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Circular Makerspaces: the founder's view

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Circular Makerspaces: The Founder’s View

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Circular Makerspaces: The Founder's View

Makerspaces – open access design and fabrication workshops – provide new contexts for design practice through ‘distributed production’. The global community of makerspaces has evolved quickly and in turn, substantial hype is attributed to its potential for radical sustainable innovation. In this article we explore this potential in the context of the new ‘circular economy’ agenda. We focus the research on the critical role of makerspace managers/founders who are recognised as gatekeepers to circular practices. The research method is action-led including expert interviews (academics and founders/managers) as well as two generative context-mapping workshops, run at selected makerspaces in collaboration with their founders/managers. We unearth everyday ‘how-to’ guidance to interweave circular practices within makerspaces from the outset by: fostering an enabling culture; building local connections; nurturing individual/community capacities; and stimulating practical know-how. However, while the research reveals immense opportunities to cultivate circular literacy from within makerspaces, the prospects to ask more profound questions about our economy, through makerspace practices, are found to be compromised by day-to-day concerns. The insights from this research can act as a starting point for future work in this emerging research area.

Keywords: makerspaces; circular economy; distributed production; design; makers; sustainability

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1. Introduction

Increasingly commonplace design and fabrication laboratories, colloquially known as makerspaces¹, are places where people can access a range of equipment and machines for personal making (Smith et al. 2016). Various known as Fab Labs, Hackerspaces, Tech Shops and Community Garages, these are (networks of) workshops that provide (open) access to technologies (such as additive and subtractive prototyping equipment, lathes, cutting machines) that allow people to make things, from beginning idea to final production (Fleischmann, Hielscher, and Merritt 2016). Makerspaces can be funded through a range of different business models including being voluntarily run, government or institution supported, or commercial ventures. They exhibit a range of activities, governance structures, scope of ambitions, regularity of use and attendance, and exist in diverse local contexts (Hielscher, Smith, and Fressoli 2015). The maker community is acknowledged in the UK government’s additive manufacturing strategy², reflecting their perceived role in a future distributed manufacturing system.

Similarly, the Circular Economy (CE) concept envisions a reformed industrial system promoting resource efficiency by adding value through closed loop resource approaches (EMF 2013a, 2013b; EMF 2015). This involves *slowing* resource loops (Stahel 1984), through the design of long-life goods and product-life extension (through maintenance, repair, refurbishing, remanufacture, upcycling) (Bakker et al. 2014) and *closing* resource loops (recycling) (Stahel 1984), resulting in a circular flow of resources (Stahel 1984; Braungart, McDonough, and Bollinger 2007; EMF 2013a; EMF 2013b). Some of

¹ *In this article we use the term ‘makerspace’ though we recognise that ‘makespace’ is also used and that the activities that characterise hackerspaces, build-space, innovation spaces, Fab labs, Tech shops etc. often overlap and can be difficult to define.*

² <http://www.ifm.eng.cam.ac.uk/resources/technology/additive-manufacturing-strategy/>

these activities can already be observed within makerspaces giving rise to speculation on the potential role of makerspaces in a future distributed manufacturing system founded on CE principles.

However, so far little research has been undertaken that evidences these claims. On the contrary, negative effects such as continued over-consumption as well as high environmental rebound effects, can be linked to both the CE (Murray, Skene, and Haynes 2015; Edbring, Lehner, and Mont 2016; Hobson and Lynch 2016; Hobson 2016) and makerspace (Ritzer and Jurgenson 2015) movements respectively.

Furthermore, resource efficiency approaches have been deeply criticised for their inadequacy in 'reducing unsustainability' (Dewberry and Monteiro de Barros 2009) when instead our goals and the system of values and motivations that drive our actions (Dewberry and Monteiro de Barros 2009) need to be radically challenged. This sheds light on the types of interventions needed if the makerspace movement is to become sustainable. In addition, the literature on sustainability within makerspaces acknowledges the need for more leadership and guidance to come from within it (Fleischmann, Hielscher, and Merritt 2016; Kohtala and Hyysalo 2015).

In light of this, in this research we explore the role of makerspace managers/founders, who are identified as both operational and strategic gatekeepers for developing circular makerspaces and anticipate that their views are key to future work in this area. The research asks: *What is the role of makerspace managers/ founders in developing circular makerspaces?* Firstly, the article reviews the literature for conceptual synergies between the CE, distributed production and makerspaces. Next, the research method is described, including expert interviews and two context-mapping workshops. This is followed by the results and then we present our analysis, discussion and final conclusion.

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2. Literature

This section analyses the current literature on the CE, makerspaces, and distributed production and concludes with a conceptual comparison of the CE and the makerspace movement to develop circular themes to inform the workshop activities described in section 3.2.

2.1 Circular economy: frameworks, principles and actors

The CE concept is described by innovation in the management of flows of resources (resources, energy, materials) and therefore CE frameworks tend towards a techno-centric focus, evidenced by measures of physical resource flows (Haas et al. 2015). This perspective on the CE has informed the development of a number of CE frameworks. The EMF’s (2013a, 2013b) ‘Butterfly Diagram’ conceptualises a dichotomy of synergistic resource cycles: a ‘biocycle’ and a ‘technocycle’. Equally, Braungart et al. (2007) conceive a cradle-to-cradle framework, also drawing on a biocycle and a technocycle concept focusing on closing resource loops. Many authors stress that both product design and business model innovation are needed (Bakker et al. 2014; Bocken, Bakker, and De Pauw 2016; Moreno et al. 2016; Prendeville et al. 2017) to realise a future CE. For instance, Bakker et al. (2014) emphasises product life extension through repair, remanufacturing, refurbishment, reuse and recycling, achievable through a combination of technical design strategies and systems innovation. Other scholars emphasise macro-level systemic interventions in spatial contexts (Lieder and Rashid 2016; Su et al. 2013; Prendeville, Cherim, and Bocken 2017). Lieder & Rashid (2016) compose a framework combining complementary *business* and *policy* activities: top-down (national efforts at societal, legislative, and policy levels) and bottom-up (company collaborations, supply chain efforts, product design, information and

communication technology), omitting that bottom-up activities can and should include citizen engagement and action. Su et al. (2013) and Ghisellini et al. (2015) each use a micro (single object e.g. ecodesign, cleaner production, single company or consumer actions), meso (symbiosis association e.g. stakeholder networks, waste management systems), and macro (city, provincial, state strategies e.g. eco-cities, circular cities, urban mining) framework to conceptualise within a CE. Such frameworks reflect the business/policy narrative of the CE as well as its emphasis on resource efficiency as a route to sustainability. In this article we use the terms '*circular/circularity*' to convey the core principles of the CE, to close resource loops, and to reflect the focus of the article on circular *practices* rather than the wider economic/infrastructural issues at hand.

2.2 Makerspaces

The maker movement upholds the individual as a maker (Toombs, Bardzell, and Bardzell 2014; Nascimento and Pólvora 2016) locating itself with values of localism, openness, sharing, and collaboration (Gershenfeld 2005; Thackara 2011; Nascimento and Pólvora 2016; Kohtala and Hyysalo 2015). Nascimento & Pólvora (2016) see the potential for citizen empowerment through making activities as a means to provoke the status quo. Appreciation for resources and culture manifests through practices for 'meaning and expression' as well as 'innovation and skills' development (From Now On 2016). However, Smith and Light (2015) describe how despite these strong social drivers, users of makerspaces are overly fixated on technology and recent research concedes that non-experts struggle to use many technologies housed in makerspaces (Lupton 2016). In addition, the diversity of makerspaces mean that commercially-oriented spaces exist who seek to do business in traditional ways that depart from this

characterisation. For instance, the London-based Central Research Laboratory³ is a UK-based *hardware* start-up established to incubate entrepreneurs bringing new products to the marketplace.

Smith et al. (2016) describe the makerspace movement as a people-centred grassroots innovation movement. Grassroots innovation has long been seen as a strategy to address climate change (Verheul and Vergragt 1995) and involves communities working on solutions for sustainable innovation, through practices that respond to local contexts, interests and values (Seyfang and Smith 2007). For example, repair networks, often hosted in makerspaces (e.g. Restart Project / Repair Cafes) (Riisgaard, Mosgaard, and Zacho 2016; RSA 2015) involve community members helping one another fix things, illustrating how localities can self-determine local resource management, indicating a form of citizen-led and local CE. In addition, makerspaces often host technologies that can facilitate rapid part manufacture, to support repair or remanufacturing, indicating a technological capacity to support CE activities. What this shows is that many activities described as product life-extension strategies by Bakker et al. (2014) can occur within makerspaces. This is further illustrated through the examples from literature and practice described in Table 1. It is worth noting that such activities can occur without a makerspace’s physical structure, even though there may be beneficial aspects of doing so in a makerspace (access to tools, skills, communities) (Salvia and Prendeville 2017).

Table 1 inserted near here

2.2.1 New manufacturing paradigm

³ <http://www.centralresearchlaboratory.com/>

Dickel, Ferdinand and Petschow (2016) describe how manufacturing and value creation are in the midst of a great transition, enabled by low-cost desktop digital technologies (such as those housed in makerspaces) and the ability to share information easily and quickly over the internet (Kostakis et al. 2015). Through new means to support product development costs (through platforms such as Indiegogo⁴ and Kickstarter⁵) and foster global communities around products, makerspaces are considered to play a prominent role in this transition. Distributed production is characterised by local production; cloud manufacturing services; flexible production environments capable of creating personalised/customisable products; sustainable and resource efficient technologies; and flexibility/agility in production suited to short ramp-up times (Srai et al. 2016; EPSRC 2013; Moreno and Charnley 2016). Srai et al. (2016) state that because decentralisation is embodied in the concept of distributed production, distributed production in-and-of-itself is the very manifestation of the CE. This is because it has the capacity to implement short/flexible production/consumption loops as well as reduce transportation (Birtchnell et al. 2017) making it an important potential enabler of a future CE.

In addition, Kohtala's (2015) integrated literature review identifies ways that sustainability may be benefitted by distributed production including through: *product longevity* (e.g. product life extension through emotional attachment, intensification of use through product-service systems); *local production* (reduced transportation reduces environmental impacts); *co-design* (users involved in the early stage of the innovation process for responsible decision-making about what is produced); and *technology affordances* (the abilities technologies personify towards sustainable practices). For

⁴ <https://www.indiegogo.com>

⁵ <https://www.kickstarter.com>

more detailed reviews of the terminology related to distributed production see Srai et al. (2016) and Kohtala (2015). This indicates distributed production intervenes dually in consumption and production, offering ways to reimagine the entire system (*over and above a resource efficiency approach*). Knowing that ‘both sides of the sustainability equation’ must be addressed in unison (Dewberry and Monteiro de Barros 2009) therefore makes the potential for the makerspace movement compelling. For these reasons, we approach the research question through the lens of distributed production.

2.3 Synergies for circular makerspaces: ideologies, visions, attributes, actors

The literature described so far allows synergies and difference to be identified between the CE and the maker movement. Importantly, both movements are led by ideologies based on new forms of governance and economics. Yet, the CE is oriented towards technological solutions, whereas the maker movement is seen as a counter-narrative to centralised and top-down socio-technical systems (Smith et al. 2016). Even if not all makerspaces can be characterised as such, we can agree that makerspaces create culture, are creative and social, focusing on opening up access to technologies. This ideology sits in stark contrast to the largely policy-driven and business-led approach that characterises the CE. Critics of the CE argue that it is limited by this bias towards technological solutions and overlooked and complex social and cultural issues, such as consumer behaviour (Hobson and Lynch 2016). Therefore, hints of a more radical CE are perceived at the nexus of the CE and makerspace movements, blending the resource benefits the CE brings to society with the social value embraced by the makerspace movement. Practical synergies can also be identified. For instance, the CE promotes a hierarchy of product life extension and these ‘inner-loops’ (reuse and repair) can be realised in makerspace and enabled by close proximity between the consumer/producer, but which are perceived to be under-addressed in the CE literature so far (Ghisellini,

Cialani, and Ulgiati 2015; Riisgaard, Mosgaard, and Zacho 2016). Table 2 compares the CE and makerspace movement according to their ideologies, visions, defining attributes and key actors.

Table 2 inserted near here

2.4 Research and practice gap

Makerspaces are endowed with a capacity to address climate change and sustainability, by fostering social inclusivity and creativity in sustainable innovations (Hielscher and Smith 2014). However, it has been found that day-to-day survival mean environmental issues are not given much concern within makerspaces (Kohtala and Hyysalo 2015; Hielscher, Smith, and Fressoli 2015; Hielscher and Smith 2014). While sustainability may be championed sustainability is not given (Smith et al. 2016) nor are sustainable design practices unequivocal within a given makerspace context (Fleischmann, Hielscher, and Merritt 2016). In addition, Fleischmann, Hielscher, and Merritt (2016) describe how support as well as co-creation between citizens and experts is needed (Fleischmann, Hielscher, and Merritt 2016) otherwise unsustainable practices will inevitably be 'reproduced unwittingly' (Smith and Light 2015). Perhaps because designing with circular practices is challenging there is a lack of exemplars to draw inspiration from. So far, very little research has been undertaken that explores the relationship between makerspaces and circular practices. Studies that have been undertaken on sustainability in makerspaces convey how it must be proactively driven from within the makerspace environment itself (Fleischmann, Hielscher, and Merritt 2016). Emphasis is placed on the critical role of managers/founders in supporting sustainability through guidance (Kohtala and Hyysalo 2015) and leadership (Fleischmann, Hielscher, and Merritt 2016), which are needed to embed certain

practices within these contexts. This is not unique to makerspaces– sustainable innovation requires intervening in what is designed, but also in the ‘*why*’: the values, beliefs, visions and objectives of organisations (Dewberry and Monteiro de Barros 2009). Drawing on this viewpoint, in this research we focus on the importance of the manager/founder vision and how this vision is enacted through its day-to-day practices.

3. Methodology

3.1 Research approach

The aim of this research is to explore the role of makerspaces managers/founders in developing circular makerspaces. The research focuses particularly on uncovering each manager’s vision and how this vision is operationalised. The manager/founder vision is explored through expert interviews and conversations in situ during the workshops. The day-to-day practices are also discussed through the interviews and elicited by using circular themes as probes during the workshops conducted.

The research methodology is action-led, qualitative and exploratory. An action research approach was chosen as it is flexible and well suited to working within organisations and socio-technological concerns (Robson and McCartan 2015) and the emergent nature of action research (Koshy, Koshy, and Waterman 2010) is seen as well suited to the makerspace context. Bryman and Bell (2015) describe action research approaches as iterative, based on applied problems that require practical results and focus on changing thinking through collaboration. The research process was iterative insofar as the researchers carried out a series of activities in collaboration with a number of makerspace managers/founders, which were then reflected upon. In addition, through informal conversations, further insights were gleaned through on-site visits to

makerspaces during the study (Appendix A). The research approach is illustrated in Figure 1.

Figure 1 inserted near here

3.2 Research activities

The research activities included six expert interviews; two workshops; and eight site visits. Firstly, the research team conducted interviews with thought-leaders in the field. The interviewees have expertise in establishing and running makerspaces for both educational and commercial purposes and many of whom have pioneered sustainability within the makerspace movement. These interviews allowed the research team to establish core aspects of embedding circular practices within makerspaces. The expert interviewees are described in Table 3 and the interview guide used to conduct the semi-structured interviews can be seen in Appendix B.

Table 3. Inserted near here

3.2.1 Workshop selection

The workshop selection was both purposive and opportunistic: on the one hand we sought recommendations for pioneering makerspaces (from the experts interviewed) and this was supplemented with a pragmatic approach. The intention was to seek a range of views. The research scope is outlined in Figure 2, which situates the research within the makerspace landscape. Figure 2 combines a classification by (Troxler 2011) with a classification by Nesta (2015). The solid coloured area indicates the remit of selected makerspaces.

Figure 2 inserted near here

Troxler’s framework describes distinct types of makerspaces – fab labs, hackerspaces, techshops and community workshops – as *more reproductive or more generative in their nature, and as more infrastructure-oriented or more-project oriented in their approach*. Nesta emphasises ‘subjective interpretation’, nonetheless noting emergent patterns of common types of makerspaces and indicating a trend towards ‘hybrid’ models’. Hybrid models include ‘cluster-models’ and are perceived as a successful approach because they select and combine a range of beneficial attributes: access to co-working space; business services and technical equipment; income through consultancy or design services; and event hosting. In addition, the researchers sought examples exhibiting the following range of characteristics: grassroots to commercially-oriented; early stage set-up to more developed initiatives; potential for circular practice; and potential for distributed production. The following makerspaces (cluster-models) were chosen for the workshops:

Fab Lab London: This Fab Lab was identified as an early-stage makerspace with unique attributes due to its partnerships and co-location (at the time of writing) with a CE focused government-funded agency, The Great Recovery⁶.

Buda::lab Kortrijk: This Fab Lab was identified through expert interviews as having a strong commercial focus and strategic links with its local context and therein high future potential for distributed production.

⁶ <http://www.greatrecovery.org.uk>

The two workshops were hosted at makerspaces chosen from an initial list of nineteen potential makerspaces. Both were conducted on-site in collaboration with the makerspace managers and founders.

3.2.2 Description of workshop activities

The workshops use a generative context-mapping approach (Visser et al. 2005). Context-mapping is a participatory/user approach that involves lead participants from the outset to build understanding of contexts (ibid). The context-mapping method was chosen to allow the researchers to directly understand the space from the viewpoint of each manager/founder. In the first case this involved observation, participating in a design challenge and a walk-around the Fab Lab London in conversation with the Fab Lab manager.

For the second workshop a series of tags, each with a circular theme, were used to map stories in the space. The themes used were identified through a combination of the literature, insights from workshop one, and insights from the expert interviews. These can be seen in Table 4. The research team developed the tagging approach to draw out and open up a dialogue with the founders/managers. This method is useful as it engages participants with the space directly and was viewed as an insightful technique to uncover and share key CE themes about day-to-day practices, in dialogue with the makerspace founders/managers. Hyysalo et al. (2014) employ a similar context-mapping approach through a tagging activity undertaken with makers who were instructed to add notes, with solutions statements to known issues, onto machines and surfaces as part of a participatory research.

Table 4. Inserted near here

Workshop 1: Fab Lab London. This workshop was run in parallel to a design challenge that was co-developed in collaboration with The Great Recovery and the Open Source Circular Economy⁷ days global community. The central topic of the challenge was the CE, focusing on issues such as: product life cycles, information flows required to improve waste management, how wearable technology can facilitate circularity and the environmental impacts of open hardware manufactured within a makerspace.

- **Approach:** Participatory context-mapping workshop integrating observation and shadowing
- **Purpose:** The purpose was to develop initial insights into how circular practices are supported and from this develop initial guidelines and criteria for workshop two
- **Participants:** 7 participants: Researchers (3); Manager/Founder (2); CAD Software Sustainability lead (1); Software Developer (1).
- **Activities:** The activities involved three key steps:
 - Walk-around: The walk-around in conversation with the Fab Lab manager included an introduction to the workshop focusing on processes and tools and examples of how it introduces circular principles and how these have been informed by its partnership with The Great Recovery, such as through understanding of proper machine set-up (e.g. correct positioning for optimal machine and material use).

⁷ It was hosted during a global hackathon on the topic of Open Source Circular Economy Days (OSCEdays: <https://oscedays.org/>) in collaboration with the global online OSCEdays community. The nature of the OSCEdays hackathon was such that the event was promoted throughout makerspace networks online and participants were given the option to choose a challenge (out of a possible five).

- Observation: The ethnographic observation activities involved note-taking during and after the workshop and visually documenting important aspects/circular themes through photographs.
- Design challenge: The researchers participated in the design challenge⁸ focusing on the topic of embedding circular practices within makerspaces through the global OSCEdays community. The process involved gathering best practices by connecting with experts, synthesising key issues from the initial research and conceptualising potential solutions that could be further developed. The outcomes were discussed with all of the participants at the end of the session.

Workshop 2: Buda::lab Kortrijk. The researchers documented stories and anecdotes about circular themes to establish a view of the overall makerspace context. Figure 3 shows an example of a tag illustrating the themes of product life cycle, waste, good practice guidance and toxicity.

Figure 3 inserted near here

- **Approach:** Participatory context-mapping approach using pre-selected tags each with a unique CE theme.
- **Purpose:** The purpose of the workshop was to: explore the makerspace activities from a circular viewpoint, as well as uncover ‘show & tell’ exemplars (similar to those identified during workshop one) through a tagging activity.
- **Participants:** 6 participants: researchers (2); managers (1); Lab user/student (1); founders (2).

⁸ <http://community.oscedays.org/t/headline-challenge-circular-maker-spaces/451>

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- **Participant selection:** Prior to the workshop, the researchers shared an explanation of the activities and purpose (Appendix C) with the workshop manager and requested that he invite relevant parties to the workshop on our behalf.
- **Activities:** The main activities included establishing a dialogue with the makerspace manager and using ethnographic observation during the visit (documented through photographs and notes taken during the workshop and detailed post workshop). The tagging activity involved laying the tags in front of the participants and asking them to choose tags to discuss. Participants were asked to choose tags that relate to an object or location within the makerspace in the context of (positive or negative) of circular practices.

4. Results

This section discusses the results of both workshops with respect to the vision and the key CE themes identified.

4.1 Workshop 1 – Fab Lab London

4.1.1. Vision

Fab Lab London was set up in 2013. Its focus is on digital manufacturing and rapid prototyping and it adheres to the Fab Charter⁹, which sets out its manifesto. It has an explicit commitment to using closed loop methods and fostering ‘sustainability thinking’. Its overarching aim is to take an educational role tailored to knowledge facilitation, training and skill sharing, through events and engagement activities. It

⁹ <http://fab.cba.mit.edu/about/charter/>

typically caters to corporate audiences through workshops and is centrally based in the City of London. In addition, it works ‘in-partnership’ with The Great Recovery¹⁰, to build knowledge on sustainable design by focusing on learning-by-doing. For instance, The Great Recovery’s signature activity, the educational ‘product tear down’ workshop, builds understanding and asks questions about what is behind manufacturing. The managers themselves are interested in CE issues and they are keen to transfer this to the lab users. The managers convey how their advocacy for sustainability through circular is realised in their educational activities. This is evident in its programme of events, trainings and open days built around circular design¹¹.

4.1.2 CE themes

The examples shown in Figure 4 communicate the key circular themes and insights from workshop one.

Figure 4 inserted near here

- A. Waste/resources:** off-cuts of all types of materials are collected and stored visibly for reuse for prototyping models
- B. Product lifecycles:** During the design challenge, participants developed concepts that relate to building knowledge of product life cycles:
 - One group designed cosmetic packaging suited to easy disassembly, 3D modelling and printing their new design of an inner plastic cartridge and outer housing that could be easily separated. With the aid of the lab

¹⁰ <http://www.greatrecovery.org.uk>

¹¹ <http://www.greatrecovery.org.uk/fab-fridays-introduction-to-the-great-recovery-and-fab-lab-london/>

technician this was quickly realised on the 3D printer and was seen as a strong example of circular product design, conveying the limitations of current design practices that fuse different materials together, thereby inhibiting clean recycling.

- Another group worked on doing a fast life cycle assessment (LCA) to assess the embodied energy of the Open Energy Monitor¹², with support from participants with expertise in LCA, illustrating how scientific knowledge relevant to circular is brought into the lab through collaborations.

C. Technology/tools: examples of ‘fast print’ highlight the size and surface finish according to chosen print setting and the print time required to convey the process duration and material requirements to ensure users choose the optimum settings for their needs. In addition, it houses a machine to test filaments for recycling.

D. Signage/visual cues: These are commonplace ‘*show and tell*’ tools that are perceived to guide the lab users towards better practices and support managers running the space. Simple examples range from labelling valuable scrap materials, to guidelines for efficient machine use, to signposting to local resources and collected off-cut material. These are useful to guide better behaviour because, according to the lab manager, it is too easy to go straight to high fidelity prototyping. For instance, using the laser cutter to cut basic cardboard shapes for models, when a cutting mat and scalpel can be fine. This is

¹² <https://openenergymonitor.org/emon/>

something that needs to be conveyed to lab users daily and represents wider issues about use of technologies and materials.

E. Value: The manager reflected on the cost of standard materials (such as hard plastics, acrylic, fibre boards, Plywood). Using the lab's materials list (excerpt Appendix D) as a talking point, he described the prohibitive cost of exotic (and perhaps more sustainable options such as Polylactic acid (PLA)) that come at a premium and moreover are not requested by lab users. He proposed that knowing better the links between the material, the process, and tool most appropriate to the product (and its system), to guide design choices via the material list would be beneficial, as well as vice versa the tool and processes.

4.2 Workshop 2 – Buda::lab

4.2.1 Vision and strategy

Buda::lab is a Fab Lab in the Belgian town of Kortrijk established in 2011 under a European interregional funding programme, in collaboration with the municipality, local design council and a polytechnic. The lab is part of the Budafabriek, a recently renovated textile factory, located within BUDA-island, situated between two river banks in Kortrijk. Its vision it is to stimulate networking between arts, entrepreneurship, education and creative citizens – it is a public space as well as a cultural centre. Both the chairman and the coordinator of the Buda::lab want to encourage people of the region to use the lab as a working place for co-creation, as well as to encourage the creative collaborative process of companies.

4.2.2 Circular themes

Figure 5 illustrates some of the outcomes of the tagging activity and theme discussion around: local collaborations; tools and technologies; typical prototypes produced in the lab; initiatives such as the open source bee-hive project¹³ and the global Fab Lab network.

Figure 5 Inserted near here

- A. Technology/tools:** Buda::lab is a public workshop where an extensive collection of machines are available to process materials. It houses conventional techniques such as sawing, drilling and tools for wood, metal or plastics, as well as advanced techniques such as vacuum forming, laser cutting and milling, as well as two high-specification 3D printers to build prototypes. This is in-line with its positioning as a commercially focused Fab Lab. It started out with a small amount of tools and over time has increased its machines through additional funding and donations (including a lathe and textile plotter).
- B. Product lifecycles:** The lab manager describes how they often don't 'see the end result' of their commercial work, reflecting their supply chain position (research and development). The open source beehive project led to a discussion about fixtures and joining and highlighted that more knowledge needs to be shared about good design practices (such as glue free joints).
- C. Value:** The lab generates financial income through commercial activities including prototyping and making high fidelity architectural models, examples

¹³ <http://opensourcebeehives.net/>

1
2
3 included a prototype mechanical gear made of a commonplace engineering
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5 plastic, a bespoke trike and a diorama.
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7 **D. *Sharing*:** The lab users have established and organise their own ‘electronics
8
9 library’.
10

11 **E. *Toxicity*:** Typical day-to-day activities at the lab generate lots of waste some of
12
13 which is problematic to dispose of (such as spray paint cans).
14
15

16 **F. *Local production/local contexts*:** Initially, the manager had a vision to promote
17
18 local production networks, connecting producers and lab users and this was
19
20 expressed in their previous attempts to set up a local supplier database. For
21
22 example, they conveyed an interest to engage with a local textile federation, as
23
24 Kortrijk was once a textile producing region. The manager expressed his desire
25
26 to enlist local providers where possible (e.g. for aluminium extrusions) and
27
28 according to them, these relationships unfold over time.
29
30

31 **G. *Education/skills*:** During the workshop, Buda::lab was hosting a six-week
32
33 educational course with introductions to tools and technologies. The manager
34
35 described how makerspaces are already reskilling and upskilling people, by
36
37 making it possible for everyone to carry out their projects themselves, offering
38
39 start-ups machines and equipment, as well as material exhibitions, and
40
41 establishing a materials database. In addition, he indicated that induction
42
43 courses, such as machine tool masterclasses as part of the PROUD work online,
44
45 help to instil good practices in lab users from the outset.
46
47

48 **H. *Guidance/signage*:** The Buda::lab also uses signage and process steps
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50 commonly throughout the space, to guide its users to encourage good behaviours
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52 for Health and Safety but also efficiency and good design practices.
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5. Analysis and discussion

5.1 Enacting circularity in Makerspaces

Through clustering and thematic analysis this section analyses and discusses the research findings. Figure 6 describes the practices identified through the research, clustered according to four themes: foster an enabling culture; build local connections; stimulate practical know-how; nurture individual/community capacities. The whole cluster analysis can be seen in Appendix E. For each theme a set of ‘*how-to*’ guidelines are described, supported by interviewee quotes and workshop data.

Figure 6 Inserted near here

5.1.1 Foster an enabling culture

Interviewees variously reflected on the necessity to facilitate a ‘...*stakeholder circle*’ to ensure dedication from those individuals who can bring relevant skills. There is a need to set a ‘*clear and principled vision*’ that emphasizes ‘*responsible products*’ from the outset. It is clear that establishing this vision sets the course for a given makerspaces and this is enacted through its admission processes (e.g. ‘initiation’, ‘joining conditions’, induction) and day-to-day practices. For instance, Fab Lab London has a strategic commitment to ‘sustainability thinking’ supported by its tools and activities, despite the absence of explicit sustainability criteria in the Fab Charter. These practices help form the culture. One interviewee conveyed the cultural differences between contexts, ‘*Hackerspaces reuse things, Fab Labs don’t place so much priority on reuse*’ and another that ‘*Fab Labs are waste machines...*’. Similarly, one interviewee describes how ‘*repair days...create a culture...and foster appreciation of design and craftsmanship*’, that itself has ripple effects. However, the hurdles of commercial

viability, lack of time, and expert know-how and relevant tools and methods were raised repeatedly.

5.1.2 Build local connections

The participants reflected on the great diversity between different makerspaces and the importance of being sensitive to distinct cultures, local contexts and values. The participants conveyed a need to integrate and work closely with their local communities stating that the local context needs to be considered in the business plan from the very outset, *'do some local context research to understand ...needs to co-develop a lab and a business plan – you need to be sensitive to the project fulfilling local needs...'*.

However, many described how this is a challenge for them, due to a lack of time to invest in building relationships and a lack of knowledge of potential local skills and suppliers. During workshop two, the manager described their intention to build a repository of local suppliers, but the activity got sidelined due to more pressing daily concerns. Yet, it is perceived that over time, by being inclusive and working on genuine local issues makerspaces can build up 'industrial ecology' and create networks of local skills, resources and suppliers. It is also seen as a means to overcome 'credibility'. Prejudices that see it as 'elitist' or the 'preserve of geeks' were raised and this can limit engagement with a diverse range of people within the local community.

5.1.3 Stimulate practical know-how

Reusing materials such as cardboard on a laser-cutter is not necessarily practical because the card burns. Similarly, specially produced technical materials are still used in the vast majority of additive/subtractive machines rather than recycled ones.

Therefore, makerspace users are shown to need support to adopt good practices and develop appropriate skills (e.g. workshop one where LCA expertise is brought in

through an external expert). These familiar (technical) issues mean that the need for *‘understanding of what it takes to have a sustainable artifact’* prevails. There is emphasis on the need to visualize problems, *‘it’s important to take things apart’*, see practical solutions and break issues down to make them manageable, *‘the sub-dimensions of circular practices’*. The interviewees described how this can be achieved by making issues *‘visible’* to users through workshops, sharing examples and good practices or for instance through practical tools that aid visualizing supply chains. Nevertheless, the research identified that tools and methods are needed to facilitate sharing this know-how amongst the global makerspace communities.

5.1.4 Nurture individual/community capacity

One interviewee described the need for individuals to *‘experience circular practices’* through activities such as tear-downs. This builds engagement with circular issues and eventually, through ongoing experimentation and experience, lab users build confidence to challenge the current norms of design practice. This focus on *‘...building aptitude rather than expertise’* provides *‘access to confidence’* and a *‘cultural collaborative landscape’*, reminiscent of a *‘community of practice’* approach to learning design. For instance, one interviewee described a time when one makerspace challenged another to identify a local waste stream, once it did, the challenger shared its information about this waste stream and how to create value from it.

5.2 Positioning makerspaces in a future CE

In this research the potential for circular makerspaces was explored through the lens of distributed production. The research found that makerspaces are perceived as having a variety of potential roles in a future CE: as educational nodes, spaces for creativity and solution development by *‘hothousing’* circular design into the mainstream, for

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2
3 prototyping, and (to a lesser degree) as places for manufacturing. This is because,
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5 *'makerspaces are not seen to be geared toward manufacturing'* at present. In contrast,
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7 makerspaces are described as *'knowledge centres'* well suited to *'experimentation with*
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9 *different approaches to see what works'* for developing circular ideas. This is important
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11 from a circularity viewpoint because it reflects whether or not these spaces can
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13 legitimately offer an alternative production system founded on circularity principles.
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18 In this research we see how managers/founders play an instrumental role in supporting
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20 circular practices. However, the research unearths many contradictions in the current
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22 narrative about circularity in makerspaces. For instance, the technology/business focus
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24 of the CE, juxtaposed with the social drivers of makerspaces (often a by-product of their
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26 funding) seem at odds. This raises questions about the willingness of businesses to
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28 collaborate with makerspaces and moreover the likelihood of makerspaces developing
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30 manufacturing competences. In addition, we already see makerspaces that depart from
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32 purely social motivations. In the absence of funding streams to establish makerspaces
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34 founded on circularity principles, this is a concern. This means that for these two
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36 agendas to meaningfully coalesce structured facilitation is required, that could
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38 nevertheless lead to an ultimately richer and more sustainable (social, economic,
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40 environmental) manifestation of the CE. Many makerspaces are not financially self-
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42 sustainable and for this reason makerspace managers and founders themselves see a role
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44 for government intervention for issues related to sustainability and emphasise the
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46 important external factors that restrict their capacity to 'act' including consumer
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48 behaviour, market forces, policy and government legislation. This is illustrative of how
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50 circular makerspaces face many similar challenges (cultural, behavioral, organizational,
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technical, infrastructural) to sustainable innovation implemented in ‘mainstream’ design and manufacturing realms.

6. Conclusion

This article aimed to explore the concept of circular makerspaces, focusing on the role of managers/founders, who were identified as gatekeepers to circular practices. Through dialogue with representatives of the makerspace movement, themselves advocates for sustainability within it, we have uncovered initial principles supported by practical ‘how to’ guidance that are perceived to support these key actors to: foster an enabling culture; build local connections; stimulate practical know-how; nurture individual/community capacity. It was found that to develop a makerspace with circularity at its core, its managers/founders need to promote a *vision* for circular makerspaces from the outset, leveraging practical tools such to embed circular practices in the day-to-day.

It was found that makerspaces can play a critical role in a future CE. However, none of the makerspaces visited were wholly conceptually orientated around a circular vision, even though they may espouse sustainability values. The pressing day-to-day concerns of remaining in operation mean that more profound activities that ask questions about our economy through makerspace platforms, are often compromised. Yet, we see that they remain abundantly promising places for exploration and inspiration for systems change for a more sustainable future. However, the lack of circular practices conveyed through this and other studies needs to be addressed. The opportunity to develop circular literacy within makerspaces is immense, yet so far untapped and the insights from this research can act as a starting point for future work.

7. Limitations and further work

This study used a combination of a purposive and opportunistic sampling approach and therefore the results have some limitations. Makerspaces are subject to rapid change and are not heterogeneous, therefore the results may not be representative, but rather offer insights to a particular set of makerspaces at a given point in time. More research needs to be undertaken in this area and the following are recognised here:

- Elaborate on the processes, people and projects synonymous with makerspaces – to explore the decisions being made and the necessary guidance needed
- Elaborate on the outputs being produced, the processes within the makerspace and within its local and global ecosystem
- Elaborate on the tools and methods that can support founders/managers (induction manuals, signage packs, online resource, processes for mapping local resources)
- Elaborate on the training needs of people running makerspaces (guidance, know-how, leadership skills) to overcome challenges they face
- Clarification on what is meant by distributed production and how it can emerge from different types of makerspaces needs to be better understood
- Mechanisms and incentives to drive local distributed production need further exploration in terms of legislation, education and technology

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References

Bakker, Conny, Marcel den Hollander, E van Hinte, and Y Zijlstra. 2014. *Products That Last: Product Design for Circular Business Models*. TU Delft Library / Marcel den Hollander IDRC.

Bakker, Conny, Feng Wang, Jaco Huisman, and Marcel den Hollander. 2014. "Products That Go Round: Exploring Product Life Extension through Design." *Journal of Cleaner Production* 69 (April): 10–16. doi:10.1016/j.jclepro.2014.01.028.

Birtchnell, Thomas, John Urry, Thomas Birtchnell, and John Urry. 2017. "Fabricating Futures and the Movement of Objects Fabricating Futures and the Movement of Objects" 101 (January). doi:10.1080/17450101.2012.745697.

Bocken, Nancy M P, Conny Bakker, and Ingrid De Pauw. 2016. "Product Design and Business Model Strategies for a Circular Economy." *Journal of Industrial and Production Engineering* 33 (5): 308–20.

Braungart, Michael, William McDonough, and Andrew Bollinger. 2007. "Cradle-to-Cradle Design: Creating Healthy Emissions - a Strategy for Eco-Effective Product and System Design." *Journal of Cleaner Production* 15 (13–14): 1337–48. doi:10.1016/j.jclepro.2006.08.003.

Bryman, Alan, and Emma Bell. 2015. *Business Research Methods*. Oxford University Press, USA.

Charter, Martin, and Scott Keiller. 2014. "Grassroots Innovation and the Circular Economy: A Global Survey of Repair Cafés and Hackerspaces." Centre for Sustainable Design.

Charter, Martin, and Scott Keiller. 2016. "The Second Global Survey of Repair Cafés : A Summary of Findings."

Cohen, Boyd, and Pablo Muñoz. 2016. "Sharing Cities and Sustainable Consumption and Production: Towards an Integrated Framework." *Journal of Cleaner Production* 134, Part (October): 87–97. doi:http://dx.doi.org/10.1016/j.jclepro.2015.07.133.

Despeisse, M, M Baumers, P Brown, F Charnley, S J Ford, A Garmulewicz, S Knowles, T H W Minshall, L Mortara, and F P Reed-Tsochas. 2017. "Unlocking Value for a Circular Economy through 3D Printing: A Research Agenda." *Technological Forecasting and Social Change* 115. Elsevier: 75–84.

Dewberry, Emma, and M Monteiro de Barros. 2009. "Exploring the Need for More Radical Sustainable Innovation: What Does It Look like and Why?" *International Journal of Sustainable Engineering* 2 (1). Taylor & Francis: 28–39. doi:10.1080/19397030802643518.

Dewberry, Emma, Lourdes Saca, Mariale Moreno, Leila Sheldrick, and Matt Sinclair. 2016. "A Landscape of Repair." In *Sustainable Innovation 2016nable Innovation 2016*, 76–85.

Dickel, Sascha, Jan-Peter Ferdinand, and Ulrich Petschow. 2016. "The Multiple Applications of 3D Printing: Between Maker Movements and the Future of Manufacturing." In *The Decentralized and Networked Future of Value Creation*, 9–26. Springer.

Edbring, Emma, Matthias Lehner, and Oksana Mont. 2016. "Exploring Consumer Attitudes to Alternative Models of Consumption: Motivations and Barriers." *Journal of Cleaner Production* 123. Elsevier Ltd: 5–15. doi:10.1016/j.jclepro.2015.10.107.

Ellen MacArthur Foundation. 2013a. "Towards a Circular Economy: Business Rationale for an Accelerated Transition." <http://www.ellenmacarthurfoundation.org/publications>.

Ellen MacArthur Foundation. 2013b. "Towards the Circular Economy: Opportunities for the Consumer Goods Sector."

Ellen MacArthur Foundation. 2015. "Growth within: A Circular Economy Vision for a Competitive Europe."

EPSRC. 2013. "Redistributed Manufacturing Workshop Report."

Ferreira, Edy. 2008. "Open Hardware Business Models." *Open Source Business Resource*, no. April 2008.

Fleischmann, Katja, Sabine Hielscher, and Timothy Merritt. 2016. "Making Things in Fab Labs: A Case Study on Sustainability and Co-Creation." *Digital Creativity* 27 (2). Routledge: 113–31. doi:10.1080/14626268.2015.1135809.

- From Now On. 2016. "The Cultural Role of Makerspaces."
https://issuu.com/deehalligan/docs/fno_report.
- Gershenfeld, Neil. 2005. *Fab: Personal Fabrication, Fab Labs and the Factory in Your Computer*. New York: Basic Books, Inc.
- Ghisellini, Patrizia, Catia Cialani, and Sergio Ulgiati. 2015. "A Review on Circular Economy : The Expected Transition to a Balanced Interplay of Environmental and Economic Systems." *Journal of Cleaner Production*. Elsevier Ltd. doi:10.1016/j.jclepro.2015.09.007.
- Gregson, Nicky, Mike Crang, Sara Fuller, and Helen Holmes. 2015. "Interrogating the Circular Economy: The Moral Economy of Resource Recovery in the EU." *Economy and Society* 44 (2). Taylor & Francis: 218–43. doi:10.1080/03085147.2015.1013353.
- Haas, Willi, Fridolin Krausmann, Dominik Wiedenhofer, and Markus Heinz. 2015. "How Circular Is the Global Economy ? An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005" 19 (5): 765–77. doi:10.1111/jiec.12244.
- Hielscher, Sabine, Adrian Smith, and Mariano Fressoli. 2015. "WP4 Case Study Report: FabLabs, Report for the TRANSIT FP7 Project."
- Hielscher, Sabine, and Adrian G Smith. 2014. "Community-Based Digital Fabrication Workshops: A Review of the Research Literature."
- Hobson, Kersty. 2016. "Closing the Loop or Squaring the Circle ? Locating Generative Spaces for the Circular Economy" 40 (1): 88–104. doi:10.1177/0309132514566342.
- Hobson, Kersty, and Nicholas Lynch. 2016. "Diversifying and de-Growing the Circular Economy: Radical Social Transformation in a Resource-Scarce World." *Futures* 82. Elsevier Ltd: 15–25. doi:10.1016/j.futures.2016.05.012.
- Holman, Will. 2015. "The Open Source Object." *Medium*.
<https://medium.com/@objectguerilla/the-open-source-object-8ceac1c8ef55#.n7diyshis>.
- Hunt, Rhiannon, and Martin Charter. 2016. "3D Printing Applications for Creating Products Made from Reclaimed Fishing Nets." In *Sustainable Innovation*, 150–64.
- Hyysalo, Sampsa, Cindy Kohtala, Pia Helminen, Samuli Mäkinen, Virve Miettinen, and Lotta Muurinen. 2014. "Collaborative Futuring with and by Makers." *CoDesign* 10 (3–4): 209–28. doi:10.1080/15710882.2014.983937.
- Kohtala, Cindy. 2015. "Addressing Sustainability in Research on Distributed Production: An Integrated Literature Review." *Journal of Cleaner Production* 106. Elsevier Ltd: 654–68. doi:10.1016/j.jclepro.2014.09.039.
- Kohtala. 2016. "Making ' Making ' Critical : How Sustainability Is Constituted in Fab Lab Ideology Making." *The Design Journal* 6925 (January 2017). Routledge: 1–20. doi:10.1080/14606925.2016.1261504.
- Kohtala, Cindy, and Sampsa Hyysalo. 2015. "Anticipated Environmental Sustainability of Personal Fabrication." *Journal of Cleaner Production* 99. Elsevier Ltd: 333–44. doi:10.1016/j.jclepro.2015.02.093.
- Koshy, Elizabeth, Valsa Koshy, and Heather Waterman. 2010. *Action Research in Healthcare*. Sage.
- Kostakis, Vasilis, Vasilis Niaros, George Dafermos, and Michel Bauwens. 2015. "Design Global, Manufacture Local: Exploring the Contours of an Emerging Productive Model." *Futures* 73. Elsevier Ltd: 126–35. doi:10.1016/j.futures.2015.09.001.
- Lieder, Michael, and Amir Rashid. 2016. "Towards Circular Economy Implementation: A Comprehensive Review in Context of Manufacturing Industry." *Journal of Cleaner Production* 115. Elsevier Ltd: 36–51. doi:10.1016/j.jclepro.2015.12.042.
- Lupton, Deborah. 2016. "3D Printing Technologies: Social Perspectives." *Social Perspectives*, 1–6. <https://ssrn.com/abstract=2865290>.
- Moreno, Mariale, and Fiona Charnley. 2016. "Can Re-Distributed Manufacturing and Digital Intelligence Enable a Regenerative Economy? An Integrative Literature Review." In *Sustainable Design and Manufacturing 2016*, edited by Rossi Setchi, Robert J Howlett, Ying Liu, and Peter Theobald, 563–75. Cham: Springer International Publishing. doi:10.1007/978-3-319-32098-4_48.
- Moreno, Mariale, Carolina De los Rios, Zoe Rowe, and Fiona Charnley. 2016. "A Conceptual

- Framework for Circular Design." *Sustainability (Switzerland)* 8 (9). doi:10.3390/su8090937.
- Murray, Alan, Keith Skene, and Kathryn Haynes. 2015. "The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context." *Journal of Business Ethics*. Springer Netherlands. doi:10.1007/s10551-015-2693-2.
- Nascimento, Susana, and Alexandre Pólvor. 2016. "Maker Cultures and the Prospects for Technological Action." *Science and Engineering Ethics*, 1–20. doi:10.1007/s11948-016-9796-8.
- NESTA. 2015. "Open Dataset of UK Makerspaces: A User's Guide." <http://www.nesta.org.uk/publications/open-dataset-uk-makerspaces-users-guide>.
- Prendeville, Sharon, Emma Cherim, and Nancy Bocken. 2017. "Circular Cities: Mapping Six European Cities in Transition." *Environmental Innovation and Societal Transitions*. doi:10.1016/j.eist.2017.03.002.
- Prendeville, Sharon M, Frank O Connor, Nancy M P Bocken, and Conny Bakker. 2017. "Uncovering Ecodesign Dilemmas : A Path to Business Model Innovation." *Journal of Cleaner Production* 143. Elsevier Ltd: 1327–39. doi:10.1016/j.jclepro.2016.11.095.
- Riisgaard, Henrik, Mette Mosgaard, and Kristina Overgaard Zacho. 2016. "Local Circles in a Circular Economy-the Case of Smartphone Repair in Denmark." *European Journal of Sustainable Development* 5 (1). European Center of Sustainable Development: 109.
- Ritzer, George, and Nathan Jurgenson. 2015. "Production , Consumption , Prosumption." *Journal of Consumer Culture* 10 (1): 13–36. doi:10.1177/1469540509354673.
- Robson, Colin, and Kieran McCartan. 2015. *Real World Research*. Fourth. Wiley.
- Royal Society for the Encouragement of the Arts, Manufactures and Commerce. 2015. "Ours to Master: How Makerspaces Can Help Us Master Technology for a More Human End."
- Salvia, Giuseppe. 2015. "Design in the New Do-It-Yourself Age : Trialing Workshops for Repairing." In *Cumulus: Virtuous Cycle*.
- Salvia, Giuseppe, and Sharon Prendeville. 2017. "Design for a Circular Future through Distributed Repair." In *Design Management Academy: Research Perspectives for Creative Intersections*.
- Seyfang, Gill, and Adrian Smith. 2007. "Grassroots Innovations for Sustainable Development: Towards a New Research and Policy Agenda." *Environmental Politics* 16 (4). Taylor & Francis: 584–603.
- Smith, Adrian, Mariano Fressoli, Abrol Dinesh, Arond Elisa, and Adrian Ely. 2016. *Grassroots Innovation Movements*. Earthscan from Routledge.
- Smith, Adrian, and Ann Light. 2015. "How to Cultivate Sustainable Developments in Makerspaces."
- Srai, Jagjit Singh, Mukesh Kumar, Gary Graham, Wendy Phillips, James Tooze, Simon Ford, Paul Beecher, Baldev Raj, Mike Gregory, and Manoj Kumar Tiwari. 2016. "Distributed Manufacturing: Scope, Challenges and Opportunities." *International Journal of Production Research* 54 (23). Taylor & Francis: 6917–35.
- Stahel, Wr. 1984. "The Product-Life Factor." *An Inquiry Into the Nature of Sustainable Societies: The Role of the Private Sector* 3: 72–96. <http://www.product-life.org/en/major-publications/the-product-life-factor%5Cnhttp://infohouse.p2ric.org/ref/33/32217.pdf>.
- Su, Biwei, Almas Heshmati, Yong Geng, and Xiaoman Yu. 2013. "A Review of the Circular Economy in China: Moving from Rhetoric to Implementation." *Journal of Cleaner Production* 42 (March): 215–27. doi:http://dx.doi.org/10.1016/j.jclepro.2012.11.020.
- Sung, K, T Cooper, and S Kettley. 2015. "An Exploratory Study on the Links between Individual Upcycling , Product Attachment and Product Longevity." *Product Lifetimes And The Environment*, no. June.
- Terzioğlu, Nazlı Gökçe, Clare Brass, and Dan Lockton. 2016. "3D Printing for Repair : A Paradigm Shift in Fixing Our Relationships with Things." In *Sustainable Innovation 2016*.
- Thackara, John. 2011. "Into the Open." In *Open Design Now: Why Design Cannot Remain Exclusive*. Amsterdam BIS Publishers.
- Toombs, Austin, Shaowen Bardzell, and Jeffrey Bardzell. 2014. "Becoming Makers: Hackerspace Member Habits, Values, and Identities." *Journal of Peer Production* 5: 1–8.

- 1
2
3 Troxler, Peter. 2011. "Libraries of the Peer Production Era." In *Open Design Now: Why Design*
4 *Cannot Remain Exclusive*, 86–97. BIS Publishers Amsterdam, The Netherlands.
- 5 Verheul, Hugo, and Philip J Vergragt. 1995. "Social Experiments in the Development of
6 Environmental Technology: A Bottom-up Perspective." *Technology Analysis & Strategic*
7 *Management* 7 (3). Taylor & Francis: 315–26.
- 8 Visser, Froukje Sleeswijk, Pieter Jan Stappers, Remko Van der Lugt, and Elizabeth B N
9 Sanders. 2005. "Contextmapping: Experiences from Practice." *CoDesign: International*
10 *Journal of CoCreation in Design and the Arts* 1 (2). Taylor & Francis: 119–49.
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Appendix A – Site Visits Undertaken

Space	Date	Purpose	Format	Actors	Selection Criteria
Fab Lab London, UK	14-16.06.15	Scoping and Testing (see section 2.3.1)	OSCEdays 2015 2-day Workshop	Organisers: OSCEdays team Challenge Setters: (1 of 5) Participants (3 of 26) Researchers (1/3)	Commercial/Educational
Lewes Phoenix Industrial Estate, UK	24.07.15	Initial mapping and observations	Invited guided tour Site visit	Organiser: Research team Guide (1) Makers, Inventors (6) Researchers (2)	Grassroots
Kortrijk Buda LAB, BE	21.08.2015	Testing and further observations	Site visit & workshop (see section 2.3.2)	Organisers: Research team Researchers (2)	Commercial /Educational
Fab Lab Amersfoort, NL	22.08.2015	Participation in workshops and observation	Site-visit, Fab Fuse event	Organisers: Fab Lab Amersfoort Participants: [20-25] Researchers (2)	Grassroots/Educational Sustainability-focused
Machines Rooms, UK	10.03.2015	Participation and observation	Launch Level 1 FMs Workshop	Organisers: Research team Researcher (1)	Commercial /Educational
Machines Rooms, UK	26-27.10.2015	Participation in workshops and observation	Sustainable Makerspaces - Workshop Event	Organisers: SPRU, STEP Speakers: 12 Participants: 25/30 Researcher (2 / 1)	Commercial /Educational
Makerversity, UK	24-25.07.15	Participation and observation	Good For Nothing Hack with Restart, Civic shop & New Citizenship Project	Organiser: Good For Nothing Participants: Approx 30 Researcher (1)	Commercially-focused hardware start-up incubation focus
Central Research Laboratory, UK	4.08.2015 onwards	Ongoing - involvement in the setting-up and running of space		Researcher (1)	Commercially-focused hardware start-up incubation focus

Appendix B – Expert Interview Guide

I: Please introduce yourself

E: Name, your role, current activities (related to distributed manufacturing and/ or circular economy)

I: If unclear from introduction, seek clarification the interviewee is familiar with terms: circular design and circular economy. Explain for the remainder of the interview the term ‘circularity’ will be used.

Questions

1. Are you familiar with the concept of distributed production / or redistributed manufacturing? [] yes ... [] no ...
If so, what do you understand DM to mean? If not, *we explain outline (see appendix)*, you imagine DM. Can you cite (A) / think of (B) / imagine (C) any examples?
2. What do you think the importance of DM is in terms of circularity?
3. From your perspective, do you think makerspaces have a role in a DM future?
4. What do you think DM mean in terms of circularity? What does this mean for the future of manufacturing?
5. What do you think this idea of circularity* means in the context of makerspaces?
6. What examples of circularity have you seen (in makerspaces), if any? *Can you direct us to any potential case studies?*
7. What do makerspaces / the people of the makerspace need to develop / improve circular their practice (rationale for development of activities/tools)?
8. What is the role of technology in makerspaces?
9. What do these technologies mean in terms of circularity?
10. What is the role of tools and technology in makerspaces?
11. What do these tools and technologies mean in terms of circularity / contribute to circularity?
12. What is the role of people in makerspaces?
13. What do these people mean in terms of circularity? What are the key: barriers; enablers; opportunities
14. What other characteristics would you say encourage a circular economy in makerspace, for example customers / ethos / expertise / resources?
15. If at all, how does the culture of makerspaces relate to sustainability /practice & regulations?

Appendix C – Pre-workshop Information for Participants at Workshop 2

Workshop 2

Purpose: To conduct a series of design research activities to build on (and test) existing insights gleaned from the earlier stages of the research on how circular practices can be integrated in day-to-day makerspace activities.

Participants: Makerspaces Founders, Manager & Users

Stage 1: focus: approach

Estimated Time: Ongoing during visit

Stage 1 Methods:

- Observations
- Conversations: managers & founders focusing on description of: vision, strategy, cultural context, manifesto

Stage 2. focus: criteria

Estimated Time: 30-45 minutes

Stage 2 Methods: “Show & Tell” – we will observe, collect and record examples of ‘circular themes’ in the space in collaboration with you the makerspace managers/founders.

- Conversations: managers & founders
- People-led analogue tagging activity using a set of criteria we provide (e.g. material; toxicity; impacts; waste; locality; technology)

Appendix D – Fab Lab London Materials List (Excerpt)

Fab Lab London - materials price list - February 2015

Material		Length (mm)	Width (mm)	Thickness (mm)	Price incl. VAT
Acrylic-cast	Clear	250 mm	500 mm	2 mm	£6.80
				3 mm	£5.70
				5 mm	£8.20
				6 mm	£10.20
				8 mm	£13.10
	Colour	250 mm	500 mm	3 mm	£6.80

Appendix E – Cluster Analysis

Guiding Theme	'How-to' Practices	Excerpts from interviews	Workshop Data
Foster an Enabling Culture	Co-develop a shared circular vision and manifesto from the outset, through coordinated communication with all stakeholders	'Stakeholder Circle' '...structured initiation from the outset reduces risk...' 'joining conditions are a social contract' 'repair days...create a culture...and fosters appreciation of design and craftsmanship'	1: Partnership approach integrating sustainability experts/skills from outset 2: Intentions to link and build connections for strategic local alliances
	Publicly articulate a clear and principled vision for responsible products	'Responsible products is [sic] part of the manifesto' 'Our role...is to set out a principled vision to create a culture'	1: Explicit commitment to sustainability/circular implemented through its day-to-day e.g. tools/technology e.g. filament recycler, part of its commitment to develop 'sustainable thinking'
	Develop and seek joining commitment through clear conditions	'joining conditions are a social contract'	1: Fab Charter 2: Fab Charter
	Provide leadership by knowing and enacting the vision	'Lead the vision, be steadfast' 'Up to people running the space not to be driven'	1: Embed practices in the day-to-day e.g. circular design workshops 2: 'Be open because you believe it...because you want to be not because the Fab Lab tells you'
Build Local Connections	Facilitate links between many stakeholders (local government, citizens, producers, local community)	'industrial ecology is slowly built up through registering skills and local materials...' 'do a social network analysis'	1: Key strategic stakeholders identified from the outset 2: Efforts to build local supplier database, strategic local partnerships, promoting local suppliers
	Map local suppliers in collaboration with users builds knowledge of local resources and skills	'User mapping' 'industrial ecology is slowly built up through registering skills and local materials...'	1: Local suppliers of materials for reuse identified and promoted 2: Efforts to build local supplier database, strategic local partnerships, promoting local suppliers
	Understand local needs, skills, knowledge, barriers, risks	'Don't just buy a machine, which is what most people do, we do some local context research to understand some needs to co-develop a lab and a business plan - you need to be sensitive to the project fulfilling local needs. '	1: Local suppliers of waste/materials for reuse identified and promoted internally 2: Efforts to build local supplier database, strategic local partnerships, promoting local suppliers
	Foster ownership in local communities through e.g. time-banking, trade-schools, skill sharing, repair days	'enlist skills' 'Business plan should include local supply from the outset'	1: Product tear-downs / repair outreach activities / circular design challenges 2: Electronics 'library' developed and maintained by users
	Develop outward looking, inclusive and welcoming communications	'seen as elitist...the preserve of geeks...closed to the masses' 'clear communications with	No data.

		different groups that should be involved'	
		'Build credibility'	
	Enlist skills for community development from the outset	Hire team members with 'community building skills...' 'enlist skills'	2: Initial efforts to build local supplier network side-lined due to lack of local strategic relationships
<i>Stimulate Practical Know-how</i>	Facilitate, enable and encourage circular workshops (e.g. basic fixing skills such as plug rewiring, efficient tool us')	'Sustainability workshops' 'repair days...create a culture...and fosters appreciation of design and craftsmanship'	1: Product tear-downs / repair outreach activities / circular design challenges 2: Educational activities on energy use
	Develop/adopt circular design guidelines and good practice induction manuals	'it's important to take things apart'...	1: Circular design guidance and visual cues are commonplace 2: Online masterclass tutorials for initial inductions/upskilling
	Signpost to external guidance on good practices in circular/sustainable design	No data.	1: Circular design guidance and visual cues are commonplace, expertise brought in when needed e.g. circular design workshops, LCA
	Break things down e.g. visualize smaller pieces of the puzzle, such as the product supply chain	'Knowledge of where materials come from, how products work, why' 'it's important to take things apart'...	1: Visualising supply-chains through easy to use online tools, product tear-downs, LCAs of specific products 2: Educational activities on energy use
<i>Build Individual/Community Capacity</i>	Foster ownership of circular issues within the community	'Not enough to talk about things, have to engage'	1: Product tear downs, reusable materials sourced locally, 2: Electronics sharing 'library'
	Build visibility, awareness and inclusivity by sharing experiences and good practice examples	'Share stories...create a cultural collaborative landscape' 'You should be open because you believe in it' 'share by necessity' 'One of the foundations of circular thinking is sharing knowledge'	1: Online documentation of circular design challenge during OSCEdays allows global community to learn
	Enlist specialist circular expertise where necessary	'Build aptitude rather than expertise'	1: LCA expertise supports environmental assessment, Great Recovery supplements knowledge
	Build individual confidence to approach circular issues through learning process	Provide 'access to confidence' 'Build aptitude rather than expertise'	1: Experience-based workshops e.g. tear-downs 2: Experience-based workshops e.g. educational visualising energy

Table 1. Circular Practices for Product Life Extension observed in Makerspaces

<i>CE Strategy</i>	<i>Makerspace Activities</i>	<i>Examples of CE Activities</i>
<i>Reuse</i>	Establishing relationships within the local environment for product, materials, tools reuse, generated through its value chain as well as through one-off donations (Smith and Light 2015)	Library of Things: http://www.libraryofthings.co.uk/
<i>Repair</i>	Hosting community-led repair meetings, building repair skills and providing access to tools (E. Dewberry et al. 2016; Charter and Keiller 2014; Charter and Keiller 2016; Salvia 2015; Terzioğlu, Brass, and Lockton 2016; Smith and Light 2015)	Restart Parties: https://therestartproject.org/ Repair Cafes: https://repaircafe.org/ Product Teardowns
<i>Remanufacturing</i>	Additive technologies can facilitate repair and remanufacturing of parts/goods through on-demand production (Despeisse et al. 2017)	Advanced manufacturing to produce spare parts in low-volume
<i>Upcycling</i>	Collecting and serving the local community as a hub of products and materials that can be upcycled to form new ones (Sung, Cooper, and Kettley 2015)	Making improvements to furniture, lampshades, old bicycle tyres
<i>Recycling</i>	Exploring local techniques of recycling materials used in makerspaces e.g. PLA shredders and re-grinders (Hunt and Charter 2016)	Precious plastic – open source shredder shreds plastic for re-processing: https://preciousplastic.com/en/
<i>Sharing</i>	Product life extension through intensification of use (Cohen and Muñoz 2016)	Library of Things: http://www.libraryofthings.co.uk/

Table 2. Comparison between the Maker Movement and the CE

<i>Characteristics</i>	<i>Makerspace Movement</i>	<i>Circular Economy</i>
<i>Belief/Ideology</i>	<ul style="list-style-type: none"> Grassroots innovation movement (Smith et al. 2016) <i>Self/local production</i> alternative to mass production and consumption (Kohtala 2016) 	<ul style="list-style-type: none"> Business/economy-led and policy-driven approach to growth and economic renewal (EMF 2013a, 2013b, 2015) Vision for a reformed economy that questions the basis of capitalism (Gregson et al. 2015)
<i>Vision</i>	<ul style="list-style-type: none"> Visions of a new industrial revolution through democratization of <i>tools/technologies</i>, enabling localised grassroots innovation (Smith et al. 2016; Kohtala 2016) enabled through the information era 	<ul style="list-style-type: none"> Vision of a new economy to preserve <i>resources/waste</i> through closed loop methods to generate profitable business activities (EMF 2013a, 2013b, 2015)
<i>Attributes</i>	<ul style="list-style-type: none"> Individuals can use accessible and cheap production <i>tools/technologies</i> for making Information and knowledge is shared with <i>offline/online communities</i> through digital platforms to rapidly diffuse innovation and foster collaboration (Dickel, Ferdinand, and Petschow 2016) <i>Value creation</i> through new business models and distributed production systems (Dickel, Ferdinand, and Petschow 2016; Ferreira 2008) <i>Product life extension</i> through emotional attachment, co-design, prosumption (Kohtala 2015) reparability and adjustability (Holman 2015) <i>Local production</i> (Kohtala 2015) <i>Community</i> development (Smith & Light, 2015) <i>Toxicity, waste</i> (Kohtala, 2015) <i>Collaboration/Partnerships</i> for internalising expertise (Fleischmann, Hielscher, and Merritt 2016) 	<ul style="list-style-type: none"> Mapping and management of resource flows <i>Value creation</i> through product lifecycle design (Bakker et al. 2014), circular business models (Bakker et al. 2014; Bocken, Bakker, and De Pauw 2016; Moreno et al. 2016; Prendeville et al. 2017) <i>Product lifecycle extension</i> strategies such as reuse, repair, remanufacturing, refurbishment, upcycling, anaerobic digestion and recycling (EMF 2013a, 2013b, 2015), upgradability and emotional attachment (Bakker et al. 2014) Short production loops (e.g. localised through repair / reuse) (EMF 2013a; 2013b; 2015) <i>Waste</i> becomes resources (EMF 2013a; 2013b, 2015) Reverse logistics and closed loop <i>supply-chains</i> (EMF 2013a, 2013b, 2015) require new forms of <i>collaboration</i> and stakeholder interaction
<i>Key Actors</i>	<ul style="list-style-type: none"> Individuals, Creative Founders Communities (Online and offline) 	<ul style="list-style-type: none"> Businesses Policy-makers

**Italicised text indicates criteria used for data gathering during workshop 2*

Table 3. Overview of Expert Interviews

<i>Interviewee Role</i>	<i>Expertise</i>	<i>Date</i>	<i>Interview Purpose</i>
Academic	Distributed Production, Sustainability in Makerspaces	14.08.2015	<ul style="list-style-type: none">• identify exemplary and/or unique makerspaces to conduct workshops with
Makerspace Founder	Incubating commercial start-ups in makerspaces	5.08.2015	<ul style="list-style-type: none">• explore concept of distributed production• identify examples of distributed production• explore role of and opportunities for makerspaces in distributed production
Makerspace Founder / Academic	Implementation, Incubating start-ups, Distributed Production, Sustainable urbanism	31.07.2015	<ul style="list-style-type: none">• explore role of and opportunities for makerspaces in circular economy
Makerspace Founder / Academic	Distributed Production, Sustainability in Makerspaces, Repair Practices	01.09.2015	<ul style="list-style-type: none">• identify their understanding of and experience with CE• identify criteria for context-mapping workshop to map activities commensurate with the development of circular makerspaces
Makerspace Founder / Academic	Distributed Production, Manufacturing, Technology	22.07.2015	
Makerspace Founder / Academic	Distributed Production, Sustainability in Makerspaces	01.09.2015	

Table 4. Description of Tags used during the Buda::LAB Workshop

<i>Tags</i>	<i>Rationale</i>	<i>Tag Explanation</i>
<i>Tools/Technology</i>	Expert interviews Literature (Kohtala, 2015)	The equipment used within the space and its relevance, relationship and impact to circularity
<i>Value Creation</i>	Literature (Bocken et al. 2016; Bakker et al. 2014; Dickel et al. 2016; Ferreira, 2008)	Creating value that includes financial survival as well as social, environmental and cultural
<i>Product lifecycle extension</i>	Literature (Bakker et al. 2014)	Consideration of raw material extraction, production, use, transport and product life extension (reuse, repair, remanufacture, upcycle, adaptability, upgradability, emotional attachment, co-design / prosumption)
<i>Local Contexts/ Local Production</i>	Expert interviews Literature (Kohtala, 2015)	Partnerships with local entities, such as through industrial symbiosis approaches
<i>Community Connections [local / global]</i>	Expert interviews Literature (Smith & Light, 2015)	Engagement with global communities for local benefit
<i>Toxicity</i>	Literature (Kohtala, 2015)	Environmental hazard of toxic materials, off-gassing of machines, waste toxicity
<i>Waste / Resources</i>	Workshop 1 Literature (Bakker et al. 2014; EMF 3013a, 2013b, Kohtala, 2015)	Sourcing materials from waste, sustainable use of resources and low environmental impact materials
<i>Collaboration/Partnerships</i>	Expert interviews Literature (Fleischmann et al. 2016)	Building partnerships to support activities, such as with experts, to assimilate knowledge
<i>Supply Chains</i>	Literature (EMF 2013a, 2013b)	Decisions about on know-how of sourcing of materials/parts
<i>Actors/Stakeholders</i>	Expert interviews Literature (EMF 3013a, 2013b; Smith & Light, 2015)	Product value chain stakeholders
<i>Good practice guidance</i>	Expert interviews Workshop 1	Guidance (e.g. signage, short descriptive overviews, visual cues, processes)
<i>Skills & knowledge</i>	Expert interviews	Capacity building to bridge knowledge-action gap / access to know-how

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Figure 1. Overview of Research Methodology

Figure 2. Map defining the scope of the research activities adapted from Troxler (2010) and Nesta (2015)

Figure 3. Example of Tags with Circular Themes (Workshop 2)

Figure 4. Documentation of Insights at Fab Lab London (Workshop 1)

Figure 5. Documentation of Insights at BUDA::lab Kortrijk (Workshop 2)

Figure 6. Circular Makerspaces: Guiding Themes and ‘How-to’ Practices

Overview of Research Methodology

180x167mm (300 x 300 DPI)

Map defining the scope of the research activities adapted from Troxler (2010) and Nesta (2015)

152x139mm (300 x 300 DPI)

Example of Tags with Circular Themes (Workshop 2)

86x61mm (300 x 300 DPI)

Figure 4. Documentation of Insights at Fab Lab London (Workshop 1)

209x297mm (300 x 300 DPI)

Documentation of Insights at BUDA::lab Kortrijk (Workshop 2)

184x268mm (300 x 300 DPI)

Circular Makerspaces: Guiding Themes and 'How-to' Practices

253x366mm (300 x 300 DPI)