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TOWARDS SUSTAINABLE LIFE CYCLES OF MAKING IN SMALL SCALE FABRICATION SPACES

Moore, George Edward (1);
Agogino, Alice M. (2);
Goucher-Lambert, Kosa (2)

1: Massachusetts Institute of Technology;
2: University of California, Berkeley

ABSTRACT

Small scale fabrication spaces have shown their potential to support our local supply chains during the collapse of many global supply chain networks at the onset of the COVID-19 pandemic. In anticipation of these spaces becoming more significant in local supply chains, it is increasingly important to reduce their environmental impacts. This work investigates the life cycle of small scale fabrication spaces by interviewing 18 participants from these spaces in the United States. Key insights from the interviews include the following: a) material selection, robust inventory management, and user support for material disposal are factors influencing optimal flow of materials and equipment through a fabrication space; b) lack of information from manufacturers and suppliers is a critical obstacle to achieve optimal use of materials and equipment, and informed decision making related to environmental sustainability and ethical labor practices; c) there are opportunities to take advantage of where financial and sustainability goals align; d) individual motivators for fabrication influences sustainable behaviors; and e) effective education about material and equipment use helps fabrication space users with more sustainable decision making.

Keywords: Product Lifecycle Management (PLM), Sustainability, Human behaviour in design

Contact:
Moore, George Edward
Massachusetts Institute of Technology
United States of America
geomoore@mit.edu

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1 INTRODUCTION

Reducing the environmental impacts of the global supply chain is an increasingly important conversation. While transparency around the environmental impact of our global supply chains still has lots of room for improvement (Gardner et al., 2019), an opportunity to reduce a community's dependency on global supply chains involves bolstering their local supply chains in industries such as manufacturing and fabrication. Diez (2011) describes an initiative to facilitate this retreat from global supply chain dependency in a white paper associated with the Fab City Foundation.

While some researchers have found little evidence to consider makerspaces, fab labs, hackerspaces, and similar spaces as significant actors in local supply chains (Hennelly et al., 2019), there are a few example scenarios regarding how these spaces stepped in to support local communities during the COVID-19 pandemic that suggest otherwise (Pierce, 2020; Capps, 2020). Also, Kohtala and Hyysalo concluded that while the making and prototyping community is still evolving quite rapidly, it is worthwhile to continue these studies in hopes of raising the standard for sustainable practices in these spaces (Kohtala and Hyysalo, 2015).

The phrase "small scale fabrication spaces" was coined for this study to include places such as makerspaces, fab labs, hackerspaces and localized digital fabrication and manufacturing spaces as well as less conventional spaces that may not use these specific terms but involve many of the same activities within a local environment. In an attempt to craft a pathway towards sustainable practices in small scale fabrication spaces that are aligned with what is needed to avoid climate catastrophe, this research study prioritized the following objectives: (1) learn from actors within small scale fabrication spaces about the current state of sustainable practices, (2) propose opportunities to introduce sustainable interventions, and (3) identify key obstacles to achieving sustainable practices that are in alignment with environmental impact goals. Specifically, this manuscript addresses the following three research questions: **RQ1)** What do influential actors in small scale fabrication spaces predict as best opportunities to reduce environmental impacts within the life cycle of small scale fabrication spaces? **RQ2)** Which actors within small scale fabrication spaces are most knowledgeable about each life cycle stage? Which actors have the most influence over the decision making and/or sustainable practices at each stage? **RQ3)** Where are the best opportunities to gather reliable data about processes within the life cycles of small scale fabrication spaces?

2 RELATED WORK

Pathways towards sustainable practices in prototyping and making have regressed with the onset of planned obsolescence. The financial return that resulted from this strategic marketing approach proliferated throughout many markets with tangible consumables. More recently, researchers have begun to acknowledge the need to educate prototyping and making communities about sustainability in hopes that more sustainable behaviors and practices begin to surface (Andrews, 2015).

2.1 Product life cycles of prototyping and small scale fabrication spaces

Few studies have taken advantage of the life cycle analysis framework to investigate entire small scale fabrication spaces. Life cycle analysis involves evaluating a product's life cycle based on five stages: Raw Material Extraction, Manufacturing and Processing, Transportation and Distribution, Use, and Recovery (or Disposal) (Ulrich and Eppinger, 2016). The life cycle analysis framework uses these five stages to assess all of the environmental impact contributions associated with a product.

For those that have used life cycle analysis as a tool to investigate sustainability in small scale fabrication spaces, the focus has been on evaluating tools and equipment within these spaces, such as 3d printers, laser cutters, and CNC mills. Minimizing idle time and machine tool paths are some of the suggestions for reducing environmental impact with these tools (Faludi et al., 2015; Kellens et al., 2014; Yilbas et al., 2017). Other researchers have used the product life cycle to assess how individuals, as opposed to an entire space, engage in prototyping and making. For example, Klemichen et al. (2018)

surveyed a large group of fab lab members across Germany and concluded a gap between the declarations of sustainability as important and the products and projects that precipitate from their experiences. Similarly, Lazaro Vasquez et al. (2020) introduced the sustainable prototyping life cycle for digital fabrication as an analysis framework to evaluate the sustainability of digital fabrication with bio-based materials. Their adaptation of the product life cycle included four stages: raw material acquisition, manufacturing and distribution, use, and end of life. Ultimately, reducing transportation distances, reducing energy consumption, and ensuring efficient use of machines were identified as opportunities to improve sustainability. This study seeks to address a scarcity within the literature by setting a foundation for holistically examining the life cycle of small scale fabrication spaces. This means that an entire small scale fabrication space (such as a makerspace or fab lab) serves as the "product" of interest in this life cycle. So, gaining a better understanding of the environmental impacts associated with each life cycle stage in small scale fabrication spaces is the common thread linking the research questions.

3 METHODS

3.1 Scope

The scope of this study included adults that self identify as involved in small scale fabrication spaces within the US. Ages included those 18 and older. All genders, races, ethnicities, languages, and literacies were welcome to participate. A total of 18 subjects chose to be involved in this study as semi-structured interview participants. Demographics of interview participants are displayed in Table 1 (where the "#" column indicates number of participants). Some participants self-identified with multiple categories for Role, Organization, and Population. Also, one participant did not submit their demographic information.

Table 1. Interview participant demographics

Role	#	**Organization**	#	**Experience**	#	**Population**	#
Founder	7	University	12	0-1 Years	0	Urban	14
Facilitator	8	Commercial	10	1-5 Years	4	Suburban	3
Member	11	Grass-roots	8	5-10 Years	9	Rural	1
Other	4	Other	1	+10 Years	4	Other	0

3.2 Data collection

Prospective semi-structured interview subjects were contacted by email, word of mouth, and phone – specifically, phone calls were made based on Makerspaces, Fablabs, Techshops, Hackerspaces and other small scale fabrication spaces that showed contact information publicly online via google search. The target number of semi-structured interviews was influenced by studies from Guest et al. (2006) and Galvin (2015). Galvin (2015) shares that given a random sample of interview participants for a particular topic of interest, approximately 12 semi structured interviews were enough to capture 93% themes that are present in at least 20% of the population. Guest et al. (2006) arrived at a similar conclusion, stating that saturation of the meta themes that are relevant to the focus of the interviews occurs after 12 semi structured interviews.

Prospective subjects for semi structured interviews were selected based on mutual availability for interviews between the researcher and the subject. Recruitment materials included a flyer, recruitment letter written via email, script for verbal recruitment, interest form & survey via Google Form, and semi structured interview guide. The "interest form" was the intake form for all potential participants. Through the interest form, prospective interview participants were prompted to share contextual background information – such as their roles within the life cycles of making, organizational affiliation, population of community, years of experience, and familiarity with tools and equipment.

3.3 Data analysis

Transcriptions for all semi structured interviews were simultaneously created during each interview using a feature in the Zoom video conference platform. After all interviews were complete, a research team of interview coders were recruited to support coding the interviews. Each interview was coded by two different members of the research team. DeCuir-Gunby et al. (2011) provide a documentation scheme that was adapted for this study while Saldaña (2013) inspired the iterative nature of the research team debriefing after each round of coding.

The coding process involved the four key components: (1) identifying important quotes from the interviewee – these would typically range from a sentence to a small paragraph in length; (2) interpreting each quote into a more succinct statement about its value to the research study; (3) assigning a life cycle stage that is most related to the quote; (4) assigning a research theme that is most related to the quote.

Table 2. Example of qualitative code components

Interviewee Quote	**Interpretation**	**Life Cycle Stage**	**Research Theme**
"Between having a space full of entrepreneurs and a space full of makers – for us makers [involves] a lot of hand holding."	Entrepreneurs tend to have some sort of expertise in something while makers tend to be at more entry level stages regarding the use of common tools and machines	Use	Reliable Data & Information

Before reviewing transcripts to create codes, research team members were reminded of the product life cycle stages and research themes that have been selected as coding categories (see Table 3). The research themes used for the coding process were created based on the research questions. This approach – creating predetermined codes before reviewing interview transcripts – is called provisional coding and is a common method used in exploratory research studies (Saldaña, 2013).

Table 3. Codes used to transcribe interviews

Life Cycle Stages	**Research Themes**
Raw Materials	Ideas for Sustainable Behaviors
Manufacturing and Processing	Reliable Data & Information
Transportation and Distribution	Decision Making Factors
Use	Social Awareness
Disposal	Obstacles to a Sustainable World
	Purpose of the Space

The product of focus for the life cycle stages refers to the actual making experience in small scale fabrication spaces. Based on that definition, the "Use" life cycle stage refers to user engagement in a small scale fabrication setting and any operational activities required to sustain this experience. "Raw Materials," "Manufacturing and Processing," and "Transportation and Distribution" refer to inputs and logistics needed to create this experience. Finally, the "Disposal" stage refers to products and waste streams that come from these making experiences.

Research themes displayed in Table 3 initially included "Ideas for Sustainable Behaviors," "Reliable Data & Information," and "Decision Making Factors," – which were determined based on the research questions. After beginning the coding process, additional research themes emerged; the research team then decided to add "Social Awareness," "Obstacles to a Sustainable World," and "Purpose of the Space."

4 RESULTS AND DISCUSSION

In total, 18 semi structured interviews were conducted. The following results are shared regarding these interviews: quantitative results of codes and insights from affinity mapping.

4.1 Quantitative results

A total of 374 codes were documented for all interviews. Table 4 displays the number of codes attributed to each life cycle stage and research theme.

Table 4. Total number of codes associated with each life cycle stage and research theme

Life Cycle Stage	# of codes	Research Theme	# of codes
Raw Materials	68	Ideas for Sustainable Behaviors	121
Manufacturing and Processing	19	Reliable Data and Information	43
Transportation and Distribution	18	Decision Making Factors	96
Use	206	Social Awareness	18
Disposal	52	Obstacles to a Sustainable World	52
–	–	Purpose of the Space	33
Total	374	Total	374

4.2 Insights from affinity mapping

This section highlights one subtheme for each pair of life cycle stage and research theme. All subthemes were produced from sorting and interpreting quotes and notes that were documented as codes.

4.2.1 Raw materials insights

Ideas for Sustainable Behaviors: outsourcing logistical work to efficiently keep materials stocked. While the implementation of outsourced services is ideal, they are often difficult to establish. An example of successful implementation of external services include Fastenal vending machine services. These services keep track of which materials are most often used by fabrication space users and consolidate the individual transactions to periodic transactions between the vending machine service and the fabrication space.

Reliable Data & Information: Material Brokers – the moderators for conversations between fabrication spaces and their suppliers. Material brokers are often staff or very involved volunteer members that have a strong personal and professional network with material suppliers and even other fabrication spaces in the community. A critical part of their role involves using personal and professional relationships to find the optimal material supply channels for their fabrication space. This might include establishing regular supply orders from large material supply companies (such as Home Depot, Lowes, etc) and frequent material donations from other larger fabrication spaces – that would otherwise go to waste. Overall, the strength of this material broker's network within the small scale fabrication space local industry is key to achieving optimal material flows into the space.

Decision Making Factors: achieving material compatibility with the cultural values of the fabrication space. Fabrication spaces vary in purpose and value to their users. Academic and community-driven spaces tend to emphasize accessibility by prioritizing affordable and safe to handle materials while commercially-backed spaces tend to emphasize material and equipment quality. Hence, the purpose of any space serves as a key filter for how staff make decisions about material and equipment purchases. Ultimately, a more refined typology of small scale fabrication spaces – and their core values – might help facilitate the match making between fabrication spaces and suppliers.

Obstacles to a Sustainable World: material and equipment donations that introduce new problems. Accepting donations without intent has led to acquiring materials and equipment that is not suitable for a fabrication space. While clarifying goals of the fabrication space is one way to address this dilemma, the issue may be more complex. For example, spaces that rely heavily on donated materials may not want to turn away offerings from an entity that supports them with materials and equipment that they do need. In this case, taking on the task of disposing of the "junk" materials and equipment may serve as a tacit component of the agreement.

4.2.2 Manufacturing and processing insights

Ideas for Sustainable Behaviors: alleviating source transparency of material and equipment repair and expected lifetime. There is a lack of transparency regarding equipment repair and material best practices communicated from manufacturers to the fabrication space. While most small scale fabrication spaces may not feel the urgency to request material and equipment details, the hypothesis held by some interviewees posits that more transparency about best practices and repair strategies would lengthen the lifetime of both materials and equipment in small scale fabrication spaces.

Reliable Data & Information: aligned financial incentives and sustainable practices as opportunities. Large manufacturing companies are concerned about their yield and the amount of energy that goes into their production system. Naturally, the best avenue to elicit change towards more sustainable practices is to find the overlap where sustainable practices also benefit their return on investment. Also, choosing larger companies, potentially located farther away, as suppliers is often more sustainable than choosing the smaller, local manufacturer.

Decision Making Factors: cost, quality, and availability as key factors in choosing domestic vs. international manufacturers. There are parts that are simply not available domestically – or when they are available, the supply is not consistent. Also, for parts where quality is more important, such as electronic components, the cost and quality provided by international manufacturers – specifically those in China – make it difficult to choose domestic manufacturers as an alternative. Unfortunately, there is rarely enough information from each manufacturer about the environmental impact of their production systems to support small scale fabrication spaces making an informed decision about environmental sustainability. This lack of transparency makes it easier for these decision makers to overlook sustainability – and in some cases ethical labor practices – as a factor altogether and instead focus on juggling cost, quality, and availability.

Obstacles to a Sustainable World: pursuit of competitive advantage through policy. Attention to policies that significantly influence a fabrication space's profitability often reduce their capacity to consider optimal sustainable practices. Hence, many interviewees mentioned how policies (both from municipal and private entities) can significantly alter a fabrication space's emphasis on sustainable practices. Regarding municipal entities, there are policies that require manufacturers to be more transparent about equipment repair as a deterrent to unsustainable practice of repurchasing equipment before the expiration of their useful lifetime. On the other hand, an anecdote from an interviewee revealed that private entities sometimes take advantage of consumers through their repair policies. For example, in one scenario, a manufacturer required the consumer (fabrication space) to purchase an entire assembly of components even when they only needed a small part within the assembly. The fact that the needed part was custom and hard to find elsewhere gives the manufacturer a lot of leverage in this scenario. Ultimately, right to repair policies supported by municipal entities are a pathway to stifle these kinds of tactics, which are not environmentally sustainable.

4.2.3 Transportation and distribution insights

Ideas for Sustainable Behaviors: robust documentation of material inventory patterns. Many interviewees encouraged formalizing the input of materials into fabrication spaces. One example includes clear and consistent organization of small parts that are likely to be misplaced (such as fasteners and small electronics). Another example involves fabrication spaces offering the bare minimum in materials needed to make – placing the responsibility on the users to find materials that are less likely to be used regularly. Ultimately, the ability to accurately predict material use within a space affects the environmental impacts produced in the Raw Materials, Manufacturing and Processing, and Transportation and Distribution stages.

Reliable Data & Information: absent information as a limitation to making informed choices. Missing or misleading information about a material's cost for labor and distribution limit a fabrication space's ability to make informed choices. One comment about the transportation of items to a fabrication space noted that external factors – such as unbalanced (and unethical) labor practices – often disguise the true cost of materials or equipment for manufacturing and distribution from long distances. However, it was hypothesized that most of the environmental impacts occur during the raw material extraction and processing stages instead of the transportation and distribution stage. Regardless, there is a need for more reliable information about these processes so that fabrication spaces are able to engage with sustainability as a strong decision making factor in their material and equipment selection.

Decision Making Factors: unbalanced fabrication space's priorities. Justifications for additional steps in the distribution phase are dependent upon the fabrication space's priorities (such as access to materials and equipment, material quality, and minimizing inhouse processing). Many examples communicated by interviewees explain that expensive and transportation intensive suppliers were justified with high material quality expectations by the users of the fabrication space. This subtheme is perpetuated by a lack of information and balance regarding the cost of labor and other inputs for material extraction and processing across the globe.

4.2.4 Use insights

Ideas for Sustainable Behaviors: innovative revenue streams that are compatible with sustainability goals. Secure, and less labor intensive, revenue streams offer flexibility for fabrication spaces to think more critically about the environmental impact of their space's operations. Examples of sustainable revenue streams mentioned during interviews include premium classes offered to community members, an employment model that varies in the percentage of paid and volunteer staff, charging users for material storage when necessary, renting excess space to local companies that value access to making and tinkering, and intentionally recruiting volunteer staff with expertise in repair of equipment that are essential to the space. While these examples vary in their compatibility with fabrication spaces – especially since some of them may compromise accessibility to users – they serve as a starting point for spaces that want to enable themselves to think more critically about their environmental impact contributions.

Reliable Data & Information: leveraging community expertise. Interviewees shared that user-driven skill sharing happens naturally when the space includes a multi-generational body of users with wide ranging contextual backgrounds and skill levels in fabrication. Thus, intentional planning for welcoming a balanced user base of skill sets and contextual backgrounds is an encouraged practice for most spaces. Additionally, it is important to note that skill sharing was most reported in interviews as a primary value of fabrication spaces that are community based – which may be because these spaces tend to rely more on volunteer staff. A major takeaway from this subtheme is that being intentional about attracting a diverse audience of users to a fabrication space enables more free skill sharing opportunities. This allows the fabrication space leadership to focus on other important tasks – such as their ability to reduce their environmental impacts.

Decision Making Factors: individual values of leaders and users in the fabrication spaces. Contextual factors drive individuals to use, volunteer, or find employment in a fabrication space. Where students are primary users, contextual factors such as project deadlines and learned prototyping techniques from classwork inform how they value their practice of using the space. Often the pressure to succeed academically overrides the need to be sustainable in their practice of using the space – which results in lots of excess materials being used to refine their work in the fabrication space. Also, instructors of prototyping and design related courses and managers of fabrication spaces (often termed makerspaces in academic settings) have a lot of influence over how these behaviors are either perpetuated or minimized. Outside of academic fabrication spaces, there is a similar relationship that exists where managers have the ability to guide users towards more sustainable practices.

Social Awareness: equipping users with knowledge and agency to make sustainable decisions. Supporting knowledgeable and empowered users may come across as an obvious pathway to sustainable practices; still, the distinction that makes it a more complex pursuit is that most users have vastly different learning styles. So, the effort to effectively empower all users with knowledge to make sustainable decisions is not a trivial task. One example of this includes open house style events that invite entry level users to meet staff and other members of the fabrication space. Another example includes providing robust equipment training and starter projects that support both achieving a desired fabrication outcome and properly using tools to minimize energy use and material waste. Overall, many aspects of what creates a welcoming and inclusive environment become key to success regarding users' developing agency to make sustainable behaviors.

Obstacles to a Sustainable World: vulnerabilities of volunteer driven operations. There are a variety of management models where volunteers are significantly involved in the day to day operations of the fabrication space. This might involve volunteers specializing in equipment repair, volunteers that have personal and professional network connections to needed materials, or volunteers that are trusted to keep the space open during business hours. Overall, these models are vulnerable to an unbalanced distribution of volunteer work. For example, in many conversations it was revealed that there are likely to be a few volunteers that commit significantly more time and effort to the fabrication space. This typically drives them to burn out and, unfortunately, other volunteers are not likely to step in for them. Also, there are likely to be volunteers that take advantage of the perks of volunteer status by doing the bare minimum in staff responsibilities.

Purpose of the Space: cultivating a safe space for a diversity of users. Many responses from interviewees mentioned that fostering a safe space for a diversity of users supported other core values of fabrication spaces – such as skill sharing, cross pollination of ideas, and partnerships with other community organizations that are critical to the success of the space. One interviewee alluded to actual fabrication and making as secondary to creating a safe space for users in the fabrication community to gather and socialize.

4.2.5 Disposal insights

Ideas for Sustainable Behaviors: tangible strategies for reducing the waste stream. Examples of these strategies include, effective signage and other visual reminders for disposing of materials, policies that require users to leave with any materials that they enter the space with, and a firm approach to accepting and denying donated materials and equipment.

Reliable Data & Information: recycled materials as sources of inspiration. Material scraps often consist of old prototypes that serve as inadvertent inspiration for users while they are searching for reusable materials. While hoarding prototype scraps can quickly become undesirable by staff and environmentally harmful, it seems to be worthwhile to consider which of them best reinforce core values or behaviors of the fabrication spaces.

Decision Making Factors: inconsistent quality and cost of recycled materials. In instances where the fabrication space managers are making decisions about what materials to order for their space, recycled materials are hard to rationalize as the right choice. Recycled materials offered by manufacturers and suppliers are not always the cheaper option and they often have variable material qualities that make them a risk to depend on for higher fidelity fabrication processes.

Social Awareness: holistic mindsets for reducing waste. There is a need for a big picture shift towards the value of being conservative with materials – countering the somewhat wasteful habits engendered by fast fashion and rapid prototyping. Within fabrication spaces this might involve an emphasis on repairing before creating new things. Also, thinking about the big picture life cycle of waste, as opposed to individual contributions, is an important mindset shift. Here, the focus is to encourage enthusiasm towards minimizing overall wastes from fabrication spaces instead of passing the guilt of disposal off to another person or group via donations.

Obstacles to a Sustainable World: minimal incentives and competing interests as barriers to proper recycling. Users often fail to account for the time and energy needed to properly recycle or repurpose usable materials. Competing interests such as project deadlines and rigid entrepreneurial timelines make this a difficult value to embrace. Within academic spaces, instructors may be able to support better practices by including recycling and repurposing materials as a critical aspect of equipment training. Similarly, fabrication space managers in commercial or community driven spaces could use financial tactics to incentivize repurposing materials – or exercise the value of social capital within a space by guilt tripping those that excessively use materials without thinking to recycle.

4.3 Limitations

Initially, the term “small scale fabrication space” was used with the intent of inviting all perspectives from tangible fabrication and making environments that contribute to their communities at a predominantly local level as opposed to those that operate more regionally, nationally, and globally. In reflection, an alternative term, or terms, may have more accurately communicated the purpose of the study. Moving forward, similar studies may find more actionable results from studying a narrowly defined subset of these small scale fabrication spaces (such as local digital manufacturing spaces, academic makerpsaces, or community makerspaces).

5 CONCLUSION

This research study explores the state of sustainable practices in the life cycles of small scale fabrication spaces. Through 18 semi structured interviews and a rigorous coding approach, insights were developed for all five life cycle stages (Raw Materials, Manufacturing and Processing, Transportation and Distribution, Use, and Disposal) of small scale fabrication spaces. Key insights from this study are detailed below.

5.1 Towards sustainable practices: operational efficiency, user training, and staff capacity

The ability to achieve a consistent and optimal flow of materials and equipment through a fabrication space is greatly affected by: discernment of material selection – particularly knowing when to turn down donations; robustness of materials and equipment inventory management; and level of support for user disposal of materials – such as signage, training, reminders to allocate time for disposal, and financial incentives and penalties.

Strategic alignment of financial incentives and goals for sustainable behaviors come into play when choosing the right manufacturer to purchase materials and equipment. It also operates as a means to reclaim capacity of the fabrication space staff so that they may focus more on sustainability as a priority.

Fabrication spaces do themselves a favor when they promote user training, education, and agency regarding sustainable practices. This involves going beyond a one-size fits all approach to equipment trainings and user support; instead, this means thinking critically about the contextual make up of users so that your approach to empowering users is holistic.

5.2 Key actors and decision makers: incentives for manufacturer transparency and sustainable user behavior

Small scale fabrication space staff are some of the most knowledgeable actors in the life cycle of these spaces. Unfortunately, other key actors, such as equipment and material manufacturers often limit the information that the staff have to make decisions with. This restricts a fabrication space's ability to realize the optimal lifetimes of materials and equipment. Generally, these information gaps make informed decisions, such as those related to sustainability and ethical labor practices, much harder as well.

The individual drivers for a fabrication space's users have an impact on sustainable behaviors. Academic, community driven, and commercial fabrication spaces typically have different value propositions that attract users to their space. In particular, community driven spaces seem to be more concerned with the community building offered by making things together instead of only prioritizing the act of fabrication and making.

5.3 Information flows from material brokers and material manufacturers

Material brokers, as defined by one interviewee as the individuals with an extensive network within small scale fabrication spaces, represent a key actor and resource for any space. Their personal and professional network is usually the shortest pathway to achieving operational and logistical efficiency.

Material and equipment manufacturers are also key sources of information for reducing environmental impact in small scale fabrication spaces. Unfortunately, the flow of information from manufacturers to fabrication space decision makers is poor. Opportunities to incentivize manufacturer transparency is an important gap to address in future work concerning small scale fabrication spaces.

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