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Do Makerspaces represent scalable production models of community based redistributed manufacturing?

ABSTRACT

This research explores the development of local community-based "*makerspaces*" as potential scalable forms of redistributed manufacturing (RDM). Makerspaces are rapidly emerging in post-industrial economies and have been identified as a catalyst of local regeneration in urban areas. However, their role in local production systems is limited. There is a gap in the literature, with respect to the evolution of makerspaces and their productive contribution. The purpose of this paper therefore is to identify, classify and examine the different types of makerspaces. Our focus is on the implementation characteristics that enable industrial production activity to take place. First, we used Leximancer (to identify from the literature) three types of makerspace. Second, we then identify five RDM implementation characteristics. The characteristics were integrated together to form the RDM-makerspace implementation model. Third, case studies were purposively selected to test and advance this model. They were subsequently classified as a Type 1 (educational), Type 2 (design) or Type 3 (production) makerspace. Only one of the case studies was classified as a fully evolved Type 3 production space. The findings concur with the literature that makerspaces tend to be primarily Type 1 or Type 2. Finally, the contribution to local production theory is emphasised.

Keywords: Makerspaces, Redistributed Manufacturing, Community based Production

Do Makerspaces represent scalable production models of community based redistributed manufacturing?

1. INTRODUCTION

There is a great deal of academic interest in makerspaces. However much of the debate has been focused on education, learning and design. Space accessibility to communities through libraries, schools and community centres is promoted by researchers as a way of engaging more local people in using the available tool and hardware in the community to develop and prototype new ideas (Barrett et al., 2015). In this article, we define makerspaces as a place in which people with shared interests, especially in crafts, technology, design and product development can gather to work on projects while sharing ideas, equipment and knowledge.

There has been a significant rise in makerspaces worldwide over the past ten years (see Figure 1 below). There is evidence (i.e. TechShop, MakerBot and ATX Hackerspace) of commercial makerspace success where prototype manufacturing and small-scale production takes place (Hirshberg et al., 2016). Though in the UK, a recent report by NESTA suggests that out of a sample of 157 makerspaces the majority have a predominant educational role. There are some notable examples of both prototype production (i.e. Camden Makerspace (bicycle helmets) and final product manufacture (i.e. Eagle House Makerspace, Bristol (furniture)). Although there are many reported makerspace facilities, there is much variety in terms of the scope of activity with respect to: education/awareness of modern

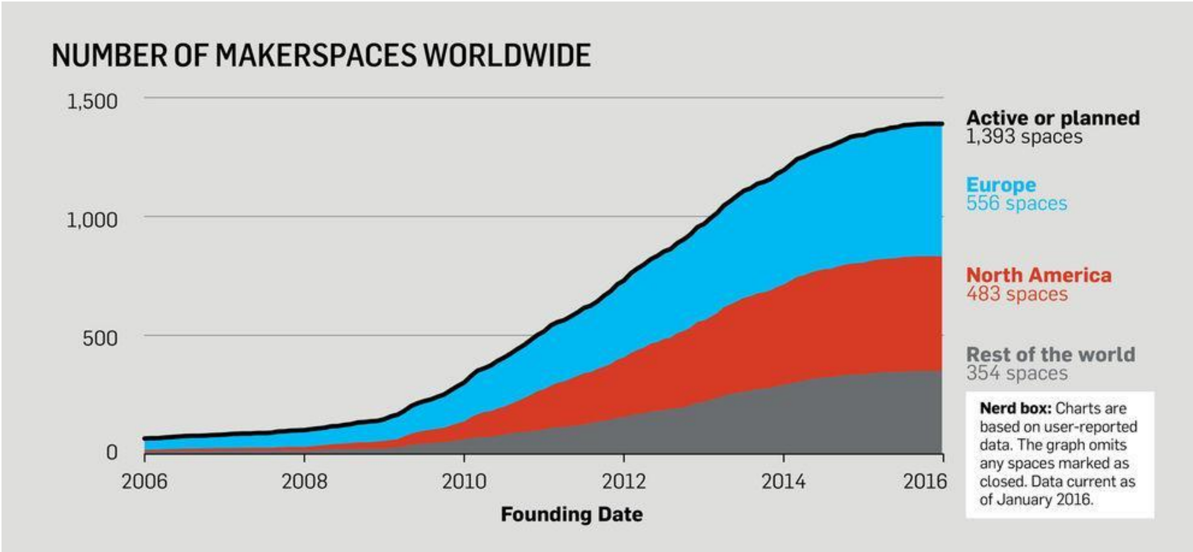

Figure 1: Number of Makerspaces Worldwide
(*Source: Lou & Peek, 2016, p. 1*)

manufacturing technologies; conceptual design utilising these emerging technologies; prototype production; and indeed, full production capability for the target market. Other than anonymised data sets (i.e. NESTA) there is a distinct lack of in-depth, case study work that: 1) categorises the different types of makerspaces; 2) explores their role in building local productive capacity; 3) identifies the characteristics for implementing redistributed manufacturing (RDM).

The subject of the "*last mile"*[1] is coming to the forefront of the field of supply chain planning. It is in this city mile context that RDM has emerged as a significant component of the industry 4.0 vision. We use the Srai et al., (2016) definition of RDM as: *"… the ability to personalise product manufacturing at multiple scales and locations, be it at the point of consumption, sale, or within production sites that exploit local resources, this is exemplified by enhanced user participation*

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[1] Last mile is a term used in supply chain planning to describe the movement of people and goods from a transportation hub to a final destination in the city (Mikkola and Skjott-Larsen, 2004).

across product design, fabrication and supply, and typically enabled by digitalisation and new production technologies" (p.5). The proposition outlined by Kumar et al., (2016) is that the enhanced data intelligence in the last mile (being provided by industry 4.0, big data and smart city infrastructure) will encourage more designers and new innovative suppliers, consumers and hobbyists to enter into local production through makerspaces.

Stewart and Tooze (2015) suggest that we are at the beginning of a fourth industrial revolution. However, clearly there is a need for understanding the extent to which production in makerspaces is rhetoric or reality. Is there indeed any actual evidence of full-scale RDM being implemented in these spaces? This paper therefore aims to better understand the context, enablers and scope of makerspace facilities in developing scalable forms of redistributed manufacturing. To achieve our aims, first, we identify and categorise the different types of makerspaces. Second, we classify five makerspace cases and examine their RDM implementation characteristics. We sought to answer the following research question: *What are the industrial contexts (i.e. product, technology), types of business model and local enablers (i.e. infrastructure, institutions and actor transformation) impacting on the evolution of makerspaces turning into scalable forms of RDM?* Our findings provide insights on the strategic role that RDM makerspaces could play in the establishment of local production activity[1].

Our paper is structured as follows. In section 2, we analyse the literature on makerspaces and RDM, using visualisation techniques and text analysis to identify three main types of makerspaces and five implementation characteristics. These characteristics are integrated together through

[1] Local production systems are defined as a concentration of production activities in a given territorial area in which several participating organisations, most of them small and medium-sized firms work together (Lombardi, 2003).

content analysis into an RDM makerspace implementation model. This will be used to classify five case studies. In section 3 the research design and methods are outlined. Case study findings with their respective classification are presented in section 4. The cross-case analysis and discussion is presented in section 5. In section 6 the conclusions are presented together with the implications for practice and research.

2. LITERATURE REVIEW

Using the text analysis procedure of Roberts (2000) and Mayring (2014) we conducted a two-step literature review. The first step focused on the analysis of key RDM and makerspace topics. Leximancer software was employed to identify the key types of makerspace. Whilst the second step involved the identification of key implementation characteristics from their sub-topic associations. These characteristics were integrated into an implementation model.

Using the Scopus database and using the "*RDM*" and "*makerspace*" search terms we located 142 academic journals, conference articles and book chapters[1]. The raw source files are presented in an online appendix (attached with the paper). All the chosen articles had to have business and management as part of their subject field (i.e. they were rejected if they focused solely on "*engineering*" or solely "*educational*").

2.1 Classification of combined RDM-Makerspace types

The Leximancer software generated a RDM-makerspace concept map. This is presented in Figure 2. The software identified three types of makerspace (each made up of distinguishable

[1] Please note only authors cited in the main text appear in the references section. For details of those authors that only appear in the author map (presented in Appendix 1) please refer to the online appendix source files.

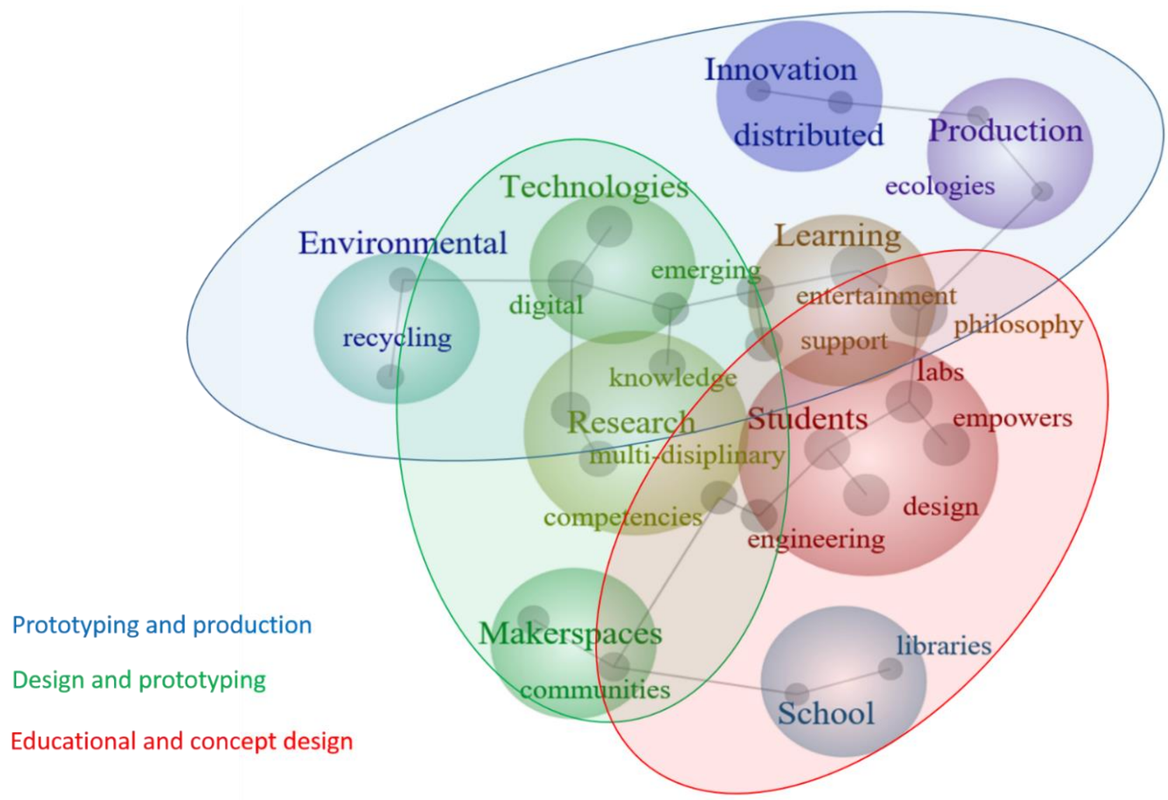

Figure 2: RDM-Makerspace topics

key topics). The three types of makerspace it identified included: Type 1 – educational and concept design; Type 2 – design and prototyping and Type 3 – prototyping and production. We sought (as advised by Mayring, 2014) not to rely solely on the use of a software algorithm to classify the makerspaces. Using content analysis techniques (Seuring, 2012) we used traditional content analysis to manually validate each of the Type 1, 2 and 3 classifications.

The authors of the literature from which the concept map was derived are presented in Appendix 1. The author map (generated by Leximancer) shows there are three distinct clusters. The more central the author is in a cluster the more productive their work is in that field (i.e. the more they have been cited by the other cluster authors). Whilst the bigger the circle, the higher is the academic impact of that article.

From the left-hand map, we can see close connections between Srai et al., (2016) and Rogers et al., (2016) and Wagner and Walton (2016). They all tend to be speculative in that they present future scenarios of alternative production systems and industrial networks based on RDM. In the lower (green) right hand cluster the central work is that of Nagel et al., (2016). The authors writing in the lower green cluster explore RDM makerspaces from an education and training perspective. The role of "*libraries*", "*universities*" and "*schools*" in makerspace development is a recurring theme in this cluster. Whilst in the upper (red) cluster the most productive work is that of Jariwala et al. (2016). This cluster explores the themes of makerspace "*design*", "*innovation*" and "*production*".

These author maps although generated by Leximancer have been interpreted by manual content analysis as we cross-checked the topic focus of the articles. Whether that is educational; design or production. The content of these articles provided additional validation for the identification of makerspace types.

2.2 Identifying Implementation Characteristics

The next step required a more detailed and in-depth investigation. Unlike the previous step and its focus on key topics this step involved a focus on the sub topics identified in the concept map (Figure 2). Leximancer was used to identify from the sub-topics the latent characteristic which associated them together. From all the presented sub-topics, it reduced these down to five latent characteristics. These are presented in Table 1 (with literature validations). Following Mayring

(2014) we again conducted content analysis, but this time our focus was on the sub-topics. This was designed to ensure that each implementation characteristic (identified) was indeed a latent factor cross-cutting the associated topic sub-set[1]. These characteristics will each be discussed in turn.

Product Requirements

RDM requires the manufacturing of products in which the customer is much more involved and participative in their development. Users are assumed in RDM to be strong co-creators in the design and production process, this leads to unprecedented levels of co-creation and personalization. The product is unique to an individual's requirements, furthermore, it is vital that makerspace production is conducted close to the point of consumption if it is capture rapidly emerging but "*transient*" source of local value.

Implementation characteristics	**Concept map sub topics**	**Authors**
Product/ Service Requirements	Proximity Customisation Real-time Innovation Environment/ Circular economy Digital User-participation	Anderson (2012) Eyers and Potter (2015) Mikkola & Skjøtt-Larsen (2004) Coronado et al., (2004) Barrett et al., (2015)
Enabling Technologies	Capability	Jariwala et al., (2016)

[1] For further information on the data reduction process the interested reader is recommended to contact Roberts (2000) or Mayring (2014) who discuss the process of building theoretical models from latent factors identified by text analysis. As an analogy, basically we have performed a qualitative version of factor analysis (data reduction) whereby the latent factor causing most variance in the independent variables has been identified. However, this has been done through a qualitative interpretation of the Leximancer software algorithm. This software algorithm identified the latent characteristic linking topics together (from the literature) but content analysis of the literature was needed to support the corresponding identification and association of topics and sub-topics.

	Maturity Capacity 3DP Big Data IT hardware and software	Emelogu (2016) Rogers et al., (2016) Wagner & Walton (2016) Thomas (2016) WEF (2015) Liu et al., (2014)
Business Model	RDM product design and materials RDM cost model Product ownership/ IP Alternative finance Commercialisation	Rogers et al., (2016) Srai et al., (2016) Brennan et al., (2015) Kuehnle (2010) Saenz de Ugarte, et al., (2009)
Local Enablement	Institutional support Local networks Social/ Communities Rebalancing Research Students/ Experts Schools/ Libraries/ Labs	Laplume et al., (2016) Holmström et al., (2016) Srai et al (2016) Tatham et al., (2015) Prendeville et al., (2016) Rauch et al., (2015) Nagel et al., (2016)
Actor Transformation	Culture Leaders Education Multidisciplinary Communication	Romero-Torres & Viera (2016) Fawcett & Waller (2014) Leonardi (2012) Sheridan et al., (2014)

Table 1: Key RDM-makerspace characteristics

The MIT concept of "*millions of markets*" supplied by "*millions of manufacturers*" drives the production function (Khajavi et al., 2014). There is high but very diverse demand and the lead time to get the product to market is extremely short. With such a fragmented market, the producer needs to create a "*lean*" and "*agile*" operations model. This synchronously serves the rapidly emerging demand. This model is characterised by high coupling points, it is market driven and close to demand (Srai et al., 2017). Design and supplier relations are organised on a temporary project by project basis as the flexible supply chain dissolves once demand has been satisfied.

RDM makerspaces are an exemplar model of short run "*flexible capacity*" in which no long run fixed logistic structures need to be created. This model is characterised by the manufacture of highly innovative, creative "*real time*" products, which have a high level of customisation (for instance, the installation of an automotive makerspace close to Ford in Detroit which is solely dedicated to prototyping parts for future connected cars and electric vehicles).

Enabling Technologies

Rapid advances in digital design and fabrication technologies are creating radical new possibilities for innovations in production and consumption. Makerspaces provide a suite of digital design and manufacturing technologies, including 3D printers, open source and web-based design tools, electronic kits, vacuum formers, computer controlled milling machines, welding, equipment, sewing machines, and laser cutters. The variety of materials and complexity of fabrication expands and knowledge systems and digital interfaces are easing user engagement (Jariwala et al., 2016). Makerspaces are networked through online social media (connecting them to designs, tutorials, debates and the movement of makerspaces globally), and through national, regional and international events (i.e. Maker Fares and Open Hardware Summits).

Actor Transformation

RDM makerspaces requires a transformative culture change in existing supply chain governance. Current models of centralization and hierarchical management of actors (i.e. suppliers) need to be reconfigured towards greater actor decentralisation and innovation driven supply chain design. There is a need to harness the creativity and innovation potential of the emerging makerspace start-ups. For instance, Ford in Detroit are in a strategic alliance with TechShop (a local makerspace specializing in automotive parts innovation) with the aim to cut their development costs and improve prototyping efficiency (Jariwala et al., 2016). There is a need to build not only design and innovation competencies within makerspaces, but also their manufacturing capability. This will require a concerted and long run transformational change in operations model and makerspace actor strategy (Thomas, 2016).

Local Enablement

The role of universities, schools and libraries as well as creating their own makerspaces provide vital seed corn funding for the development of commercial makerspaces (Nagel et al., 2016). In theory, Jariwala et al., (2016) suggests education and local council institutions will provide vital links for the local community to engage and develop their design and production expertise. They provide initial makerspace education and access to local production networks and manufacturing facilities.

In this RDM production model paradigm, we might envisage factories in local communities, meeting the needs for employment and wealth generation. In addition, to public investment and the expansion of educational makerspaces; this would be made possible by investment from traditional manufacturers, using their R&D and technology base to remove any issues of physical location.

Small-scale local manufacturing means that a high level of customisation of products is possible – with autonomous systems able to anticipate needs as much as respond to them – and create direct relationships between customer and factory (Srai et al., 2016). In the context of the importance of sustainability and limited resources, localisation means far less need for costly international supply chains, low energy use and carbon footprint, and more reliance on domestic materials that come from recycling processes or are grown or produced in the community (Holmström et al., 2016).

Srai et al., (2016) suggests that local sourcing and the use of nearby material and energy flows for production drawing on enterprise can deliver a range of sustainability benefits. Localization can facilitate the internalisation of externalities. It is aspired that RDM factories could lead to the enrichment of the community that they are in (Khajavi et al., 2014). Since proximity to market will dictate materials chosen, many RDM manufacturing attributes get shaped and sized to their city or region. The city serves as a material boundary for the manufacturing arrangement (Tatham et al., 2015). There is also closer feedback between production and consumption.

Business model

The different business models link the unique contexts and enablers for a given sector and/or region for effective implementation. Processes and supply chain activity need to be organised to create and sustain value in the supply chain. Theoretically the business model implies that local material resources are used locally to locally produce goods for local consumption and disposal. The production activity is supported by a global flow of non-material resources such as capital, technical expertise, patents, data analytics and business planning (Thomas, 2016). The flow of both material and non-material resources is managed locally by either the global firm or local organisation (Srai et al., 2016). A RDM-makerspace business model links the drivers and operational implementation categories together. RDM needs to be considered as an operational form of competitive advantage (Rogers et al., 2016). Processes and supply chain activity need to be organised to create and sustain value in the supply chain. Our focus is on identifying how the drivers lead to its operational implementation but from the perspective on the value it will create through the resources it brings to the organisation and the capabilities needed within the space to fully implement RDM to create competitive advantage (Thomas, 2016).

2.3 An Integrative RDM-Makerspace implementation model

These characteristics have been conceptually integrated together into a model. This is presented in Figure 3. The characteristics of product/service requirements and enabling technology are interrelated with local enablement and actor transformation through the business model characteristic.

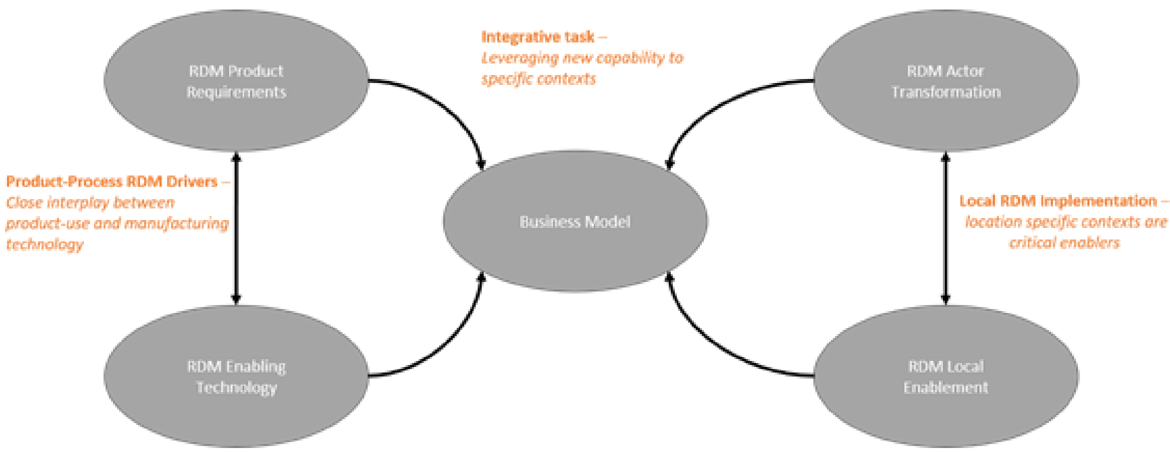

Figure 3: RDM-Makerspace implementation model

There are many hybrid forms of makerspace RDM business models that emerge from the three types identified earlier, namely: Type 1 – RDM enablers focused on education and concept design; Type 2– RDM enablers focused on design and initial prototyping and; Type 3 – RDM enablers focused on final prototype and production. The literature suggests that most makerspaces tend to be Type 1 or Type 2 (Jariwala et al., 2016; Nagel et al., 2016 and Prendeville et al., 2016). This paper is particularly interested in exploring the development of Type 3.

Since the majority of literature has covered makerspaces from an educational and design perspective (namely what we refer to as a Type 1 or 2 makerspaces). We have developed the RDM-makerspace implementation model to test against real-life case studies in order to distinguish whether some makerspaces represent Type 3 makerspaces, demonstrating scalable forms of RDM production (Putnik et al., 2013).

3. METHODOLOGY

The methodology adopted in this study followed the procedure of previous RDM studies (Srai et al., 2016). It aimed to capture the critical categories of a business model, namely, the context, resources, activities, processes, actors and interdependencies that support the creation and delivery of products and services. Therefore, five cases were purposively selected (Eisenhardt, 1989) to cover the full range of makerspace strategies, from Type 1 (educational) through Type 2 (design and prototype) and finally Type 3 (production). Whilst some of the makers could be clearly identified as having strategies of design and education others were combining different activities together. A judgement had to be made by the researchers as to where their strategic emphasis resided, education, design or production.

The research objective here was to explore whether emerging RDM makerspace application case-studies might provide further insights into implementation contexts and drivers. As this work was intellectually positioned to advance the emerging corpus of conceptual work into actual practice, we adopted an exploratory approach as the cases were more towards the descriptive end of the spectrum.

The case selection criteria required cases from the real-world where makerspaces were operational and had a decentralised arrangement. Five cases were chosen as they included a mix of the three different types of makerspace facility. From a purely educational and learning driven facility, through to design and finally those RDM spaces which had a production focus. Two cases were considered to be Type 1; one a Type 2 makerspace; one a Type 2/3 makerspace; and one a Type 3 makerspace. The case companies verified their makerspace categorisation as part of this study.

In terms of a local production context, the categorisation approach incorporates institutional actors (including government bodies, regulators, research bodies, demonstrator facilities) and specialist industrial actors that do not normally form part of the supply chain design agenda, such as local authorities, community groups and universities, sector specific finance and venture capitalists. Finally, thematic categorisation enables connections and interdependencies between business model actors by capturing value flows (transactions), and the flow of information and materials and production capacity (Srai et al., 2016).

Our primary case study data collection instrument was that of the semi structured interview. A total of 18 interviewees were conducted. These interviewees were selected based on their level of expertise on the topic and their previous experience of setting up and running makerspaces. A summary of the interviewees who participated in the investigation is presented in Appendix 2.

Our review of leading makerspaces from the many thousands of registered sites making up the maker population in the UK and US (NESTA (2015)) revealed that very few had implemented anything markedly different to our cases (with respect to their commercial scalability). So, the extent of these differences we believe to be marginal. Furthermore, we are confident that the choice of our case studies is well justified and that they cover the full range of educational, design and industrial strategies being implemented. They also provided enough access and a wide breadth of data to inform meaningful representation, comparisons and contrasts to be made that could be fed directly into the theoretical advancement of the model.

3.1 Qualitative data analysis procedure

The final stage of the case analysis involved cross-case data presentation and synthesis involving cross-sector comparison and analysis. As mentioned the primary cases were conducted with semi structured interviews, passive and participative observations at makerspace meetings and site visits. Internal documentation was also analysed with one of the case studies. Multiple informants and interviewees participated in each of the case studies. The data analysis was structured around the key implementation characteristics identified by the text analytics.

All the primary evidence including the answers and comments to each thematic characteristic were grouped by company according to the level of agreement/disagreement of identified response patterns. Excel spreadsheets were then used as response matrices to identify patterns of consensus and disagreement, and then to determine similar patterns between the different maker facilities (Molleda & Moreno, 2008). As the goal of this study is to detect cross-maker similarities, we focused on the main items of consensus in every organisation to compare them all together (Roberts, 2000; Poindexter & McCombs, 2000).

We aimed to advance our knowledge of the RDM makerspace constructs outlined in the classification stage, through their thematic extension with primary data (Eisenhardt, 1989). Through the thematic interplay of data with theory we could now confirm, modify or reject parts or the whole classification. Together, the five cases purposively represented the sampling diversity required to meet the study aims across the three types of makerspace.

4. FINDINGS

The case studies have been organised in accordance with the categories of the "*2:1:2*" implementation model (presented in section 2.3). Each case will be discussed in turn before a cross case comparison is completed to highlight key similarities and differences.

4.1 Results from the Case Studies

The results from each of the five case studies will be presented on an individual case by case basis.

4.1.1 Case one - Ravenswood Makerspace Collaborative, USA

Ravenswood Makerspace provide students with opportunities to learn and explore STEAM subjects through technology and tools. Ravenswood is one of seven schools with inbuilt makerspaces in their district. At present, six of the seven sites are open, equipped and staffed, for use by students aged 4-14 years old. Their objective is to stimulate creativity and entrepreneurial thinking amongst young and disadvantaged groups.

- *Product Requirements*

There is a need for proximity of materials and equipment where Ravenswood can share its technology capacity across its local network of seven schools. The organisation is a supplier of educational services and it raises funds to buy new equipment and provide new programmes to as many school children and disadvantaged groups in their local community. Ravenswood is strategically positioned to build maker culture, and stimulate creativity and entrepreneurial thinking amongst young and disadvantaged groupings. They are measured on their capability to reach as many young and disadvantaged people in their local area as possible.

- *Enabling Technology*

Through their Stanford grant Ravenswood have bought desktop CNC mills, however, they have had several issues in trying to use the technology. Other technologies in the makerspace include laser cutters, 3DP, iPads, humming bird robotics kits, Arduinos and Lego robotics kits. They encourage school children of all levels — groups of 25-30 at a time with mentor's present — to learn about robotics through Dash and Dot coding robots, and computer science and coding through Code.org[2]. Typically, a learn through play philosophy is adopted in workshops and there is very much a discovery and problem-solving ethos. For instance, rather than trying to learn basic programming or algorithm skills, the ethos is trying to solve problems through games or puzzles.

- *Local Enablement*

Apart from its government links, Ravenswood have developed several partnerships with external institutions such as the University of Stanford where they receive support to develop new

[2] Technology start up Wonder Workshop created robots Dash & Dot to teach kids to code while they play. Using free apps and a compatible tablet or smartphone, kids learn to code while they make Dash sing, dance and navigate all around house. Sensors on the robot mean that they react to the environment, including children. Further details can be found at: https://www.theguardian.com/technology/2015/sep/07/robots-teach-kids-to-code-dot-dash

education programmes based on STEAM subjects. Google and Facebook donate equipment and staff to work in the makerspace. The aim and focus of the makerspace typically revolves around building social networks to target community problems, for example, students are tasked to identify local environmental problems and then engineer solutions to those problems within the makerspace.

- *Actor Transformation*

Ravenswood have monthly "*Cafecitos*", where parents come in and have coffee with the principal, and they are offered the opportunity to volunteer to work at the makerspace. Finding local based leaders with an educational background is vital for Ravenswood, they rely on recruiting volunteers to support different projects, help small groups, or bring in a technology to share with school children, getting parents in the community involved is a long-term goal they are working towards. However, an issue raised when hiring volunteers was the bureaucracy in place that made deploying staff a very long process. The cultural focus is to foster creativity and inquiry based learning where students can apply their STEM knowledge, develop entrepreneurial skills and gain experience working with emerging technologies.

- *Business Model*

The strategic objective is to encourage practical skills, creativity and entrepreneurial thinking through the development of maker spaces and activities in schools and communities. Ravenswood is funded solely by the State government and through external grants from technology companies to buy equipment such as 3DP and laptops. They have a research partnership with the University of Stanford's Transformative Technologies Lab. Another way Ravenswood generate income is by tapping into the local business community, for example, they received a $2000 donation from a local women owned and run technology company. Ravenswood's success is measured on their capability to reach as many young and disadvantaged people as possible. This case is positioned on the makerspace continuum as a type 1 makerspace which aims to build a long run educational culture of production amongst its users, indirectly. This is through creative learning programmes linked to STEAM education.

4.1.2 Case two – Fab Lab, Devon, UK

FabLab Devon, was the first makerspace of the FabLab UK network to be built in a library. The makerspace was created as part of a three-million-pound library upgrade. It is a small-scale workshop that is open-access, not-for-profit and considered a community resource (https://librariesunlimited.org.uk/services, 2017).

- *Product Requirements*

There is a lot of local interest from the public in terms of personalisation of products, *"... occasionally we have people come in here who are from a business, perhaps they want to make a prototype and we charge them what we call a bureau charge for making something which is more than members would pay if they were producing a prototype"* (Volunteer).

- *Enabling Technology*

"We've got the following advanced technologies: electronics equipment, PCB manufacturing, computers free to use for anybody who comes in, running Linux, laser cutters and 3D printers. On the lower technology side, we own a sewing machine, woodworking equipment in the form of circular saws and finally, the space owns a 7-foot pattern making lathe" (Member).

- *Local Enablement*

The FabLab relies on local networks in the community to run programming code clubs and some of their volunteers run courses for adults and children for programming. The public can become members for a year and be trained on machinery. These training sessions are delivered by its volunteers: *"… we are very welcoming of the general public to actually come in to our makerspace and manufacture things"* (Volunteer).

FabLab is associated with the rebalancing of community resources where it has very strong links with Exeter's local schools: *"We have found that schools are very keen to bring their children to have courses here and find out about modern technology. The primary schools don't have the resources to do this and we believe that making should be an important part of their education."* (Founder).

- *Actor Transformation*

Currently the FabLab hires an administrator who is paid by the County Council, however, they also have a pool of volunteers co-supporting the initiative. There are two volunteers on any shift (usually three hours). Many of the volunteers use the FabLab to design their own products and occasionally develop prototypes. The FabLab take demonstrations outside to other libraries, to schools and run courses. They usually have a lot of commercial enquiries to use their facilities: *"… we had an architect in a few weeks back. He wanted to use our printers to 3D print models of buildings"* (Volunteer).

- *Business model*

This Makerspace was funded through three main sources. These were Devon County Council, NESTA (the technology charity) and the Real Ideas Organisation (RIO). There are also revenues raised through membership subscription fees. *"We are not in the business of competing with businesses for production artefacts or finished products. Our position is that we are too small and we are funded by charities and Devon County Council. So, it would not be good if Devon County Council were seen to be competing with and taking business away from the local businesses in the county"* (Member). We classify FabLab as a type 1 makerspace, where it has a primarily educational and skills development role, they offer training and practical skill development not only to school children but to the wider local community and business community. Some examples include welding, blacksmith skills and fabrication.

4.1.3 Case three – Sheffield Hackspace, UK

Sheffield hackspace is a non-profit makerspace run by its members who pay a monthly subscription fee. Their aim is to build a community within central Sheffield to get people involved and support them in creating and developing their own hobby-scale projects.

- *Product Requirements*

FabLab Sheffield collaborate with Pimoroni (a local company of makers and educators). Pimoroni supply 3D printers. The makerspace has a lot of local business connections with small to medium-sized ICT, electronics and steel manufacturers. In the words of one trustee: "*… so in effect our 3D printers are operating as self-replicating machines*". The founder of the makerspace revealed that about 70% of machine capacity is directed towards spare parts whilst the other 30% of users are working with the technology to make a wide range of items from brackets to jewellery.

- *Enabling Technology*

The core technology in this space was electronics (Arduino and Raspberry Pi), 3DP, CNC machining, textiles, woodwork, metalwork.

- *Actor Transformation*

Sheffield Hackerspace focuses on supporting the local community. "*Skills and knowledge which is what I think this is for, rather than, you know, manufacturing*" (Trustee 1). The facility is aimed at community users who want to come in and get on with making things on their own. The focus of many users was having access to tools and machinery that were not freely available to them in their homes. "*Previously we were – we met up with a – it's a place called Access Space and they're what you call more of a fab lab where it's staffed*" (Member).

- *Local Enablement*

A makerspace network was emerging in Yorkshire, Derbyshire and Nottinghamshire and they were beginning to share resources, expertise, knowledge and capabilities.

"We've got quite a few contacts with other makerspaces around, so we've done visits to Leeds, Nottingham Hackspace and Derby Makers. We have worked with a couple of other organisations such as Code>Make>Win which is an event for young people with start-up ideas." (Trustee 3).

- *Business Model*

This makerspace is entirely funded by members. Their model was confirmed by the trustee: "… *we are pretty much entirely funded through a combination of donations and subscriptions from members. We've had some funding come in recently from Sheffield Soup, which is a colloquial crowd funding thing*".

Many constraints existed that were preventing the growth of the makerspace facility in Sheffield. In particular, finding a large enough central space: *"... given that we don't want to end up taking out business loans and our rent is a kind of a catch-22: we need lots of members to afford a big space. It's difficult to gets lots of members without a big space*" (Founder). The hackspace is considered to be a type 2 makerspace. This is because it is a non-profit, member-run organisation which does not focus on formal education and is not supported financially by a local council, school or university educational body. Instead, it focuses on supporting its paying members (local Sheffield community) to develop hobby-scale projects, fostering new product designs and converting them into prototypes through the creative use of technology and tools. For example, electronic key entry systems, kit knifes, clock stands, book cases, electronic textiles and furniture.

4.1.4 Case four – FIX makerspace, Norway

FIX is a makerspace collaboration between DIGS, an innovation platform, built on exchanges between members and partners who unite entrepreneurs, "*makers*" and "*doers*" from varied sectors, (www.digs.no), Norwegian Creations, a private company offering "*makers as a service*", and keen individuals from Trondheim's maker community. FIX's main objective is to stimulate the maker culture in Trondheim.

- *Product Requirements*

We design and build everything from custom PCBs to complete interactive installations to industrial products. *"We design and develop prototypes for other businesses as well as develop our own products. We use the Makerspace (technologies) to actively to realize our ideas"* – (Norwegian Creations and FIX Makerspace Interviewees.

- *Enabling Technology*

The FIX facility is equipped with a soldering station, 3DP, vinyl cutter with dedicated computer, mechanical tools, woodworking tools, drill press 4’ x 8’ CNC router (for wood and plastic) with dedicated computer, power tools such as saw, drills, angle grinder and belt grinder.

- *Local Enablement*

FIX participate in entrepreneur/ maker networks across Norway, Europe and internationally and aim to strengthen ties, stimulate the local community and increase economic generation in and around the region of Trondheim.

- *Actor Transformation*

FIX aims to stimulate the maker culture in Trondheim: *“... we want to attract a diversity of makers, beyond just Trondheim’s microcontroller community. We want to reach out to product designers and those working with textiles, wearables, woodworking and metalworking”* (Trustee). They offer entrepreneurs, SMEs and independent workers access to the makerspace, meeting rooms, internet, printers as well as access to lawyers, accountants and business developers. *“I hope to see a 50/50 split between small businesses and start-ups that work on prototypes during the day, and hobbyists and makers in the evening”* (Trustee).

- *Business Model*

They are open 24/7 to members, FIX makerspace is funded solely by membership fees and donations. We classify Fix Makerspace as a type 2/3 makerspace. It is not only involved in developing hobby-scale projects with its members but it also aims to have a 50/50 mix of start-ups and small businesses that can develop prototypes and produce them, though at a low production (i.e. boutique) capacity, for example, electronic lighting kits, displays and walking robot gaming kits (i.e. programming skills).

4.1.5 Case five – Leeds Hackspace, UK

Leeds hackspace is based around a community group of hackers and makers, the hackspace is not-for-profit and is both run and funded by its members.

- *Product Requirements*

Many of the hackspace's members are involved in prototype design and manufacture with intentions to commercialise: "… *there's several people who have designed products who use the makerspace. Not necessarily design them at the makerspace, but they do sometimes. One guy works for a start-up that's got a home intrusion burglar alarm-type system that's sort of similar to a Nest. There's another guy who's creating a system for brewing beer"* (Volunteer). Other examples of prototypes manufactured by members include customised raspberry pi cases, DC motor drive for a go-kart, jigs.

Despite designing and manufacturing prototypes and one-offs, there is interest from members in scaling up production; *"On open nights, people have said, "Oh, can I make sort of a batch of these, a few of these?"* (Director).

- *Enabling Technology*

The facility has a 3DP, laser cutter, vinyl cutters, t-shirt presses, lathe, CNC machine. *"The 3D printer facilities we've got here are very sort of rustic, very much 3D printers that you fiddle with. We do have a commercial one, which is actually mine but I leave it here. The print quality can be* *variant and 3D printers that are filament based have a tendency to jam and constantly need unblocking. There are powder printers available, which are really nice; they're also really bloody expensive. So those machines are much more targeted at the sort of medium to large scale production"* (Management Committee).

- *Actor Transformation*

Most of the users are students, existing designers or working in the engineering sector.

"Well, I design product myself. A lot of people here design products. We're a group of designers. Every cut with a laser, every build with a 3D printer, or every textile using the sewing machines inside is a design process, is part of the design process" (Member).

- *Local Enablement*

The hackspace has numerous informal connections with the local council and the city library, other informal links have been made with the local University via hackspace members who are university employees. Awareness of the hackspace has been problematic: *"... one of the areas that we struggle with, is getting the Leeds Hackspace name out into the community"* (Director).

- *Business Model*

The primary source of income for the hackspace comes from membership fees, there are also occasional donations. Running the space as a commercial venture is questionable; *"It's a lot easier for UK makerspaces to be limited companies that are run not-for-profit. Being a charity puts extra onus on the space. You can't sell items at workshops. You can't make things, per se, for sale. So, we opted for limited company and we sort of share the responsibility of being directors of that limited company"* (Director).

"We don't have any funding, mostly because we didn't want to rely on it as much as anything else. , we wanted to aim towards autonomy based on the group's income as compared to actually relying on grants, then they disappear" (Volunteer).

We classify this Leeds hackspace as a type 3 makerspace. Despite the makerspace being not-for-profit, it encourages users to take on their entrepreneurial ideas to develop new products that can be taken from design prototype to actual product to be considered for commercialisation, via links with external manufacturing facilities.

Their focus is on building member's capabilities to run a local production model with RDM characteristics. Some successful products developed include medical devices, clothing, footwear, jewellery, replacement car parts, toys and bicycle (high performance) equipment. It links closely with the Leeds Enterprise partnership and manufacturing advisory service which provides members with access to finance to start up and expand their manufacturing business.

5. CROSS CASE ANALYSIS AND DISCUSSION

Figure 4 (the spectrum) summarises the observations at a cross-case level and this section will utilise this schematic to initiate a discussion on these findings. First, we observe that there are very distinctive characteristics between Type 1, Type 2 and Type 3 makerspaces, with the most marked differences being in the actors involved in setting up, running and using the facilities. For instance, the social benefits in Type 1 (Ravenswood, Devon FabLab) are somewhat at odds with the commercial orientation with Type 2 (Sheffield Hackspace) Type 2/3 (Fix) and Type 3 (Leeds Hackspace). Type 3 makerspaces provide more opportunities for local economic development through the full implementation of RDM characteristics.

The makerspace brand is thus somewhat misleading in that it is in the minority of cases that we observe Type 3 implementations (FIX, Leeds Hackspace). Furthermore, Type 3 implementations have significant industrial involvement – both in kind and financial – and this invariably leads to product/sector specialisation.

Further, where Type 3 implementations are observed there are very specific market drivers, industrial contexts and technologies that have allowed them to flourish; these present constraints also need to be understood at the outset of any public or private makerspace investments. Good examples where this evolution pathway is possible include music labs migrating to production houses, lighting technologies leading to servitised product centres (FIX Makerspace), and medical devices where prototype manufacture can lead to personalised products for patients (Leeds Hackspace).

Other observations on the potential transition pathways include where there are appropriate conditions (i.e. industrial contexts) and no impediments (i.e. no product/technology constraints) there are still challenges in that Type 1 (free to use) facilities have very different revenue models than Type 2 (membership fees) and Type 3 (contract), different capacity considerations (i.e. space) and specialist skills requirements.

As expected, we can see that Type 1 facilities (Ravenswood, Devon FabLab) constitute equipment that is amenable for generic and multi product use, and therefore have significant adaptability and agility to changing educational needs. Type 2 (Sheffield Hackspace) extends this capability for prototype manufacturing. However, Type 3 implementations are increasingly specialised with unique equipment investments that whilst de-risking product supply chains are vulnerable to low utilisation and market uncertainty. Notable exceptions however are in IT and other platform technologies that can have multi-sector relevance.

Type 3 RDM makerspaces are particularly attractive in that they involve relational investments where there is a degree of both financial and social capital working together to create local capability (FIX). This development can lead to a more sustainable business model and engines for future economic growth. It presents a genuine RDM production model and further research on what are the contextual, technological conditions and constraints that might facilitate successful implementation may provide insights as to how significant this manufacturing model can become.

We also can observe that with the right conditions makerspaces in all categories can flourish in both developed and developing world contexts. We can observe this in all three categories of makerspace. Of particular interest are the characteristics of the entrepreneurial leaders, where in Type 3 models we observe commercially aware technology savvy individuals (Leeds Hackspace) that can manage the uncertainties of new technologies and the development of new products and market opportunities.

Finally, in applying the RDM implementation model to the makerspace context it has proven insightful and suggests broader application to other RDM paradigms. A potential enhancement to the implementation model could be to consider potential transition pathways between alternative RDM executions. Further, whether there might be emerging archetypes that capture constraints to specific implementation options by introducing a dynamic environmental dimension, which might capture changing contexts, capability and technology developments (Teece et al., 1997, 2007) and policy environments.

Even though we classify the Leeds hackspace as one of the more advanced spaces in the production continuum, it still contains elements of Type 1 and Type 2 activity. Therefore, the empirical work extends the original static analysis to more of a life-cycle continuum in which different activities such as education are found in Type 3 but they not as dominant or as common as they in Type 1 maker classifications. It is only the level of significance (weight) of each activity whether that be education, design or production, which determines both our and their classification of space strategy, culture, capabilities and resources.

Local Enablement

Regional school/ networks (Case 1,2) Rebalancing community resources (1, 2)	Regional library collaboration Institutional support (Case 1, 2, 3)	Crowd funding (Case 2-5) University research partnerships (Case 2,3,5)	Co-location with specialist, research centres	Co-location with service centres Local production networks with SMEs and start-ups (Case 3-5)	Industry/ sector pre-competitive collaboration

Actor Transformation

University staff, teachers, parents, skilled machinist educators Specialised mentoring Community culture	Volunteer specialists (Case 1-5) Education (Case 1,2) General staff (Case 1-5) Students, teachers (1,2)	Semi-skilled operators Open network of users Non-contractual (Case 1-3)	Technology Entrepreneurs (Case 3-5) Training (Case 2, 4, 5) Technology experts (3-5)	Specialised actors with specific product/ technology focus (Case 3-5) Entrepreneurial culture Change agents	Venture capitalists Paid specialists (Case 5) Contractual (Case 4,5) Multidisciplinary expertise

RDM Enabling Technologies

Generic technologies. Integrate specific resources that enable programmed, curriculum based learning	Generic assets for multi-use Flexible, low capacity Distributed resources	Manual production Capacity sharing across makerspace networks (Case 1-3,5)	Production close to market (Case 4,5) Mature and nascent technology	Specific assets for specific use (Case 4,5) High capability, low capacity production	Technology specialisation (Case 4,5) Nascent technology

EDUCATIONAL ← Type 1 — Type 2 — Type 3 → **OPERATIONAL**

RDM Product Requirements

Demonstrator products to explore technology capability (Case 1-5) Social responsibility (Case 1, 2)	Prototype development (Case 1-5)	Prototype High material variety New materials testing and development (Case 2-4) Product co-design (Case 2-5)	Prototype/ small-scale production (Case 3-5) Cycle time optimisation Product innovations	Product/ sector specialisation (e.g. music, IT, healthcare) (Case 3-5) Novel materials Fast design process Reduced supply chain complexity	Real-time, batch production Product/ sector specialisation (Case 3-5) High customisation

Business Model

Government/ external funding (Case 1,2) Educationally driven entrepreneurship	Costs covered through membership fees (Case 2-5)	Not for profit limited company (Case 3) Local value capture	National centres of excellence (e.g. graphene centre) Product/ design ownership agreements Leveraging new capabilities	Alternative finance/ industrial sponsorship (Case 1,4,5) University spin-out (Case 3,4) Product commercialisation	Commercially viable, Limited company Capacity building IP agreements New RDM product/ service solutions

Figure 4: RDM-Makerspace Implementation Spectrum

6. MAKERSPACE DIFFUSION IN MANUFACTURING INDUSTRIES

At this stage of our research programme we have found a number of examples where several industries are leveraging, cooperating or setting up a makerspace. These examples are presented in Appendix 3. There are certain types of industrial activity which could in the long run, we believe be under threat from makerspace activity. For example, industries, or industry segments, where customisation and quick responsiveness to fast-changing consumer preferences and market conditions are important rather than in commodity production based on economies of scale. This echoes the heralding of new, flexible production paradigms coined as mass customisation (Pine 1993), delayed product differentiation (Lee & Tang, 1997), and reconfigurable manufacturing systems (Mehrabi, Ulsoy, & Koren, 2000).

Whilst in contrast there are other industries, including the manufacture of basic metals and chemicals that are unlikely to be affected in any foreseeable future. It seems unlikely that makerspaces will take root in industries or industry segments characterised by long production runs and/or industry segments where manufacturing is already highly automated. There is evidence of capacity leveraging by manufacturing firms of makerspaces now and potentially into the future. For instance, in textiles, leather products, PCBs (printed circuit board) fabrication, robotics and electronics. Industrial diffusion is also evident in the automotive sector, where Ford Motor Company and TechShop Detroit have created a joint makerspace (http://www.techshop.ws/ts_detroit.html).

7. CONCLUSION

Makerspaces have a vital role to play in changing local culture towards innovation and making. Therefore, our assertion in this paper is that makerspaces are a fundamental foundation to the spread of RDM. They could facilitate a growth in local innovation, product development and market niche identification. Local production models and supply chains need development and re-establishing and their needs to be actor transformation and public/private sector subsidization and the stimulation of such activity. The Type 3 spaces we have identified are rare and we advocate that policy makers need to work with Type 2's to develop their productive and competitive capacity in the short run. Type 1's need long run investment and incentives built into to their education focus so that they are rewarded for projects designed to build local social and economic impact (i.e. job creation, new industrial start-ups, making skills and qualifications). As they are primarily dealing with school children they are vital in changing perceptions of manufacturing as a career or entrepreneurial opportunity for creating new industrial activities. They certainly need to be made more commercially aware and focused on market as well as purely education output. A more targeted and strategic educational agenda needs to be put in place for users in these spaces, as well as having fun or being a hobby.

Our theoretical contribution to local production theory (Lombardi, 2003) comes from filling the existing gap in the role of makerspaces in stimulating RDM activity. To date most studies of makerspaces have focused on their educational and design role in local production contexts. Our work makes a vital contribution by identifying how spaces can start making and manufacturing products for local consumers. Local production theory stresses the traditional role of SME's in this space which is to act purely as assemblers, maintenance facilities or distribution actors for global corporations. This study presents future organisational forms emerging from RDM makerspaces as potential disruptive innovators, making customised products for highly localised niches.

The RDM implementation model suggests that as well as limiting constraints related to product characteristics and technology maturity, there are also significant local enablement constraints to its full-scale adoption in makerspaces. Therefore, local authority and university investments in platform technologies, such as 3DP and continuous manufacturing can lower barriers to entry. Further, investment in local capacity and capability are necessary conditions that may benefit from policy interventions. Finally, the model provides a theoretical and empirical explanation of some of the challenges as to why RDM uniquely requires the interplay between product design, enabling technology, dissolvable capacity, and transformational actors.

The implementation approach tries to classify spaces into three distinctive types. However, it is important to recognise that spaces themselves could classify themselves using the model characteristics. Though they did point out that they could combine multiple agendas/models cutting across the three different types and that they were not mutually exclusive. Therefore, makerspaces are ambidextrous in their strategy and move between types depending on project specifics, and what is made and produced (knowledge, culture, products, innovations. Interesting none of our spaces self-identified themselves entirely as "*Type 2 spaces*" and usually combined this with other types of activity.

7.1 Implications for future research and practice

Going forward, four types of research are urgently needed. First, given the growing importance of local production for economic regeneration and last-city mile logistics, new analytic frameworks, tools and techniques need to be developed to systematically capture relevant data and generate reliable insights to inform the operational and strategic decision making of operations managers working in RDM enabled makerspaces. Some existing frameworks and tools can be adapted for local production, but new ones need to be developed to address emerging opportunities.

Second, it is necessary for more research to be undertaken on industries likely to be affected by makerspaces, for example, (1) industries with no, or low, current or future adoption of makerspaces, (2) industries currently being affected by maker capacity, and (3) industries into which makers are likely to diffuse in the future.

Third, intensive case studies of the transformation of maker space models and the development of new production models in different urban regeneration contexts, such as smart cities need to be identified and documented.

Fourth, and perhaps the most important, is new theoretical and empirical research about the transformation of traditional production models and the emergence of makerspace RDM models. RDM will significantly extend the scope for the digital transformation of local production models across different sectors, from personal, domestic and community services, to a wide range of new products and services that demand close geographic proximity between providers and consumers. In terms of practice we hope that our classification of makerspaces provides a means for the spaces themselves to identify their industrial strategies as well as being useful academic categorisations.

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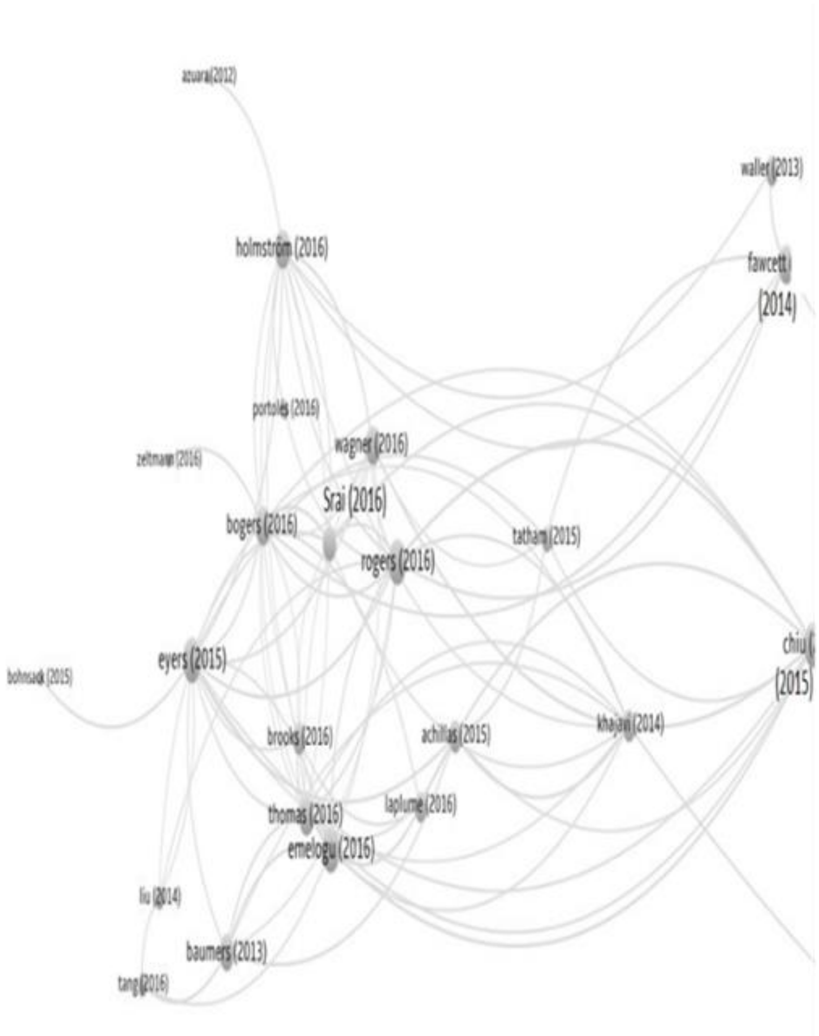
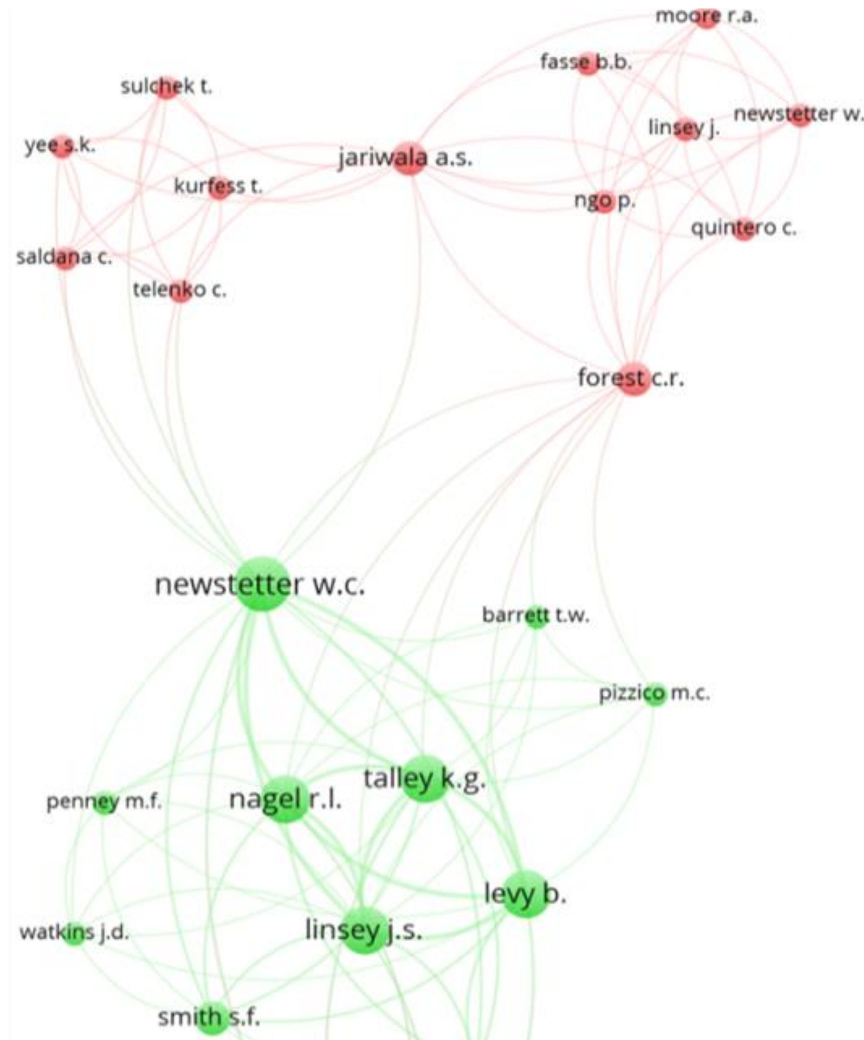
Appendix 1: Leading RDM-makerspace authors





Appendix 2: Case Study data sources

Case study ID	Makerspace interviewee role
Ravenswood Makerspace Collaborative (East Palo Alto, California, USA)	1. Volunteer Staff /coordinator
Fab Lab Devon (England)	1. Volunteer staff member 2. Member/customer
Sheffield Hackspace (England)	1. Trustee 2. Member/technical staff 3. Member 4. Trustee 5. Trustee
FIX Makerspace (Trondheim, Norway)	1. Owner (2) 2. Makers (2) 3. Users and volunteer staff (3)
Leeds Hackspace (England)	1. Director 2. Management committee 3. Volunteer staff 4. Member

Note: Additional data was collected from documents, websites and observations

Appendix 3: Examples of Makerspace Industrial Activity

Manufacturing industries (ISIC)	**Products**	**Makerspace/Industry collaborations**
22 – Textile mill products	Knitting and textile products Leather products	Berlin Fab Lab (https://fablab.berlin/en/) MakeSouthBend (Indiana, US) (https://www.makesouthbend.com/makerspace-features.html)
25 – Furniture and fixtures	Architectural products Props and theatre set design	Space10 (https://space10.io/) FIX Makerspace Barcelona Fab Lab (http://fablabbcn.org/) Building Bloqs London (http://www.buildingbloqs.com/blog)
26 - Computer, electronic products	PCB Fabrication Drones Privacy, Security and Connected Devices	Origin Base (Dubai, UAE) (https://www.originbase.com/pcb) Build Brighton (http://www.buildbrighton.com/) Sheffield Hackspace Leeds Hackspace DAI Makerlab (https://www.dai.com/our-work/solutions/dai-maker-lab) Machines Room (https://machinesroom.co.uk/) Foxconn Makerspace
29 – Motor vehicles	Automotive spare parts and components	TechShop (http://www.techshop.ws/)
32 – Stone, Clay, Glass, and Concrete Products	Pottery, Glassware, Stone products,	North Street Potters (http://www.northstreetpotters.com/)
34 – Fabricated metal products	Metal castings	Autodesk Pier 9 (https://www.autodesk.com/pier-9) FIX Makerspace
36 – Electronic and other electrical equipment and components	Robotics Sensors, Modules	DFRobots (https://www.dfrobot.com/) Tiree Tech Wave (http://tireetechwave.org/)
37 – Transportation Equipment	Bicycles, Motorcycle parts,	Chaihuo Makerspace (www.chaihuo.org) Staten Island Makerspace https://www.makerspace.nyc/copy-of-digital-fabrication
39 – Miscellaneous Manufacturing Industries	Toys, Jewellery	Gearbox (http://www.gearbox.co.ke/) Nanjing Makerspace (www.do-idea.org)