Makespaces: From Redistributed Manufacturing to a Circular Economy

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Abstract. Redistributed manufacturing is an emerging concept which captures the anticipated reshoring and localisation of production from large scale mass manufacturing plants to smaller-scale localised, customisable production units, largely driven by new digital production technologies. Critically, community-based digital fabrication workshops, or makespaces, are anticipated to be one hothouse for this new era of localised production and as such are key to future sustainable design and manufacturing practices. In parallel, the concept of the circular economy conceptualises the move from a linear economy of take-make-waste to a closed loop system, through repair, remanufacturing, and recycling to ultimately extend the value of products and materials.

Despite the clear interplay between redistributed manufacturing and circular economy, there is limited research exploring this relationship. In light of these interconnected developments, the aim of this paper is to explore the role of makespaces in contributing to a circular economy through redistributed manufacturing activities. This is achieved through six semi-structured interviews with thought leaders on these topics. The research findings identify barriers and opportunities to both circular economy and redistributed manufacturing, uncover overlaps between circular economy and redistributed manufacturing, and identify a range of future research directions that can support the coming together of these areas.

The research contributes to a wider conversation on embedding circular practices within makespaces and their role in redistributed manufacturing.

1 Introduction

In its vision for manufacturing in 2030, the EU (2015) identifies megatrends of mass customisation, flexible, responsive, personalised and integrated (in homes) manufacturing, enabled by metropolitan manufacturing ecosystems which are built through the digitisation and virtualisation of society, as well as the diffusion of new production technologies. Such digitisation is an enabler for Redistributed Manufacturing (RDM),

adfa, p. 1, 2011.

which sees a move away from centralised production facilities, towards local manufacturing and the use of digital technologies, leading to shortened supply chains and thereby reduced transportation impacts on the environment. In doing so, RDM is also expected to reduce waste (through digital production technologies) and energy consumption of production through shortened supply chains (WEF, 2015). Critically, community-based digital fabrication workshops, or makespaces, are anticipated to be one hothouse for this new era of localised production and as such are critical to future sustainable design and manufacturing practices.

In parallel, the concept of the circular economy (CE) conceptualises the move from a linear economy of take-make-waste to a closed loop system (Ellen Macarthur, 2014) through repair, remanufacturing, refurbishment and recycling, to maintain materials and resources in a closed cycle. Its integration in international policies from China, through its 11th and 12th 'Five Year Plans' (Su et al., 2013), to Europe through its Circular Economy Roadmap (European Commission, 2014) reflect the increasing importance of CE globally. Despite the potential interplay between RDM and CE, there is limited research exploring this relationship. In light of these interconnected developments, the aim of this paper is to explore the role of makespaces in contributing to the CE through RDM activities.

2 Literature Review

2.1 The Emergence of Makespaces

Community-based digital fabrication workshops, or makespaces, are organisationally diverse (Hielscher & Smith, 2014), creative and social places where makers can network, learn and access a variety of (previously inaccessible) fabrication tools and technologies. Despite limited research on the characteristics and activities of makespaces in general, some studies exist (Hielscher & Smith, 2014). Understanding the activities and structures of makespaces is important, given the range of activities underway, disparate governance structures, scope of ambitions, and diversity of local contexts (Hielscher & Smith, 2010). Troxler (2010) devised a framework to interpret the diversity of makespaces, from tech shops, to sharing platforms, Fab Labs, and hackerspaces spanning activities from open hardware design to repair workshops. Indeed, some say that, through the act of making itself, the new 'prosumer' can foster a stronger connection with the object being made (Kohtala & Hyysalo, 2015) and therefore a longer product life can be expected.

Nonetheless, at the heart of many maker communities are values that relate to sustainability. 'A third place', Kohtala (2014) identifies the tendency to collaborate openly, to adopt industrial ecology principles, to focus on local problems, and to draw on needs-based solutions. Makespaces are defined by local values, openness and freeness, Gershenfeld, (2005); collaboration and sharing (Thackara, 2010); respect for resources and cultural assets Kohtala (2014). However, Kohtala (2014) also states that socio-economic imperatives (short-term survival) mean environmental issues are not given much concern.

2.2 Re-distributed Manufacturing (RDM)

While there are common threads, a clear consensus on what RDM actually entails and its benefits have yet to be determined. The EPSRC (2013) identifies: local manufacturing for local communities and economies; cloud manufacturing services; dynamic production environments capable of creating customisable or multi-variant products; sustainable /resource efficiency; and flexibility/agility in production suited to short ramp-up times as key characteristics of RDM. Table 1 presents a list of definitions of RDM reflecting these characteristics and more.

Table 1. Defining Redistributed Manufacturing

Source	Definition
WEF	"...enable...efficient use of resources, with less wasted capacity in centralized factories...to reduce the overall environmental impact of manufacturing: digital info is shipped over the web rather than physical ...and raw materials are sourced locally...reducing the energy...for transportation."
BIS	"...potentially disruptive impact on supply chains. The development of AM [additive manufacturing] faces unique technical challenges, but there are huge potential benefits including the possibility for more localised manufacturing and the reduced need for part inventory."
EPSRC	"Technologies, systems and strategies that change the economics and organisation of manufacturing, particularly with regard to location"
Kuhnle (2010)	"A decentralised approach could make production systems more flexible and adaptable"

One catalyst for the increase in makespaces globally, is the diffusion of digital production technologies such as additive manufacturing; however subtractive processes (5-axis CNC) and other processes like laser cutting are also important. These new technologies are purported to contribute to both increasing and reducing emissions and energy usage. For example, Gebler et al. (2014) claim, with somewhat large deviations, that 3D-printing has the potential to reduce costs (for companies) by 170-593 billion dollars (US), the total primary energy supply by 2.54–9.30 EJ and CO2 emissions by 130.5–525.5 Mt by 2025.

However, the risks of digital fabrication are also recognised. Smith & Hielscher (2015) see diminished scale leading to process inefficiencies and disruptions in waste collection as key issues. Drizo & Pegan (2006) raise the issue of toxicity of rapid-prototyping materials and highlight the broad lack of knowledge on the life cycle impacts of related materials. In addition, the trade-offs between energy consumption, the crossover point at which additive technologies become less energy intensive, given the production volumes, needs to be fully understood. While the promise and vision for RDM within makespaces is compelling, there is limited understanding about what is being made. Some of the more 'needs-based' solutions Kohtala (2014) alludes to are mentioned in the literature, such as a device which can monitor milk quality for farmers or skin conditions in rural areas (Troxler, 2010). In contrast, Gebler et al (2014) summarise key markets for the uptake of 3D-printing to 2025 including: consumer products, aerospace, automotive, medical components and tooling. Importantly, this illustrates a divergence from the activities of makespaces in general, from the sectors and goods forecasted to take up the opportunities. It also indicates the another potential significant trend of large-scale manufactures seizing the market opportunity, to localise their own production either through owned outlets or franchised operations.

2.3 Circularity: Circular Product Design & Circular Business Models

The terms circular product design and circular business models are derived from the overarching concept of the CE and are increasingly brought together through models and frameworks (Costa et al, 2014; Prendeville & Bocken, 2015). In simple terms, a business model is about the way you do business (Margretta, 2002) and therefore a circular business model can be viewed as a business model with a CE vision. Circular product design, promoted by Bakker et al (2014) is achieved through designing for attachment and trust; durability; standardisation and compatibility; ease of maintenance and repair; adaptability and upgradability. This is because, to realise a CE, changes in both product design practices and business models are critical (Teece, 2010, Bakker et al, 2014). For example, Teece (2010), states that product development needs to iteratively inform developments in the business model. Therefore, building linkages between design strategies and business models is important.

2.4 Literature Summary: Research & Practice Gap

The suggested benefits of additive technologies seem out of alignment with the observed characteristics of makespaces. For example, forecasts for market uptake of key technologies are linked to heavily regulated business-to-business sectors, whereas, the benefits observed (from the viewpoint of the makespaces) are around local solutions. Existing knowledge sees makespaces as powerful local connectors, with positive social impacts and the potential to build resilient local activities.

In addition, little research has been undertaken that demonstrates how waste can be reduced using digital production technologies and many questions remain about the environmental impacts of many of the materials and production systems used for digital fabrication. In addition, Troxler (2010) states that most successful open hardware initiatives operate within market conditions and are not ‘radically decentralized’. Another concern that appears to be overlooked in the literature, is how the on-demand nature, of a redistributed future, impacts on consumption levels in society, given the absence of any real basis to show that prosumption in and of itself, can overcome this. For example having on-demand local production may even lead to more irresponsible production and ever greater consumption.

3 Methodology

The aim of the research is to explore the interplay between makespaces, RDM and CE. In light of this the research question driving the research asks, 'what is the role of makespaces in a sustainable RDM future? The research methods are qualitative and based on six interviews designed to explore this topic. The interviews were semi-structured, conducted online, recorded and transcribed. The interviewees were provided with a participant information sheet in advance of the interview to describe the purpose and format. The interviewees were selected from an initial list of 36 identified potential interviewees, based on their expertise on the topic, experience of setting up and running makespaces and to cover a wide range of geographical contexts. Table 2 presents an overview of the interviews and Table 3 describes the semi-structured interview questions. Finally, the interviews were analysed thematically, within and across cases.

Table 2. Overview of Expert Interviews

	Interviewee Role	**Date**	**Interviewee's Location**
1	Academic	14.08.2015	Finland
2	Makespace Founder	5.08.2015	UK
3	Makespace Founder / Academic	22.06.2015	China
4	Makespace Founder / Academic	01.09.2015	UK
5	Makespace Founder / Academic	01.09.2015	Italy
6	Makespace Founder / Researcher	31.07.2015	Spain / Venezuela

Table 3. Semi-structured Interview Guide

	Questions
1	Are you aware of the concept of redistributed manufacturing (RDM)? What do you understand RDM to mean? Can you cite any examples?
2	What do you think the importance of RDM is in terms of circularity?

3	From your perspective, do you think Makespaces have a role in a RDM future?
4	What do you think RDM mean in terms of circularity? [a] What does this mean for the future of manufacturing?
5	What do you think this idea of circularity means in the context of Makespaces?
6	What examples of circularity have you seen (in Makespaces), if any?
7	What do makespaces / the people of the MS need to develop / improve circular practice (rationale for development of activities/tools)?
8	What is the role of technology in makespaces? What do these technologies mean in terms of circularity? What are the (1) barriers (2) enablers (3) opportunities?
9	What is the role of people in makespaces? What do these people mean in terms of circularity? What are the (1) barriers (2) enablers (3) opportunities?
10	What other characteristics would you say encourage a circular makespace?

4 Results & Analysis

This section presents the results of the interviews with an integrated thematic analysis.

4.1 Redistributed Manufacturing: Terminology and Examples

The concept of RDM was not familiar to all of the interviewees and during the interviews the term 'distributed manufacturing' was raised as a more familiar phrase. Nonetheless, the research identified that RDM is characterised by the following aspects:

- Open source, open design, sharing practice, knowledge and skills (as well as products)
- Reshoring manufacturing to Europe
- Open, digital networks
- Collaborative and open innovation
- Enabled by diffusion of new technologies
- Personalisation and customisation
- Prosumption: bringing the custodian closer to manufacturing processes
- People-focused: not solely technology-centred / driven, but also about local networks and social interactions

However, one interviewee stated that RDM is really a ‘partial phenomenon’, widely discussed over the last ten years but with very few examples in practice. Those examples that were cited, illustrate more meso-level (urban activities such as agriculture and distributed energy projects) rather than directly relevant to the production of manufactured products.

The respondents communicated that makespaces activities are predominantly the prototyping and testing of ideas and therefore are promising spaces for incubation and experimentation of new potential circular solutions and ideas. While local production is a goal, it’s not happening at any significant scale. Current outputs identified include components or prototypes that go on to be manufactured in a ‘traditional’ manufacturing environment. ‘The maker movement talks so much about local production, but in reality that doesn’t happen’. Despite this, interviewees who play a more active role within makespaces responded favourably to the future prospects for batch production perceiving an increase in demand on the horizon. Examples cited as being close to, or moving towards RDM, and CE, but not wholly RDM in the sense that some characteristics of the approach is centralised, include:

- Fairphone, through its community-focus, ethical suppliers and material use
- Urban agriculture which is well developed at a city level e.g. Farm Shop Dalston
- Off-grid distributed energy solutions – energy is generated or stored by a variety of small, grid-connected devices referred to as distributed energy resources (DER) or distributed energy resource systems
- Will.i.a.m collaboration with Coca Cola to produce ‘ Ekocycle’ which can process recycled PET (Coca Cola) bottles
- Filabot – sustainable 3d printing, recycling parts to make new filaments which both saves money and reduces waste
- Solowheel, rapid versions developed, already in its 3rd generation after 6 months, in the loosely coupled manufacturing ecosystem of Shenzhen, China
- Dexta Robotics’ Dexmo by Seeed Studios, the Shenzhen-based firm was founded as a bridge between Western makers and China’s agile manufacturing ecosystem; aiming to design with manufacturing specs in mind; its Open Parts Library (OPL) catalogues compatible components for the most widely used parts in printed circuit board (PCB) designs.

4.2 The Role of Makespaces in a Sustainable Redistributed Future

From the interviews it is clear that makespaces are perceived to play a key role in an RDM future. This is perceived in a number of ways and some of these perspectives are reflected in the wider academic literature:

- Through the implementation of shorter production loops to reduce waste and environmental impacts of transport.
- Additive technologies can facilitate repairability of products, by on-demand manufacturing of spare parts to extend the life of products. While this is broadly beneficial for society, in some cases (e.g. electronics) repairing products may not be the best option, if more energy efficient solutions have come on to the market.
- Makespaces can encourage a broader demographic of people to engage in making. Assuming that people care more about things that they have had a role in making, thereby increasing the 'responsibility' of individuals and their attachment to products. Nonetheless, some interviewees communicated scepticism about the realities of this at present, but also indicated that with the right support mechanisms (governmental incentives) this could be a future reality.
- Open design practices, underpinned by sharing design files and solutions through digital networks, can address barriers to wider diffusion of CE. For example through the development of meaningful/viable open source (legal / business) framework, to overcome intellectual property issues that currently hinder CE, but also by fostering greater supply chain transparency.

Nonetheless, broadly speaking, within makespaces, the understanding of the concept of CE, and indeed wider sustainability, varies greatly. This is clear when comparing the activities of, as one cited example, Amersfoort Lab, which takes a deeply embedded sustainability approach (akin to industrial ecology) in comparison with other spaces that fail even to implement basic waste separation facilities. Other visionary industrial ecology-like examples were cited, such as the ability to grow, harvest and process resources in localities close to makespaces. This example also touches on the widespread perspective that the greatest potential for makespaces is seen in opportunities for incubation of creative start-ups, experimentation with new ideas and the space to test different approaches and innovative solutions. This relates to the capacity of makespaces to effectively educate, build and share skills and knowledge, which was consistently and enthusiastically communicated during the research.

4.3 Challenges & Opportunities

Certain conditions limit the capacity for makespaces to implement RDM and CE principles. Similarly, many opportunities exist. Tables 4 and 5 summarise these findings. It is important to note that many of the challenges identified are not unique to makespaces as organisational entities, but rather reflect a wider body of knowledge on barriers to sustainability in industry and this literature should and can be drawn on to inform future interventions (Prendeville et al., 2010, O'Rafferty & O'Connor, 2010).

Table 4. Challenges to Redistributed Manufacturing and Circular Economy from the Viewpoint of Makespaces

Challenges to RDM	**Challenges to CE**
Scalability • Uncertain how to mature from prototyping to batch production • Supply chain management issues e.g. space (storage facilities) • Need to develop knowledge of production management • Need to identify and develop means to access local markets	*Know-how (lack of)* • sustainable design • supply chain transparency • efficiency (product and machining)
Context • Need for routes to local integration and methods to access and manage local material supplies	*Leadership* • lack of aware 'eco-champions' to drive initiatives • knowledge-action gap *Organisational challenges* • time poverty, money, personnel • decisions on materials and equipment, can be guided by bureaucracy and the need to streamline processes • mission drift
Collaborations& Competition • Greater need for collaborations with producers • Competition with large scale producers who seek to downscale and localise production facilities	*Networks & Resources* • lack of a central, connected, space to access relevant knowledge and support • invisibility and intangibility of issues • dated / inefficient technologies that are far from state-of-the-art • lack of incentives (market demand and/or governmental) for makers to develop sustainable/regenerative goods and services
Skills & Education • Educational tools and guidance for makers to become CE-ready • Educational tools and guidance to encourage local actors to engage with local production	*Markets* • Perceived lack of market demand for sustainable goods

Table 5. Opportunities for Redistributed Manufacturing and Circular Economy from the Viewpoint of Makespaces

Culture

- Underlying ethos of openness and collaboration, which can be built on to diffuse and share best-practices, for example:
  - Use of digital networks and sharing platforms provide an existing infrastructure through which to share knowledge, therefore, disseminating relatively simple technical knowledge on (for example) cutting practices to reduce waste, existence of local industrial symbiosis programmes and efficient ways of running machines is likely to have a strong positive effect.
- Experimentation is facilitated and encouraged
- Natural investment in practical skills development and education and learning

Specialist Expertise & Capacity Building

- Skills and knowledge for product repair and reverse-engineering of products through product tear-downs is common practice
- Building capacity to design and make localised product solutions that are more effective in their context than ubiquitous global mass product offerings.
- Customisation for local consumers
- Responding to changing contexts, rapidly changing climate challenges.

Unifying Social & Environmental Sustainability

- Potential to unify social and environmental sustainability practices
- Evidence of industrial-ecology like approaches in combination with strong social, local networks

Innovation, & Incubation

- Potential to build in circular practices at the early stages of product conceptualisation and development
- As paces for incubation and experimentation of new potential circular solutions and ideas

4.4 Overlaps between Makespaces, CE and RDM

Figure 1 summarises some of the key findings of the research, showing the current state of interplay between makespaces, CE and RDM. This figure is derived from the existing definitions of RDM and CE combined with the insights from the interviews. For example, it conveys the current role that makespaces play in CE, by contributing to repair. In addition, it shows how the strong social dimension seen within makespaces, could enrich CE to move towards a deeper sustainability approach that unifies social and environmental imperatives. This figure captures a picture of the research at a point in time, but will be adapted and built into a theoretical framework for future research.

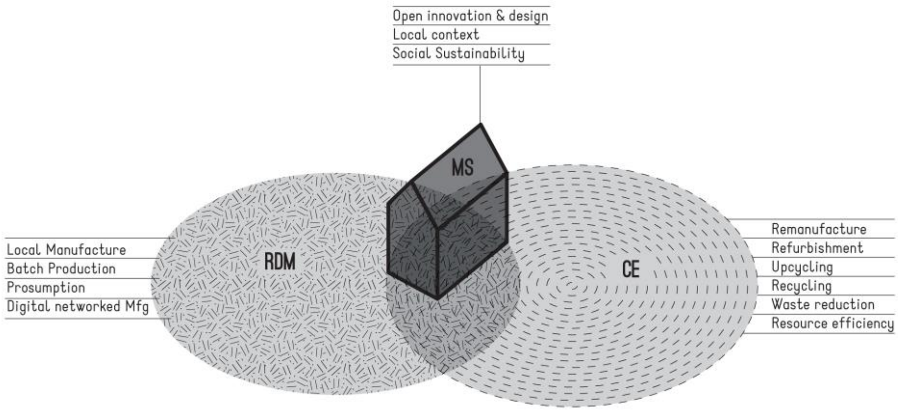

Fig. 1. Conceptualising Overlaps between CE, RDM and MS

5. Conclusion

This paper set out to discuss the role of makespaces in contributing to the CE through RDM by identifying key challenges to overcome. We found that these challenges many and varied (described in Table 4) and illustrate the need for a broad set of actions from funding bodies, local and national government to support the professionalisation of makespaces to effectively play a role within a sustainable RDM ecosystem. In addition, the research uncovers a clear set of positive opportunities which can be harnessed by makespaces to increase their capacity to survive and bridge the gap to the CE (Table 5).

The literature review, combined with the interview data has provided an initial conceptual description of the overlap between makespaces, RDM and CE (Figure 1). This is a starting point to underpin future research on this topic

From the analysis and literature review, we forecast a rapid divergence of makespaces in the mid-term and this should be considered within any future support actions from governmental and funding agencies. This segmentation of makespaces is important, because, the research highlights that there is a risk of undermining the current value of makespaces, many of which foster social cohesion in their local contexts. Others, based on their mission, capacities and capabilities are potentially more suited to organised RDM activities. This combination of attributes means makespaces are in a unique position to unify social and environmental sustainability imperatives.

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