainability-oriented faction was seen as playing a key role, proposing concrete solutions and trends, as well as expressing more contextual critique of digital fabrication. Particular proficiency was shown around topics of energy and recycling, where numerous normative "ought to" trends were also well concretised. The participants clearly operationalised what they found as the most pressing problems in making activities. In practice, recycling is beginning to be addressed in personal fabrication, but research on processes is dispersed and often experimental and art based (e.g. Baechler et al., 2013; Marchelli et al., 2011; Hakken, 2013). Additionally, the numerous participant suggestions to use solar and wind power resonate with published studies on the energy intensity of digital fabrication processes in comparison with mass production (e.g. Telenko and Seepersad, 2012; De Decker, 2014).

In contrast, trends with clear but unaddressed sustainability implications related mainly to emerging topics of making such as DIYbio, new materials such as nano based (Helland and Kastenholz, 2008), new technologies and the overall implications of distributed manufacturing displacing mass production. The toxicity of additive manufacturing materials was also weakly addressed by a single observation, even as this topic has been raised to the fore in research by Drizo and Pegna (2006) and Huang et al. (2013). A key dynamic was that the more technical and future-oriented issues were not at the focus of sustainability-oriented participants and the rest of the participants did not pay systematic attention to their potential environmental impacts.

7. Conclusions

The participants in this study were well able to envision the future of making, but they appeared to differ in their capacity to anticipate environmental issues: those competent and interested in assessing environmental impacts were different people from those competent and interested in keeping track of rapidly evolving new technologies and materials for making. This gap in practitioner orientation and competence is therefore potentially problematic.

Three obvious lines of implications and recommendations come forward. First, research objectives need to address these gaps in sustainability orientation and competence among makers. There is a clear need for targeted research on the environmental impacts of personal fabrication technologies and materials, as well as real-life maker practices. Availability of such research now could help mitigate or prevent negative impacts later, especially as the maker phenomenon becomes more widespread.

Secondly, dialogue should be fostered between and among maker subcultures. Interaction and communication between pro-environmental and new-technology-oriented practitioners can be enhanced through shared spaces, workshops and conferences.

Thirdly, guidance and solutions should be produced to better guide practitioners' everyday activities and the design of makerspaces. According to the current findings, maker practitioners are less likely to succeed in addressing environmental impacts on their own to the extent they espouse. On the other hand, precisely because makers like to represent themselves as environmentally benign, such practical, concrete guidance is more likely to be adopted, from manuals and checklists, to designs and solutions for equipment, better recycling systems and the like.

These conclusions may be generalised beyond the particular setting used in this study due to several contextual factors in how the envisioning workshop was set up. First, the group of practitioners in the workshop was chosen so that different maker subcultures were well represented and included environmentally-oriented maker groups. Each participant was proficient if not a leading practitioner in the Finnish context. Second, the Finnish context in the Helsinki region itself represents a middle ground in the competences of maker practitioners. It is not a global forerunner context such as the Netherlands or some regions of Italy, but

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personal fabrication activities are at roughly similar levels as in most Western capital regions. Third, the maker facility in the flagship Helsinki library presented a form of makerspace that was not fixed (in contrast to e.g. a fab lab), and library planners emphasised the flexibility in what their makerspace could become. The current findings are thus not confined to any particular type of maker facility or setting even as a public institution-run makerspace was the one that was being envisioned.

Currently, no evidence-based handbooks or manuals exist for how to conduct or organise environmentally-sound makerspaces or activities. Practitioners carry much of the burden for sustainability decision-making, based on scattered and not easily accessible research findings. Enhancing makers' competence in environmental issues through dialogue as well as practical solutions is paramount. Personal fabrication and its disruptive technologies present an important emerging study area for the cleaner production community.

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