International Journal of Production Research

ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: https://www.tandfonline.com/loi/tprs20

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To cite this article: Letizia Mortara & Nicolas Gontran Parisot (2016) Through entrepreneurs’ eyes: the Fab-spaces constellation, International Journal of Production Research, 54:23, 7158-7180, DOI: 10.1080/00207543.2016.1198505

To link to this article: https://doi.org/10.1080/00207543.2016.1198505

Published online: 14 Jul 2016.

International Journal of Production Research, 2016
Vol. 54, No. 23, 7158–7180, http://dx.doi.org/10.1080/00207543.2016.1198505

Through entrepreneurs' eyes: the Fab-spaces constellation

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(*Received 15 October 2015; accepted 20 May 2016*)

Fabrication spaces (Fab-spaces) provide individuals with access to numerous manufacturing equipment (including additive manufacturing), to carry out different types of projects. Although scholars are starting to speculate about the importance of these new organisational forms and their potential for future distributed innovation and production ecologies, this phenomenon is still largely unexplored. Building on existing multidisciplinary research, this paper offers the first empirical analysis of existing fab-spaces as providers of knowledge and production competencies. Amongst all the possible perspectives to derive a framework, we choose that of fab-space users who have an entrepreneurial intention. After deriving an analytical framework to position fab-spaces in the current academic discourse, the paper develops a classification, which considers the competences available to entrepreneurs, via fab-spaces, in conjunction with how these competences are provided. The resulting map reveals the complementarities amongst the different fab-spaces. It also shows that the current portfolio of fab-spaces supports mainly the distribution of innovation across locations and social groups. Several types of fab-spaces are currently well placed to support the transition from innovation to manufacturing, but their geographical distribution and range of manufacturing capabilities are not yet enough to provide a fully distributed manufacturing model. This study has practical consequences for entrepreneurs, in the better identification of the appropriate fab-spaces for their needs, and for policy-makers, to help position the different types of fab-spaces as elements for national systems of innovation and production.

Keywords: FabLabs; TechShops; makerspaces; hakerspaces; fabrication spaces; makers; peer production; 3D printing; additive manufacturing; entrepreneurship; innovation; cluster analysis; business models classification

1. Introduction

Anderson (2012) anticipates a significant transformation in society leading to a 'third industrial revolution', based on accessible digital and manufacturing technologies throughout geographies and across society. This scenario is underpinned by significant advances in both computational/digital and manufacturing process technologies. This theme is only just starting to be discussed in many fields – including technology and innovation management (Petrick and Simpson 2013), sociology (Rigi 2013) operations management and engineering (Wittbrodt et al. 2013; Thiesse et al. 2015; Holmström et al. 2016) and geography (Gress and Kalafsky 2015) – all pointing towards an impending socio-technical transformation (Dekkers 2009; Holmström et al. 2016).

In fact, across disciplines, many scholars envision a radical economical and societal shift from the current patterns of production – based on economies of scale – towards a more personalised and inclusive manufacturing scenario – based on individuals' participation in both the design and the production of goods. This shift is often referred to as distributed manufacturing (DM), whereby geographically dispersed production processes and supply chains allow to manufacture products and services closer to the point of consumption (Holmström et al. 2016). However, many scholars have also pointed out how the democratisation of production technologies presents opportunities for individuals, at every strata of society, to become sources of innovation (Open or Distributed innovation) (e.g. Chesbrough 2003; De Jong and De Bruijn 2013; Piller, Weller, and Kleer 2015).

Even if the 'personal' manufacturing machines – such as home 3D printers – are rapidly improving (Gardan 2015), they do not yet allow for the production of multi-material and complex products (Guo and Leu 2013).

However, currently a very concrete opportunity to access the most advanced manufacturing technologies for ordinary people is represented by fabrication spaces (Fab-spaces) (Thiesse et al. 2015). 'Fab-spaces' encompass organisations which provide a suite of manufacturing tools and technologies openly accessible for use by the public. They are growing in number in many countries, taking a variety of forms and providing an assortment of different innovation/production

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environments which many consider to be a stepping stone to enable DM. As a result of this availability, new businesses are emerging which, relying on Fab-spaces as platforms for both innovation and production, deliver on the vision of a DM future. One example, is that of opendesk[1] which connects individuals interested in buying furniture with a community of designers and one of local individuals with 'makers' skills and access to manufacturing tools via Fab-spaces.

Hence, the emergence of Fab-spaces excites scholars across many disciplines and policy-makers alike, who project a stronger role of Fab-spaces for manufacturing and innovation ecosystems for future economies. Some authors pose an emphasis on their role as production elements of the ecosystem (Petrick and Simpson 2013), others focus on their potential to leverage individuals' creativity for the development of innovative products (Ratto and Ree 2012; Birtchnell and Urry 2013; Cautela, Pisano, and Pironti 2014). However, to date, little is known about this emerging phenomenon: it is not yet clear how Fab-spaces differ from each other and what is their individual role in the innovation–production ecosystem.

Building on the small multidisciplinary research available to date, as a first step towards this understanding, this paper maps the current Fab-spaces landscape and provides a detailed classification of these emerging organisations. To do so, we take a particular perspective for the development of the classification: that of those who use the Fab-spaces for launching their entrepreneurial ventures. By evaluating the Fab-spaces according to two logics (availability of complementary competences (Miotti and Sachwald 2003) and the way in which these competencies are offered (Landry et al. 2013)), we obtain, via cluster analysis, a classification of Fab-spaces seen through the eyes of entrepreneurs.

The benefits of our analysis are multiple and include:

- The provision to scholars of a framework of observation for these emerging organisations. As a result, it will be possible to position Fab-spaces more clearly in the innovation/production/ecosystem literatures.
- The provision of an initial snapshot of the landscape of Fab-spaces and their role to support open innovation and DM at the beginning of their evolution, which could be used as a reference point for future analyses.
- The provision of information useful to entrepreneurs who will be able to identify the appropriate Fab-space for their own circumstances.

Following, Section 2 highlights an analytical framework to position Fab-spaces in extant literature, drawing attention to the particular perspective of entrepreneurs. The methodology followed for the characterisation and classification of Fab-spaces is illustrated in Section 3 whilst the results of the cluster analysis are presented in Section 4, and Section 5 discusses the most significant observations, implications and the limitations of this research and outlines future work.

2. Fab-spaces: an analytical framework

Fab-spaces are a new and hence understudied phenomenon which requires attention to understand what is their role and potential contribution to innovation and manufacturing systems. This section establishes an analytical theoretically rooted framework to explore this phenomenon.

After a general description of Fab-spaces, we move on to describe the different dimensions relevant for their analysis and the development of a classification, with a reference to what has been highlighted so far by the literature (Figure 1(a) and (b)).

2.1 *Fab-spaces: what are they?*

With 'Fab-spaces', we encompass a number of organisations which provide a suite of fabrication technologies openly accessible for use by individuals and firms alike. Through Fab-spaces it is possible to access professional grade manufacturing technologies once only available to trade organisations, including additive manufacturing equipment; Laser cutting and CNC tools; wood and metalworking machinery and electrical/electronic components assembling tools. Fab-spaces are growing in number in many countries, taking a variety of forms and providing a range of innovation/production environments. Many Fab-spaces are physical places, the most famous of which are known as Makerspaces, Hackerspaces, FabLabs and TechShops; however, Fab-spaces include also those which provide access to digital manufacturing technologies remotely via Internet platforms such as Shapeways or i.materialise (Rayna and Striukova 2013).

2.2 *Production (manufacturing) or knowledge creation (innovation) providers?*

At one extreme, Fab-spaces are seen as providers of knowledge (and innovation), on the other as potential providers of production (manufacturing) resources. In fact, there is an anticipation that Fab-spaces might provide a route for becoming a node of the modern manufacturing supply chain of customisable goods, which will be produced on request, close to the point of demand, making economies progressively less dependent from large-scale production and logistics (Birtchnell and Urry 2013; Petrick and Simpson 2013). In this scenario, some authors see the Fab-spaces' potential to incubate a deeper socio-economical revolution, based on peer-production, which, in the long run, might subvert the capitalist paradigm as '[…] *each volunteer chooses the tasks s/he performs, the amount of time s/he devotes to the collective production, and the place and time of her productive activity.*' (Rigi 2013).

However, many scholars, following Leonard-Barton's perspective (1992), indicate that the most significant contribution of production environments relates to their knowledge-creation (and hence innovation) potential. Fab-spaces – seen as community-based learning laboratories – are places where the community is dedicated to 'knowledge creation, collection and control' during problem-solving, garnering and integration of knowledge, the challenging of the status quo and the creation of knowledge networks (Leonard-Barton 1992).

2.3 *Fab-spaces' business models (BMs)*

Those who first identified Fab-spaces as interesting phenomena, (e.g. Troxler and Schweikert 2010; Rayna and Striukova 2013; Cautela, Pisano, and Pironti 2014), point to the importance of appreciating BM for Fab-spaces as a suitable lens to understand how organisations position themselves in a competitive landscape (Teece 2010). The analysis of Fab-spaces should hence include not only what capabilities are available through Fab-spaces, but also how they are provided (Landry et al. 2013). BMs could be analysed in many ways (e.g. Osterwalder 2004; Baden-Fuller and Mangematin 2013; Hartmann et al. 2014). However, following the distinction between open and closed BMs (Vanhaverbeke and Chesbrough 2014), an important element could be represented by the level of reliance of the Fab-space on others' knowledge (e.g. the communities of participants to these environments) for their BM to deliver new value. In many cases, participants to Fab-spaces are not interested in profiting from taking part in Fab-space communities (Moilanen 2012), but join and contribute out of their personal satisfaction, as Fab-spaces grew out of the social and cultural heritage of open movements (Moilanen 2012; Moilanen and Vadén 2013). In this sense, some Fab-spaces fit within the emerging organisational paradigm of 'meta-organisations' (Gulati, Puranam, and Tushman 2012), comprising multiple legally autonomous entities that are not held together through the traditional forms of organisational administration and control such as formal contracts or pecuniary incentives. In fact, for many Fab-spaces, it is the members contributing their individual knowledge, based on a social contract of trust and relational power within these meta-organisations, which allows the knowledge and innovation creation (and for Fab-spaces also production) to occur between partners (Larson 1992).

2.4 *Perspectives in the evaluation of the roles played by Fab-spaces*

Different perspectives can be taken in the evaluation of Fab-spaces, providing a range of units of analysis. These are spanning, from societal-ecosystem perspective (macro) to that of individual firms (meso) and of individuals (micro). For instance, at the macro level, some authors point to the Fab-spaces' potential for social transformation, for instance as translators of scientific into technical knowledge. They see Fab-spaces as the social infrastructure which accelerates progress and makes science production accessible to society (e.g. Kera 2012). Others equate Fab-spaces to business incubation environments for makers-entrepreneurs (Mortara and Parisot, in press). Others see the contribution of Fab-spaces in manufacturing ecosystems and value chains (Gress and Kalafsky 2015) and, for some types of Fab-spaces, in their contribution to innovation as open-source hardware innovation communities (Raasch 2011).

For firms seeking to integrate their innovation processes with external knowledge (Chesbrough 2003), Fab-spaces may provide access to lead-users' knowledge (Von Hippel 2005; Piller and West 2014) as illustrated by the examples of Airbus[2] and Magneti Marelli.[3] Additionally, in some cases, Fab-spaces might be seen as providers of specialised manufacturing capabilities, for example, useful for the production of small numbers of niche products, such as spare parts (Liu et al. 2014; Pilkington, Frandsen, and Rehnberg 2016; Sasson and Johnson 2016).

However, the majority of examples of firms which so far interface with Fab-spaces to stimulate innovation or develop and produce their goods are that of individual entrepreneurs (makers-designers-entrepreneurs) who see in these facilities both an opportunity for accessing innovation and production capabilities (Bianchini and Maffei 2012; Aldrich 2014; Cautela, Pisano, and Pironti 2014; Thiesse et al. 2015; Mortara and Parisot, in press). Examples of individuals who have used Fab-spaces to start a business are growing (Dougherty et al. 2013; Mortara and Parisot, in press) with one of the most famous and successful examples being that of Makerbot Industries, a producer of low-end additive manufacturing equipment for hobbyists and home users, that grew out of a Fab-space, NYC Resistor.[4]

2.4.1 *From the perspective of entrepreneurs*

To develop a classification, it is important to define in first place its scope and domain (Noy and McGuiness 2001). Amongst the dimensions highlighted in the theoretical framework above, we choose:

- As the domain: the configuration of resources provided by Fab-spaces and the way they are made available (the Fab-spaces' BM)
- As the scope: the perspective of entrepreneurs.

This scope was chosen, not only because of the potential value that Fab-spaces could have in lowering barriers to entrepreneurship (Aldrich 2014), and consequently enhancing dynamism and competition, employment and social and political stability (Gorji and Rahimian 2011), but also because the entrepreneurs' evaluation of Fab-spaces combines an assessment on their provision of both knowledge (innovation) and production capabilities in one.

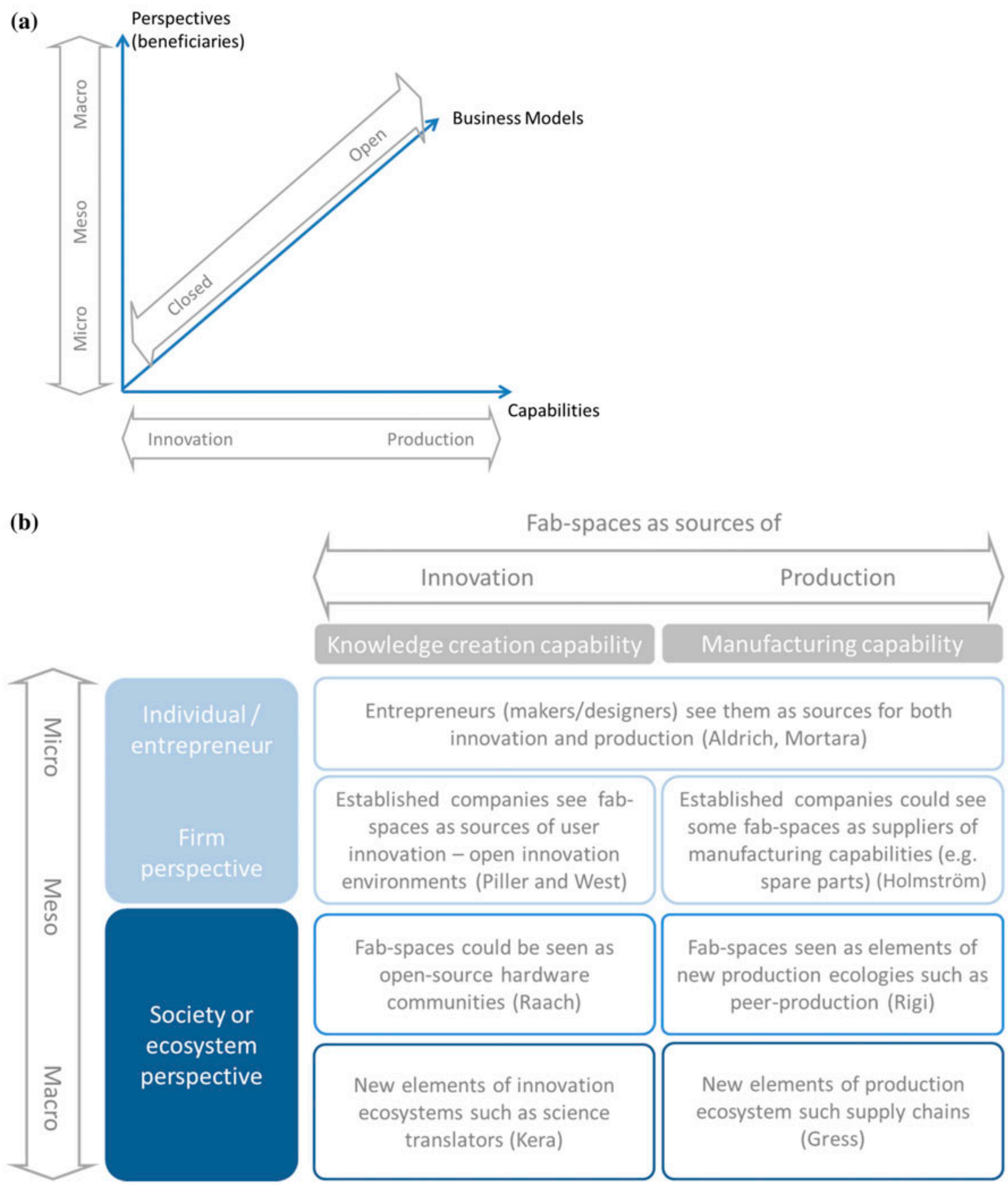

Figure 1. (a) Dimensions in the analysis of fab-spaces. (b) Detailed view of the capabilities/perspective dimensions.

There is not a clear agreement amongst the entrepreneurship scholars about a universal way to describe the entrepreneurship process. Bhave (1994) suggests that three steps lead entrepreneurs towards a venture creation: (1) opportunity recognition; (2) technology and firm set-up and (3) exchange (i.e. the commercialisation of a product). These stages are constituted by a number of other stages which concur iteratively to launching a new firm around a new product. A discussion on the entrepreneurial process is beyond the scope of this paper and, for pragmatic reasons, to include the innovation to production dimensions highlighted above, we adopt a simple view involving three stages merging the new product development with venture creation processes. The resulting process includes 'Ideation', 'Development' and 'Commercialisation and production' (see Table 1):

- Ideation: the individual finds an idea and understands its embedded commercial value (opportunity recognition [Shane 2000] and commitment to venture creation [Bhave 1994])
- Development: the individual develops his idea and a prototype to test its feasibility (idea development [Brem 2011] and production technology – product [Bhave 1994])
- Commercialisation and production: the individual launches the production, and reaches a market (exchange stage [Bhave 1994])

Beyond the competences required for product development, a number of other (primary and support) activities are needed to establish a firm which Brem consigns to parallel processes (2011).

Moving along this process, individuals go through a path of learning, adapting and abandoning routines (Aldrich and Yang 2014) for which they need competences that they often seek externally. Fab-spaces are well placed to provide many of these (Aldrich 2014; Mortara and Parisot, in press). The resource-based theory (Barney 2001) implies that Fab-

Table 1. The entrepreneurial process exemplified along three main stages with examples from literature (the literature listed is not meant to be exhaustive).

Name	Definition	Author(s)
	Stage 1 – Ideation	
The discovery of entrepreneurial opportunity	The entrepreneur 'recognises that the opportunity exists and has value'	Shane and Venkataraman (2000)
The research stage	Learning and discovery, whether internal to an organisation or externally in networks or with partners, focused on the generation and acquisition of knowledge and skills	Shipp, Stone et al. (2008)
Opportunity recognition	(1) sensing or perceiving market needs and/or underemployed resources, (2) recognising or discovering a 'fit' between particular market needs and specified resources, and (3) creating a new 'fit' between heretofore separate needs and resources in the form of a business concept	Ardichvili, Cardozo et al. (2003),Shane (2000)
Innovation	Get an idea, 'assess' its value	Brem (2011)
Idea generation	combining insights and knowledge from different parts of the same company in order to develop new products and businesses	Hansen and Birkinshaw (2007)
Ideation	Forming or relating of ideas by individuals or communities	Fox and Stucker (2009)
	Stage 2 – Development	
Opportunity evaluation	In the case of inventions, prospective new products or services, the first formal evaluation may involve a feasibility analysis, which addresses the question of whether the proposed combination of resources can, in fact, deliver specified value	Ardichvili, Cardozo et al. (2003)
Exploitation	'Shape' & 'Develop' the idea	Brem (2011)
Idea conversion	An idea 'still must be turned into revenue- generating products, services, and processes'	Hansen and Birkinshaw (2007)
Creation	Bringing something into existence through digitally-enabled design/ production	Fox and Stucker (2009)
	Stage 3 – Commercialisation	
Commercialisation	Commercialisation of the idea	Brem (2011)
Idea diffusion	spread the new products, businesses, and practices across desirable geographic locations, channels, and customer groups	Hansen and Birkinshaw (2007)
entrepreneurial action	creating new resources or combining existing resources in new ways to develop and commercialise new products, move into new markets and/or service new customers	Hitt, Ireland and Sexton. (2001)
Propagation	Multiplying by reproduction through digitally enabled networks	Fox and Stucker (2009)

spaces are chosen according to their potential to provide complementary resources (Miotti and Sachwald 2003) and that these resources represent their value proposition to entrepreneurs. On the other hand, the conditions under which competences are offered represent an important element of the choice of external services (Landry et al. 2013), and hence analysing Fab-spaces' full BM (not just the competences) is required.

3. Methodology

The methodology employed is presented in Figure 2. Firstly, we characterised 73 Fab-spaces' BMs along 65 dimensions based on Osterwalder and Pigneur's BM ontology (2004). Although criticised by some scholars for its complexity and non-inductive origin (e.g. Baden-Fuller and Mangematin 2013), this taxonomy provides a granular template for the detailed characterisation of Fab-spaces' BMs. Data for the characterisation were obtained via the webpages of Fab-spaces, reproducing the typical limitations of makers-entrepreneurs who, mostly, have access only to the information available on the web.

Secondly, to prioritise the most significant characteristics in the experience of the entrepreneurs and encompass the bias of entrepreneurs in the evaluation of the BMs, we used the results of 12 interviews with makers-entrepreneurs who managed to push their products and businesses forward thanks to Fab-spaces (Mortara and Parisot, in press). Finally, a hierarchical cluster analysis algorithm was used to develop a classification.

These phases are explained in details in the following sections.

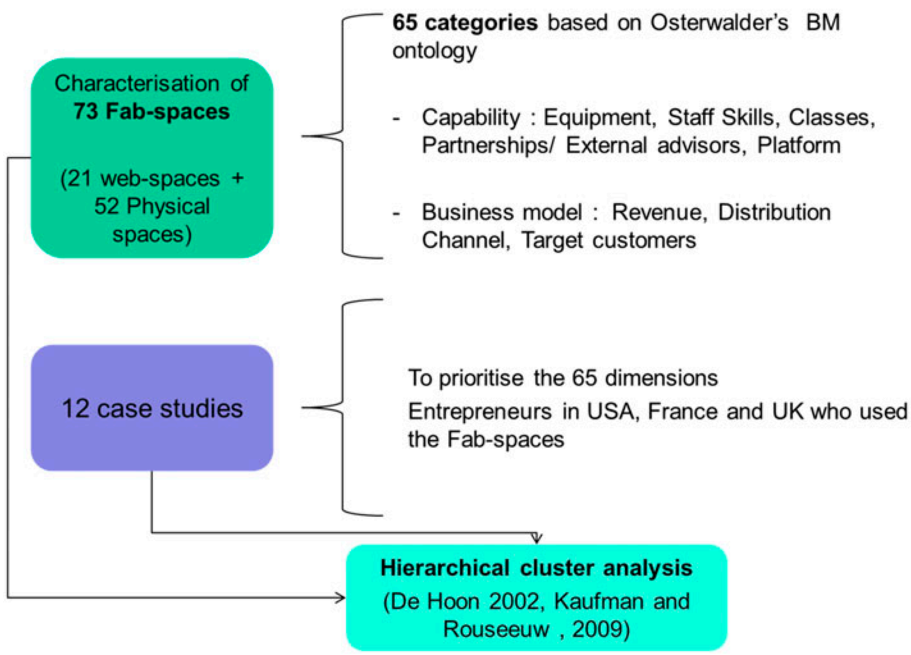

Figure 2. Overview of methodological process.

3.1 *Characterisation of Fab-spaces*

In the spring–summer 2013, 73 Fab-spaces (see Table 2) were identified through a review of websites, newsletters, research papers and two websites which list the majority of the physical Fab-spaces: http://hackerspaces.org/wiki/ and http://wiki.fablab.is. For inclusion in the analysis, Fab-spaces needed to be more than one year old, as it was assumed that these had more mature and hence more stable characteristics. Further, the information on the website had to be in English or could be translated with tools such as 'Google Translate'.

Overall, through a first inspection of the websites, a list of 65 variables and their codification, either binary (i.e. yes-no) or categorical (e.g. Low, Medium, High), was collated (see Table 3) and used for the codification of the information available on each website.

Table 2. Full list of fab-spaces characterised along the dimensions listed in Table 2.

	Organisation details	
#	Website	Organisation
1	www.3trpd.co.uk	3TRPD
2	www.3dfactoryusa.com	3D factory USA
3	http://www.3dprint-uk.co.uk/	3DPRINTUK
4	http://www.3dcreationlab.co.uk/	3D creation Lab
5	http://www.rpprototype.com	RP Proto
6	http://crdm.co.uk/	CRDM
7	http://www.rapman.hk	Rapman
8	http://www.sunpe.com/	Sunpe
9	http://www.star-prototype.com	Star Prototype
10	http://inspiring-visuals.com	Inspiring visual
11	http://www.prototypeprojects.com/	Prototype Projects
12	http://www.shapeways.com/	Shapeways
13	http://www.sculpteo.com	Sculpteo
14	http://www.kraftwurx.com/	Kraftwurx
15	http://i.materialise.com/	i.materialise
16	http://www.cubify.com	Cubify
17	https://www.ponoko.com/	Ponoko
18	www.100Kgarages.com	100KGarage
19	http://www.3dhubs.com/	3D Hubs
20	http://www.makexyz.com/	Make XYZ
21	http://www.redeyeondemand.com/	Red Eye
22	http://techshop.ws/austin_round_rock.html	TechShop Austin
23	http://www.artilect.fr/	Artilect FabLab Tulouse
24	http://www.techshop.ws/	TechShop Menlo Park
25	http://www.techshop.ws/	TechShop San Francisco
26	http://www.techshop.ws/	TechShop San Jose
27	http://www.techshop.ws/	TechShop Detroit
28	http://www.techshop.ws/	TechShop Pittsburgh
29	www.nextfabstudio.com	NextFab studio
30	http://thecrucible.org/	The Crudible
31	http://artisansasylum.com	Artisan's Asylum
32	http://www.adxportland.com/	ADX
33	http://www.fablabmanchester.org/	Fab Lab Manchester
34	http://fablab.waag.org	Fab Lab Amsterdam
35	http://www.fablabgroningen.nl/	CabFabLab (Fab Lab Den Haag)
36	http://cabfablab.nl	Fab Lab Barcelone
37	http://fablabbcn.org	Fab Lab Utrecht (Protospace)
38	http://www.protospace.nl	Fab Lab Leon
39	www.fablableon.org	Fab Lab Luxembourg
40	http://fablablux.org	Fab Lab Imal (Brussels)
41	http://www.imal.org/	Fab Lab Groningen
42	http://www.faclab.org	Fac Lab (University Cergy Pontoise)
43	http://www.labfab.fr	LabFab (Rennes - Ecole des beaux arts)
44	http://fablabo.net/wiki/Accueil#.C3.A9quipement	FabLab-O
45	http://atxhs.org/wiki/Main_Page	ATX hackerspace
46	http://www.hackpittsburgh.org/	Hack Pittsburgh
47	http://makerspace.ca/	Makerspace Victoria
48	http://acemonstertoys.org/	Ace Monster Toys
49	http://www.lansingmakersnetwork.org/	Lansing makers network
50	http://wiki.032.la/	The Null Space
51	http://sktechworks.ca/	Saskatoon Techwork
52	http://www.i3detroit.com	i3 Detroit
53	www.sector67.org	Sector 67
54	http://thebuildshop.org/	The build shop
55	https://noisebridge.net/	Noisebridge Hackerspace
56	http://www.xerocraft.org/	Xerocraft Tucson Hackerspace
57	http://wiki.london.hackspace.org.uk/view/London_Hackspace	London Hackspace

(*Continued*)

Table 2. (*Continued*)

#	Organisation details	
	Website	Organisation
58	http://shop.23b.org/	23b
59	http://edinburghhacklab.com	Edinburgh Hacklab
60	http://www.midsouthmakers.org/	Midsouth Makers
61	www.connecticuthackerspace.com	ConnectiCutHackersapce
62	http://ohmbase.org/	Ohm Base
63	http://wiki.hal9k.dk	HAL9K
64	http://sbhackerspace.com	SB Hackerspace
65	http://www.uwe.ac.uk/sca/research/cfpr/research/3D/bureau/	University of the West of England
66	http://fflib.org/creationlab	FFL Creation Lab (Fayetteville free library)
67	http://monroetwplibrary.org/studio_m	Studio M (Monroe Township library)
68	www.westportlibrary.org/services/maker-space	Westport Public library
69	http://www.lib.muohio.edu/computing/3d-printing	Miami University Libraries
70	http://clubworkshop.com	Club Workshop
71	http://mojavemakers.wordpress.com/	Mojave Makers
72	http://www.hacdc.org/	HACDC
73	http://www.maglaboratory.org/	Mag Laboratory

3.2 *Dimensions weighing*

In order to derive results specifically relevant to start-ups, interviews were conducted with 12 entrepreneurs in the USA and Europe who used Fab-spaces and were either in their late development or commercialisation stage of their venture. Focusing on the latest stages of the entrepreneurship process enabled a more reliable account of the realised benefits of attending Fab-spaces (see Mortara and Parisot, in press); however, this choice induced several biases (see limitations section below).

The interviews were conducted telephonically using a semi-structured questionnaire, and lasted approximately 1 hour. The interviewees were firstly asked to freely talk about their experience and the role that the Fab-space(s) played in their entrepreneurial process. Then specific queries regarding the three stages of entrepreneurship (ideation, development and commercialization) were prompted to gather more details about the progression of the ventures and the role the Fab-spaces played on each occasion (for data of these case studies see (Mortara and Parisot, in press). The aspects which emerged, impacting the entrepreneurs' choices of the Fab-spaces, were:

(1) Geographical accessibility: local physical spaces are more relevant to entrepreneurs at the beginning of their process than webspaces to develop their products.
(2) Access to a community of like-minded and skilled people.
(3) The quality of machines and software.
(4) The organisation: presence of staff and classes.
(5) Monetary considerations (cost aspects).

Accordingly, the interview data were converted following the rules described in Table 4, leaving blank the values not filled from the analysis of the websites. As illustrated in Table 4, each aspect in the list above was linked to the appropriate dimensions in Table 3, following a Manhattan metric. This means that the dimensions linked to the most important factor emerged from the interviews were multiplied by 10, the characteristics linked to the second were multiplied by 5, the third, by 3, the fourth by 2 and the fifth by 1 (i.e. all the characteristics not linked to the key aspects were considered as important as the 5th aspect in our prioritised list).

3.3 *Clustering methodology*

In the resulting table, each Fab-space was hence represented by a vector $X(x_1, \ldots, x_{65})$ (see Figure 3).

To develop a numerical classification with cluster analysis, it is necessary to (1) select the appropriate clustering method; (2) select the most appropriate linkage criterion and (3) the distance function to use (Milligan and Cooper 1987; Jain, Murty, and Flynn 1999). As this work aimed to develop a hierarchical classification – i.e. a classification where Fab-spaces are ordered hierarchically, considering their characteristics from the most relevant to the least important – a hierarchical cluster analysis algorithm was selected amongst other clustering methods. This choice was also due

Table 3. Full list of characterisation dimensions adopted.

		Dimensions					
		Code	Meaning	Scale			
Value proposition & Capabilities	Prototyping	Nr.	Number of machines	L ≤ 15 Machines	M = 15 to 30 Machines	H > 30 Machines	
		M	Metal machines	L = Low-end machines	M = Medium quality machines	H = High-end machines	
		W	Wood machines	L = Low-end machines	M = Medium quality machines	H = High-end machines	
		P	Plastic machines	L = Low-end machines	M = Medium quality machines	H = High-end machines	
		E	Electronics bench	Yes	No		
		3DP	3D Printers	No	L = Low-end machines	M = Medium quality machines	H = High-end machines
		DS	Design software	L = Low-end (consumer)	H = High-end (professional)		
	Office	O	Offices	Yes	No		
		WB	Workbenches	Yes	No		
		CR	Conference rooms	Yes	No		
		S	Storage	Yes	No		
	Access to information	LS	Library service	Yes	No		
		D	Database (publications)	Yes	No		
	Staff knowledge	DE	Design Engineering	Yes	No		
		M	Marketing	Yes	No		
		L	Legal	Yes	No		
		F	Financial	Yes	No		
		B	Business Management	Yes	No		
	Personal Consultancy	DE	Design Engineering	Yes	No		
		M	Marketing	Yes	No		
		L	Legal	Yes	No		
		F	Financial	Yes	No		
		B	Business Management	Yes	No		
	Classes	DE	Design Engineering	T = Tutorials (high level)	B = Basic	A = Advanced	
		M	Marketing	T = Tutorials (high level)	B = Basic	A = Advanced	
		L	Legal	T = Tutorials (high level)	B = Basic	A = Advanced	
		F	Financial	T = Tutorials (high level)	B = Basic	A = Advanced	
		B	Business Management	T = Tutorials (high level)	B = Basic	A = Advanced	
	Internal network composition	DN	Designer network	P = Physical (in person)	O = Online		
		FN	Fabbers network (people with home equipment)	P = in person	O = Online	N = No	

(*Continued*)

Table 3. (*Continued*)

	Dimensions					
	Code	Meaning	Scale			
	EN	Entrepreneurs network	P = in person	O = Online	N = No	
	MN	Machine network platform	P = in person	O = Online	N = No	
	DS	Design Sharing platform	Yes	No		
	SP	Selling platform	Yes	No		
Education	E	Educational events (children)	Yes	No		
Target Customers	K	Children (<18 years)	L=Local	NL= Not necessarily local		
	I	Individuals (privates)	L = Local	NL = Not necessarily local		
	S	Students	L = Local	NL = Not necessarily local		
	B	Businesses	L = Local	NL = Not necessarily local		
Distribution Channel	I	Internet	Yes	No		
	P	Post	Yes	No		
	W	Workshop facility	Yes	No		
Partnership External network access	DE	Design Engineers	Yes	No		
	M	Marketing specialists	Yes	No		
	L	Legal advisors	Yes	No		
	F	Financial advisors	Yes	No		
	I	Investors	Yes	No		
	B	Business Mangers	Yes	No		
	P	Production facilities	Yes	No		
Revenue stream	CPM	Customer has to pay membership	F: Free	L: 5–20 $ /month	M: 20–60 $/month	H:> 60$/month
	OM	Optional membership	Yes	No		
	CPH	Customer pays per hour	No	L: < 10$ / hour	M: 10–40$/h	H: > 40$/h
	CPQ	Customer pays per material quantity	No	L: < 1$/cm^3 for plastic a <5$/cm^3 for metal	H: > 1$/cm^3 for plastic and >5$/cm^3 for metal	
	Q	Ad hoc Quotations	Yes	No		
	C	Class Pricing	F: Free	L: < 10$ / hour	M: 10–30$/h	H: > 30$/h
	OR	Office Rentals	Yes	No		
	EP	Eternal Prototypes (Production of prototypes for external customers)	Yes	No		
	Co	Consultancy (Design)	Yes	No		
	PC	Personal consultancy (other type)	Yes	No		
	SR	Storage Rental	Yes	No		
	TC	Transactions cut	Yes	No		
	SpR	Space (Workshop) Rentals	Yes	No		
	Ef	External funding (donations, government, etc.)	Yes	No		
	OT	Open Time slots (anyone can use machine for free at certain times)	Yes	No		
	M	Machine sales	Yes	No		

Table 4. Prioritised dimensions, according to the results of the interviews. Weighting developed according to the Manhattan metric (10, 5, 3, 2, 1). All other dimensions remained as originally quantified.

# Aspect	Linked dimensions			Resulting values (including weighting multiplier)
Aspect 1: physical space	Distribution Channel	I	Internet	Yes = 10; No = 0
		P	Post	Yes = 10; No = 0
		W	Workshop	Yes = 10; No = 0
Aspect 2: communities	Networking	DN	Designer Network	P (Physical) = 10; O (Online) = 5 No network = 0
		FN	Fabber Network	P (Physical) = 10; O (Online) = 5 No network = 0
		EN	Entrepreneur Network	P (Physical) = 10; O (Online) = 5 No network = 0
		TN	Tool Network	P (Physical) = 10; O (Online) = 5 No network = 0
		DS	Design Sharing	Y = 5; No = 0
		SP	Selling Platform	Y = 5; No = 0
Aspect 3: quality of equipment	Prototyping	M	Metal	No capability = 0; L = 3; M = 6; H = 9
		W	Wood	No capability = 0; L = 3; M = 6; H = 9
		P	Plastic	No capability = 0; L = 3; M = 6; H = 9
		3DP	3D Printer	No capability = 0; L = 3; M = 6; H = 9
		DS	Design Software	No software = 0; L = 3; H = 9
Aspect 4: staff and classes	Staff	DE	Design and Engineering Skills	Yes = 2; No = 0
		M	Marketing Skills	Yes = 2; No = 0
		L	Legal Skills	Yes = 2; No = 0
		F	Financial Skills	Yes = 2; No = 0
		B	Business Skills	Yes = 2; No = 0
	Classes	DE	Design and Engineering Class	No Class = 0; T (Tutorials) = 1; B (Basic) = 3; A (Advanced) = 5
		M	Marketing Class	No Class = 0; T (Tutorials) = 1; B (Basic) = 3; A (Advanced) = 5
		L	Legal Class	No Class = 0; T (Tutorials) = 1; B (Basic) = 3; A (Advanced) = 5
		F	Financial Class	No Class = 0; T (Tutorials) = 1; B (Basic) = 3; A (Advanced) = 5
		B	Business Class	No Class = 0; T (Tutorials) = 1; B (Basic) = 3; A (Advanced) = 5
Aspect 5: Costs	Revenue stream (from customer)	CPM	Customer Pays Membership	No = 0; F = 1; L = 2; M = 3; H = 4
		CPH	Customer Pays per Hour	No = 0; F = 1; L = 2; M = 3; H = 4
		CPQ	Customer Pays per Material Quantity	No = 0; F = 1; L = 2; M = 3; H = 4
		C	Classes	No = 0; F = 1; L = 2; M = 3; H = 4

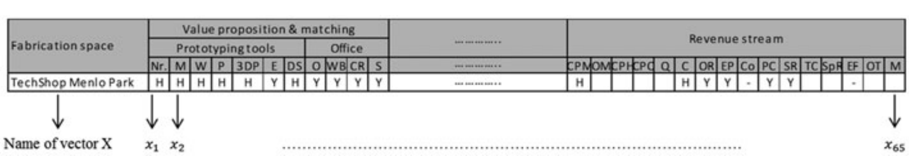

Figure 3. The Fab-space's BM vector.

to the nature of the data-set. In fact, the clustering method uses a measure of distance between pairs of observations in the sets, to judge the similarity/dissimilarity of data points as a function of the pairwise distances between the observations. As our data-set was derived from a number of qualitative observations – see Table 3 – we could not use the

Euclidean distance to evaluate the distance between points. This precluded the use of cluster analysis algorithms such as k-means and Self Organising Maps. The principal components analysis method was also excluded as this technique requires the variables to be continuous.

Instead, we used the Manhattan distance/city-block metric (Grabusts 2011) to evaluate the distance between the various points (Fab-spaces). This metric was appropriate as it identifies the distance between two points as the sum of the absolute differences of all their Cartesian coordinates (i.e. the characteristics of Fab-spaces).

Hence, the distance was calculated following Equation (1).

$$d(X,Y) = \sum_{i-1}^{n} |x_i - y_i| \tag{1}$$

where n = 65 (the number of dimensions characterising each Fab-space).

For our analysis, we employed the 'complete-link algorithm' because it is known to produce more compact clusters and it is less susceptible of outliers compared to single-link algorithms (Jain, Murty, and Flynn 1999) – i.e. the single-link algorithm would have been more likely to produce a small number of big clusters with many data points and a large number of clusters with a single data point.

For the analysis, we used the software Cluster 3.0 (De Hoon 2002; Kaufman and Rousseeuw 2009).The hierarchical divisive clustering was stopped at 28.

4. Results

We obtained 13 Fab-space clusters presented in the dendogram in Figure 4 and in Tables 5a and 5b, where information about the occurrence of each individual characteristic in the cluster is reported. For example, in Tables 5a and 5b, all the Fab-spaces in Cluster 7 target Local (L) Individuals, Students and Businesses. However, only 20% of them have a partnership with legal advisors. A description of the clusters is presented below.

4.1 *High-end machines, professionally run virtual Fab-spaces*

(1) High-end 3D printing services. Design and Engineering skilled staff. Mail prototypes to customers. Design services and consultancy services. Typically, expensive and quotations provided on request.
(2) Like cluster 1 and also offering other CNC prototyping machines.
(3) Like cluster 1 and also offering high-to-low-end 3D printing machines and low-end software (with online tutorials). Also they provide online platforms or sharing, selling and buying designs. The costing model is proportional to the quantity of prototypes printed or for each design sold/bought. A few of these Fab-spaces also sell 3D printers.
(4) Only Ponoko features in this cluster which has the same characteristics of cluster 3 but also offers laser-cutting services. Further, the designs sold/bought via Ponoko might contain electronics.

4.2 *Connected 'fabbers' network: variable quality machines, community run, virtual Fab-spaces*

(5) This cluster features web-based networks which connect individual owners of equipment to people who want to use machines. Prices are agreed independently on each job. Collaboration could be in person or online.

4.3 *High-end machines physical spaces*

(6) This cluster includes physical Fab-spaces which provide workshops equipped with numerous workbenches, high-end CNC and non-CNC machines and high-end software. The tools available allow obtaining high-quality products made of different types of metal, plastics and wood and which can feature also electronic parts. To learn how to use equipment and software, expensive advanced classes in design and engineering are available from professional staff. Some of these spaces also have staff or partners qualified to teach Marketing, Legislation, Business or Financial skills. In addition, staff can also provide personal consultancy in design and

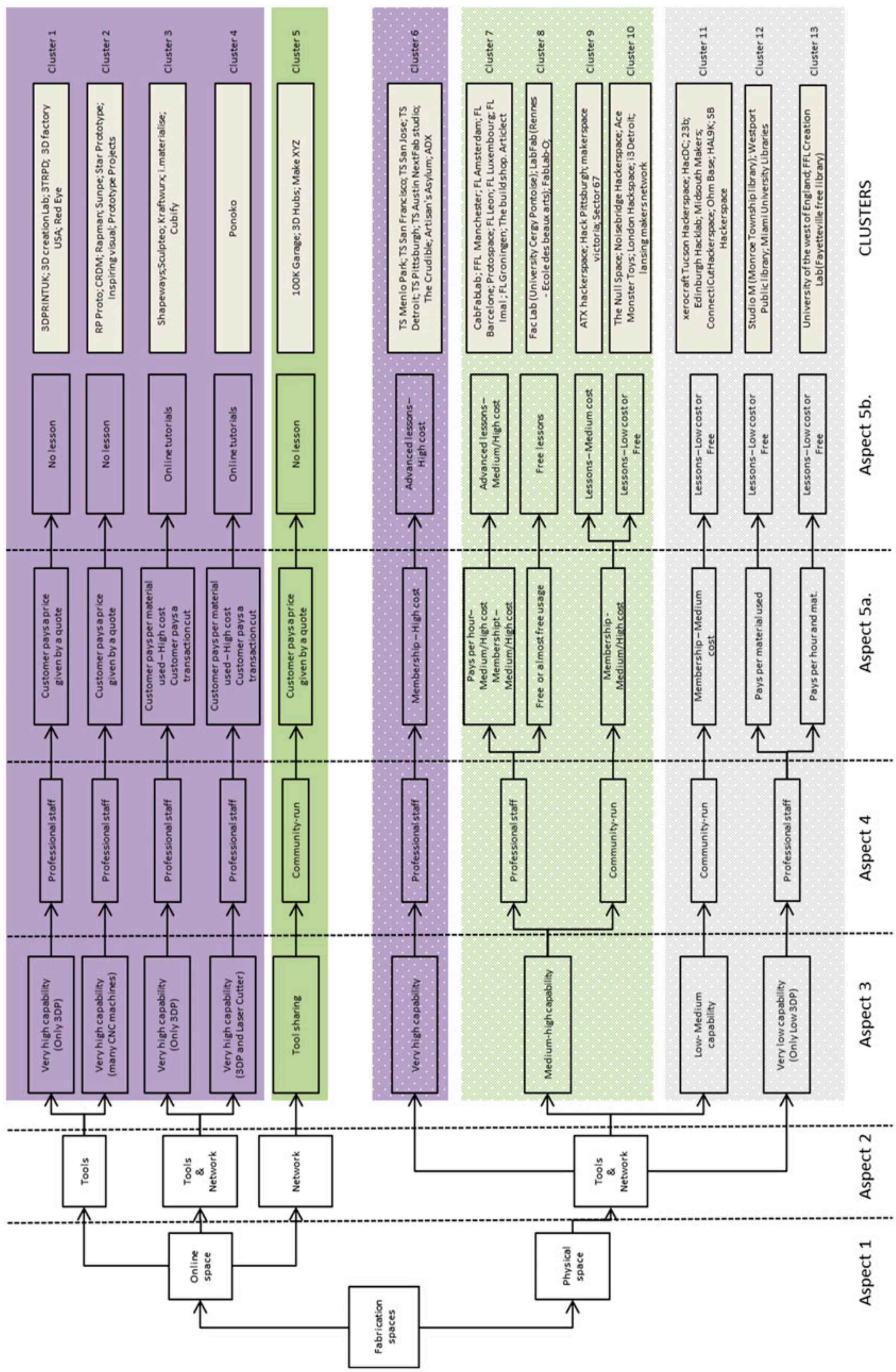

Figure 4. Dendogram.

Table 5a. Description of the characteristics of the "Value Proposition" of each Fab-space cluster. Refer to Table 3 for the keys. The values indicate the portion of the Fab-spaces in the group displaying them. Cells with no value indicate that 100% of Fab-spaces in the cluster have that characteristic. For the other characteristics of the clusters see table 5b.

Cluster	Value proposition (i.e. capabilities on offer)																																		
	Prototyping							Office				Access to info.		Staff knowledge					Personal Consultancy					Classes					Networking						Education
	Nr.	M	W	P	3DP	E	DS	O	WB	CR	S	LS	D	DE	M	L	F	B	DE	M	L	F	B	DE	M	L	F	B	DN	FN	EN	MN	DS	SP	E
Cluster 1	-				H									Y										T(0.4) N(0.6)											
Cluster 2	-	H		H	H									Y					Y(0.3) N(0.7)																
Cluster 3	H				H		L							Y										T					O				Y	Y	
Cluster 4	H		H		H	Y	L							Y										T					O				Y	Y	
Cluster 5																													O(0.3) N(0.7)	O	O(0.3) N(0.7)	O			
Cluster 6	H	H	H	H	H(0.8) L(0.1) -(0.1)	Y	H	Y	Y	Y(0.7) -(0.3)	Y			Y				Y(0.2) N(0.8)	Y	Y (0.2) N(0.8)			Y (0.2) N(0.8)	A					P	P	P	P			Y(0.1) N(0.9)
Cluster 7	L(0.9) M(0.1)	M	H	H	L	Y	H(0.9) -(0.1)		Y	Y(0.1)/ -(0.9)	-			Y	Y(0.1) N(0.9)				Y(0.6) N(0.2) -(0.2)					B(0.1) A(0.6) -(0.3)					P	P	P	P			Y(0.9) -(0.1)
Cluster 8	L	M	M(0.3) H(0.7)	H	L(0.7) N(0.3)	Y	L(0.3) -(0.7)		Y		-			Y										B(0.7) A(0.3)				B(0.3) N(0.7)	P	P	P	P			Y(0.7) N(0.3)
Cluster 9	M	M	H	H	L	Y	L(0.2) (0.8)		Y		Y(0.5) -(0.5)													B(0.5) A(0.5)					P	P	P	P			
Cluster 10	M(0.3) H(0.7)	M(0.8) H(0.2)	M(0.2) H(0.8)	H	L	Y	H(0.2) L(0.2) -(0.6)		Y		Y(0.4) -(0.6)													B					P	P	P	P			
Cluster 11	M(0.6) L(0.4)	M(0.6) L(0.4)	M	M	L(0.5) H(0.1) N(0.4)	Y	L(0.6) -(0.4)		Y		-													B					P	P	P	P			
Cluster 12	M	M	M	M	L	Y	-		Y		-													B					P	P	P	P			
Cluster 13	L				L	Y(0. 3)	L							Y										B					P	P	P	P			
Cluster 14	L				L(0.5) H(0.5)		L		Y(0.5) N(0.5)					Y										B					P	P	P	P			

Table 5b. Description of the business models characteristics of each Fab-space cluster (with the exception of the "Value proposition" – for these see table 5a). Refer to Table 3 for the keys. The values indicate the portion of the Fab-spaces in the group displaying the specific characteristics. Cells with no value indicate that 100% of Fab-spaces in the cluster have that characteristic.

Cluster	Target Customers				Distribution Channel			Value Configuration			Partnership/External advisors							Revenue stream															
	K	I	S	B	I	P	W	VC	VS	VN	DE	M	L	F	I	B	P	CPM	OM	CPH	CPQ	Q	C	OR	EP	Co	PC	SR	TC	SpR	EF	OT	M
Cluster 1		NL	NL	NL	Y	Y			Y													Y			Y	Y (0.6) N(0.4)							
Cluster 2		NL	NL	NL	Y	Y			Y													Y			Y	Y(0.7) N(0.3)	Y(0.3) N(0.7)						
Cluster 3		NL	NL	NL	Y	Y			Y	Y	Y					Y					H				Y				Y				Y(0.4) N(0.6)
Cluster 4		NL	NL	NL	Y	Y			Y	Y	Y					Y					H				Y				Y				
Cluster 5		NL	NL	NL	Y					Y												Y									Y		
Cluster 6	Y(0.1) N(0.9)	L	L	L			Y		Y				Y(0.1) N(0.9)	Y(0.5) -(0.5)	Y(0.5) -(0.5)			H					H	Y	Y	Y(0.3) N(0.7)	Y	Y			-		
Cluster 7	Y(0.9) -(0.1)	L	L	L			Y		Y				Y(0.2) N(0.8)	Y(0.1) N(0.9)		Y(0.1) N(0.9)		H(0.1) M(0.1) N(0.8)	L(0.1) N(0.9)	H(0.2) M(0.4) -(0.4)			H(0.2) M(0.2) I(0.1) -(0.5)		Y(0.8) N(0.2)	Y(0.8) N(0.2)	Y			Y(0.7) N(0.3)	Y	Y	
Cluster 8	Y(0.7) N(0.3)	L	L				Y		Y									L(0.2) F(0.8)					F								Y	Y	
Cluster 9		L	L				Y		Y									M(0.2) H(0.8)					M								Y	Y	
Cluster 10		L	L	L(0.2) N(0.8)			Y		Y									M(0.7) H(0.3)	Y(0.3) N(0.7)	M(0.2) N(0.8)			F(0.8) -(0.2)					Y(0.2) N(0.8)			Y	Y	
Cluster 11		L	L				Y		Y									M	Y(0.2) N(0.8)				F(0.5) L(0.3) -(0.2)								Y	Y	
Cluster 12		L	L				Y		Y									M					L								Y	Y	
Cluster 13		L	L				Y		Y												L		Y(0.3) N(0.7)								Y		
Cluster 14		L	L				Y		Y											L(0.5) M(0.5)	L									Y(0.5) N(0.5)	Y		

engineering. To get access, an expensive membership has to be paid. In addition, most of these spaces also provide offices and storage area that the individuals can rent per month, and conference rooms which can be booked for free. Finally, some of these spaces propose design and prototyping services to members and external businesses.

4.4 *Medium-quality machines physical fab-spaces*

(7) Like 6 but equipped with medium-to-high-end CNC and non-CNC machines and high-end software. The tools available allow obtaining high-quality products made of different types of plastics and wood but only medium quality for metal. A station to work on electronics is also provided. Prices of classes vary (low, medium or high) from Fab-space to Fab-space. The access to these fabrication spaces is usually free, but users need to pay per hour of use or per material quantity used (typically costs are medium or high). Moreover, these spaces propose one or two 'open-time slots' (usually evenings) per week during which individuals can come and use the space for free. Finally, most of these spaces also allow businesses to rent their whole workshop for a day (or part).

(8) This cluster consists of physical fabrication spaces which provide workshops equipped with several work-benches, a couple of medium- and high-end CNC and non-CNC machines and low-end software. The tools available allow machining high-quality products (for plastics and wood) but the results which can be achieved with metal are usually of medium quality. A station to work on electronics is also provided. Free and typically basic classes in design and engineering are taught by a professional staff. The access to these fabrication spaces and its machine is free or very low.

(9) This group represents community-run physical fabrication spaces which provide workshops equipped with several workbenches, several medium- and high-end CNC and non-CNC machines and low-end software. The tools available allow obtaining high-quality products in plastics and wood, but medium quality in metal. Basic to advanced classes in design and engineering are taught by other members or external contractors for a medium price. Expensive (medium or high price) memberships apply. In addition, most of these spaces also provide offices and storage areas that the individuals can monthly rent. Finally, these spaces propose one or two 'open-time slots' per week (usually in the evenings) when members can use the space for free.

(10) Like 9, this cluster is populated of community-run physical fabrication spaces with medium–high equipment and low-end software and could allow achieving similar quality artefacts. The only difference in this group is in the costs: the basic classes in design and engineering are taught by other members for free or at a very low cost. Membership has a medium cost and is sometimes optional. Moreover, some fabrication spaces charge individuals extra (usually per hour) to use specific machines. No rental space service is available.

4.5 *Community-run low-end machines physical Fab-spaces*

(11) Also cluster 11 consists of community-run physical fabrication spaces with medium-to-low-end CNC and non-CNC machines and low-end software. The tools available allow only medium-quality products in plastics and wood but low to medium quality in metal. Basic classes in design and engineering are taught by other members for free or almost free. Membership is typically medium cost, and sometime it is optional. Also here 'open-free-time slots' are available weekly.

(12) Cluster 12 consists of public or university libraries which provide access to low-end 3D printers and low-end design software. Whilst in other Fab-spaces this is the norm, only in some cases in this cluster a station to work on electronics is also provided. Free basic classes in design and engineering are taught by the library staff. Users pay a low price, proportional to the quantity of materials used.

(13) Cluster 13 consists also of public or university libraries which provide access to low- or high-end 3D printers and low-end design software. Here users pay a low or medium price, proportional to both the quantity of materials used and/or the duration of the equipment use.

Figure 5 shows the distribution of the Fab-spaces on the equipment quality-cost plane. This shows that, with the exception of home 3D printer networks (Cluster 5), in general physical Fab-spaces offer lower end equipment at a more modest cost.

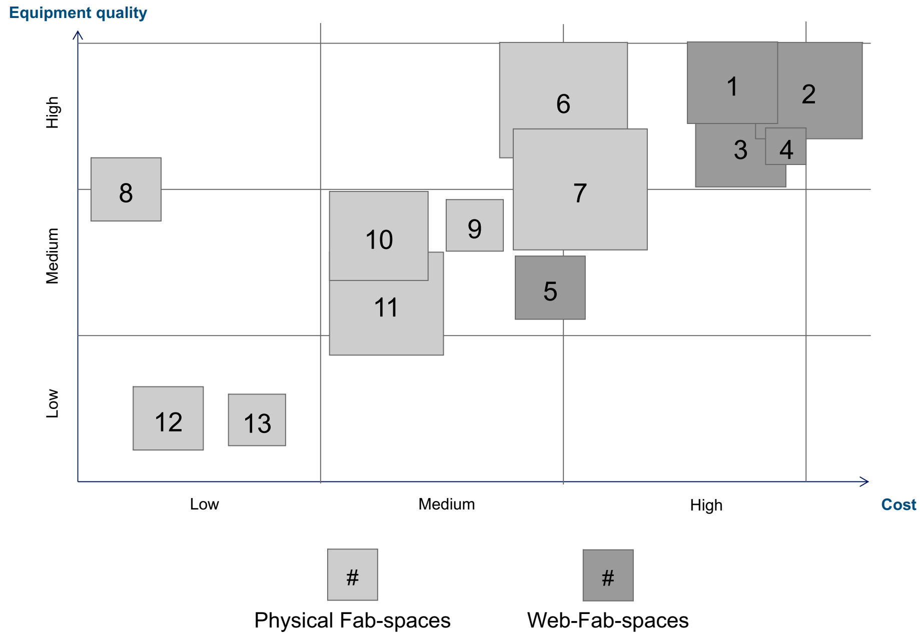

Figure 5. Approximate distribution of fab-spaces on cost vs. quality space.

5. Discussion & areas for future research

Fab-spaces are a recent development which represents an opportunity for research on many fronts. This paper reports an exploratory work done in 2013 to help researchers understand and position these new organisations via the development of a three-dimensional analytical framework and an empirically derived classification. Fab-spaces could be evaluated along three dimensions:

(1) As providers of competences for innovation (e.g. De Jong and De Bruijn 2013) or production (e.g. Petrick and Simpson 2013);
(2) According to their BMs. Along with other researchers who suggest that the resources provided need to be evaluated together with how they are delivered to the users (e.g. Landry et al. 2013; Colombo, Dell'Era, and Frattini 2014), we have analysed Fab-spaces provisions of capabilities including their costing and their degree of openness (Vanhaverbeke and Chesbrough 2014).
(3) At various levels of analysis (ecosystem/society; firm; individual level). Amongst other valid perspectives, Fab-spaces could be seen as an opportunity for understanding how they provide different types of resources to individual entrepreneurs. This perspective allows the evaluation of Fab-spaces both as innovation and production environments.

Case-study evidence indicates that entrepreneurs, who successfully have progressed towards the launch of their products with Fab-spaces support, have dynamically moved from one Fab-space to another to outsource the resources required to overcome the key entrepreneurial barriers (Mortara and Parisot, in press). Indeed, Fab-spaces provide different capabilities through different BMs which complement each other in an escalation of competence and quality of resources.

Figure 6 reports an estimated distribution of the clusters in respect of their potential to support the various stages of the entrepreneurship process. At the time of the research, scant evidence was found that Fab-spaces supported much of the ideation phase, even if this finding might be a by-product of the timing of the research (Mortara and Parisot, in press).

Figure 6 shows that in current Fab-space practice there is no single value proposition, however pre-dominantly Fab-spaces provide resources supporting the development stage and early production run (Mortara and Parisot, in press). The list of key aspects derived from the case studies indicates how important is the geographical dimension (the proximity) of the service provision and the real contacts with people, particularly at the early stages of the product development. Physical spaces have been shown to be more suitable for their entrepreneurs at the early stages of development, due to the high costs and long waiting time required with the majority of web-based Fab-spaces (Mortara and Parisot,

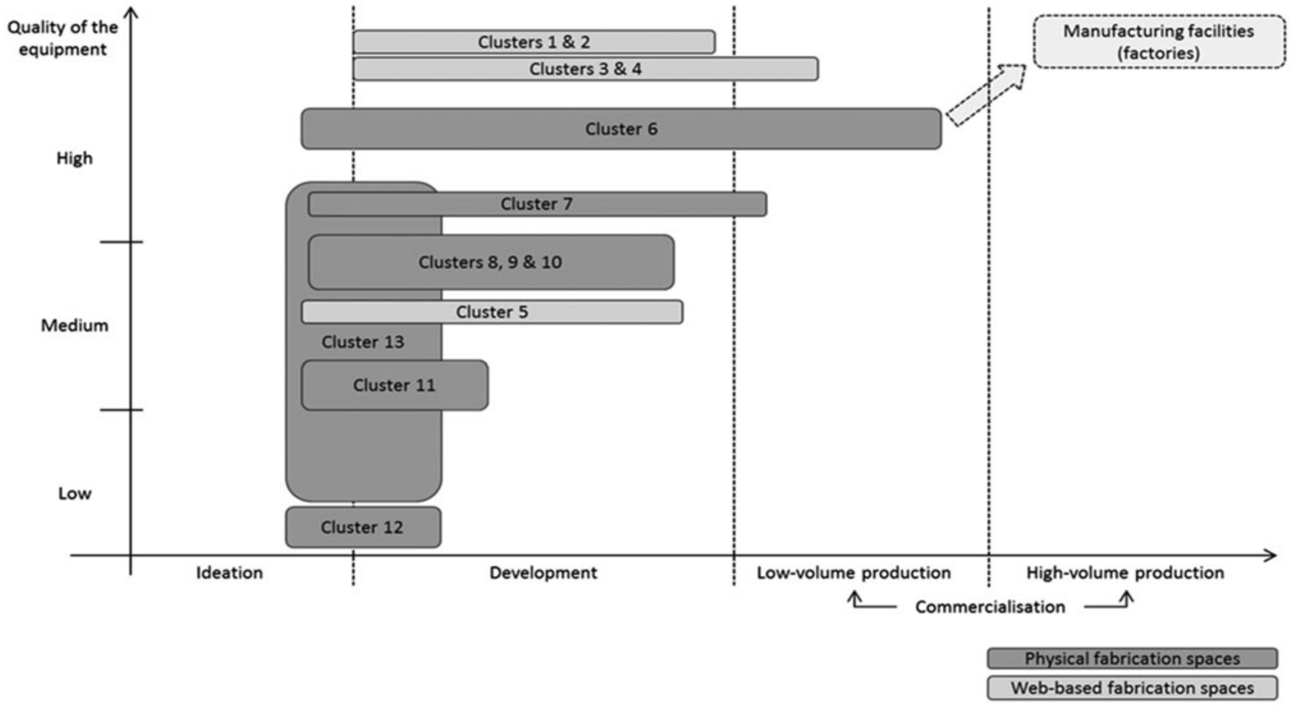

Figure 6. Approximate positioning of the Fab-space clusters along the innovation-entrepreneurship pipeline.

in press). Community-run physical Fab-spaces are in general less costly than the others, however anecdotal evidence indicates that they are also less well appointed and maintained (Mortara and Parisot, in press). A particularity is cluster 5, composed of networks of web-connected, home-based 3D printer owners through which users could find a local expert-machine. Whilst data regarding the real impact of these new forms of design/ manufacturing networks on industrial economies are not yet available, it can be observed that cluster 5's costing models and resources positioning might compete with some of the mid-range physical Fab-spaces (cluster 9) and hence could provide an opportunity for accessing competences for the entrepreneurs more distant from a physical Fab-space.

The physical- or web-based nature of the Fab-spaces' BM (i.e. the customer engagement channel [Baden-Fuller and Haefliger 2013]) seems to indicate differentiation on some of the other aspects of the BM (e.g. target customers, monetization and value chain) (Baden-Fuller and Haefliger 2013). The physical spaces dominate as examples of open BMs (Vanhaverbeke and Chesbrough 2014) for the breadth of expertise on which they base their offering. As shown in Tables 5a and 5b, clusters 6–13 rely on the knowledge of an extensive community of experts in different areas. Amongst the physical spaces only cluster 6 and 7, albeit marginally, include formal partnerships with external advisors. Of all the webspaces, only 30% of cluster 5 provides access to a comparable range of expertise via online channels. Also clusters 3 and 4, however, base their offering on an open (even if it is less broad) proposition as they foster online design networks and provide the platform for participants to share and sell designs and products. In addition, through external partnership they offer access to knowledge in design and business management. The least available knowledge type, across the entire set, relates to marketing business or finance, whist the most available is in design and engineering.

5.1 *Implications*

Beyond the value for entrepreneurs, in overcoming one of the key cognitive difficulties in selecting the appropriate business support for their needs, this analysis could have strong implications for policy-makers.

It is clear that at the beginning of the product development process, the key value proposition in the eyes of entrepreneurs is represented by the face-to-face contact with the knowledge providers inside the communities and the possibility of a fast iteration of their idea into prototypes (Mortara and Parisot, in press). It is a stage when entrepreneurs face problems s/he does not yet have the capability to frame and solve (problems with high level of ambiguity [Brusoni and Prencipe 2013]). For this, the direct contact with the knowledge source in a knowledge-rich environment such as physical Fab-spaces helps entrepreneurs quickly identify knowledge to progress their venture to the next steps (Larson 1992).

The possibility of a fast iteration between concepts and prototypes is another key aspect of the value proposition at the earliest stages of the venture development (Mortara and Parisot, in press). The prototypes, as key boundary objects, speak consistently across people with different expertise and background (Carlile 2002, 2004), making sure that entrepreneurs could pull together the expertise required for problem-framing and solving more efficiently (Cacciatori, Tamoschus, and Grabher 2012). As, for entrepreneurs at the beginning of the product development, proximity with the knowledge source is the most important aspect of the Fab-spaces, the 'local buzz' (Bathelt, Malmberg, and Maskell 2004) is more relevant than other types of knowledge channels. This evidence contradicts the idea that virtual knowledge channels could supplant direct knowledge exchange for the development of innovation (e.g. Mendikoa et al. 2008).

It is also clear that this direct exchange of knowledge has to be accompanied by a 'low investment' of personal resources of both money and time to reach the community. Although cost has been somewhat downplayed by interviewees, in accordance with prospect theory (Kahneman and Tversky 1979), the monetary investments for a membership for a more professional Fab-space service could be seen as too 'risky' when passing from the opportunity recognition stage to the commitment to the venture (Bhave 1994). More evident from the interviews was the risk represented by investing too much time either to travel to a remote Fab-space or to wait for the return of a prototype from an online service provider. Hence, it could be inferred that community-run physical Fab-spaces (Clusters 11/12/13) with an open BM respond well to the needs of entrepreneurs at the earliest development stage, when passing from the opportunity to the commitment to the venture stage (Bhave 1994) and could be considered fundamental elements of national systems of innovation which might create the conditions to lower the barriers and enable potential individuals to start along the path of entrepreneurship.

The kick-start advantage of low-end machinery Fab-spaces exhausts itself when the product idea is more stable and higher quality of prototypes is required. The problems to solve for entrepreneurs move downstream and relate to production and manufacturability issues (Bhave 1994). The higher reliability and technical variety of the machines available through Fab-spaces and professional help and training in their use becomes more important and entrepreneurs are ready to invest higher amounts to obtain more professional outcomes. The knowledge interaction remains an important aspect and hence physical spaces (clusters 6/7/8/9/10) provide viable options. Cluster 6 represents physical Fab-spaces with the highest quality of machinery and with professionally trained staff, as well as hosting communities who are willing to share their expertise. This cluster hence provides the broadest capability range, with the potential to support entrepreneurs from ideation and early product development through to the early production runs. This cluster includes TechShops, deliberately set up with entrepreneurs' needs in mind and are very positively described by entrepreneurs (Mortara and Parisot, in press). However, the accessibility and availability of such spaces is typically geographically limited to main cities even though some 'mobile' spaces are being piloted.[5] Distributed and networked manufacturing facilities and networks of fabbers (Cluster 5) could partly respond to the needs of entrepreneurs showing that hybrid physical–virtual knowledge networks could be potential substitutes (Song et al. 2007; Bathelt and Turi 2011). This could be an important finding for policy-makers in the development of national systems of innovation as fabbers' networks could be the nearest model to the physical-community Fab-space and could represent an important innovation element in regions with a disadvantaged geography. Virtual Fab-spaces in clusters 3/4 could also provide an alternative even if with lower performances.

For early production runs (rather than innovation issues), the community present at Fab-spaces often pointed entrepreneurs towards potential suppliers. However, entrepreneurs did not seem to be drawn to the idea of exploiting Fab-spaces for scaled up production purpose. The cultural drivers of the maker community, which some see to support peer-production (Rigi 2013), were brought forward as an obstacle to using Fab-spaces for large production runs. Even when technically possible, which is not always the case, the community needs access to the machinery and it is considered 'unfair' to occupy them for selfish purposes (Mortara and Parisot, in press). This issue might be reduced for web-Fab-spaces (clusters 1/2) or the type of Fab-spaces which are run as service providers more than as communities.

5.2 *Conclusions and limitations of the research*

By building upon existing multidisciplinary research, we analysed, from the perspective of entrepreneurs, the full complexity of the offering of Fab-spaces, shortly after the emergence of the 'sector', showing how the spaces are encouraging the distribution of innovation and manufacturing processes across society and geographies (Chen et al. 2015). This study also provides a starting point to understand how Fab-spaces evolve, and how this type of service industry is emerging and diversifying. Entrepreneurs were chosen, as they have a privileged viewpoint along the full process, from the innovation (ideation and development) to the production (manufacturing) of products. The analysis shows that whilst Fab-spaces currently facilitate the distribution of innovation across society (open innovation) and (partly) across geographies, they are still weaker in the provision of opportunities for distributed manufacturing.

For the innovation and development of products, Fab-spaces provide entrepreneurs with a range of capabilities. However, access to experts' knowledge and the possibility of fast iterations during product design and development are the most important (Mortara and Parisot, in press). For these needs, currently, the physical Fab-spaces (Clusters 6–13) were shown to be the most appropriate types of Fab-spaces, in that they provide access to local communities of skilled individuals and local facilities to develop innovative products. Most of these facilities are located in main cities, and their density is rapidly increasing. Cluster 5 – consisting of Fab-spaces platforms connecting entrepreneurs with the individual owners of equipment such as 3D printing – complements the capability offering, allowing even the most isolated potential innovators to identify local expertise and equipment, to develop innovative products and to start to conceive their manufacturability.

When accessing viable production routes for scaling up becomes relevant, the entrepreneurs' choice shifts to a more traditional manufacturing model: identifying remote manufacturing facilities which could ship back the final manufactured products or, more often, the components (Mortara and Parisot, in press). Fab-spaces resources accessible via virtual platforms (Clusters 1–4) are well positioned to supply on-demand small-to-medium batches of product components, but, as most products require further assembly, they are insufficient to guarantee a completely distributed production. Further, although many of these platforms rely on manufacturing equipment distributed worldwide, these are not yet spread uniformly and densely across geographies.

A similar model to Cluster 5 – i.e. platforms that connect independent high-grade manufacturing equipment owners with the public – could represent an opportunity for identifying a local manufacturing facility. However, even if this type of platform did not yet exist at the time of our data-capture, Cluster 5 includes 3D Hubs, who have just started connecting industrial quality 3D printer-owners (3D Hubs HD.[6]) This emerging type of Fab-space is expected to increase the opportunity for the establishment of a DM paradigm.

Another opportunity is that represented by Cluster 6 (physical Fab-spaces with high-end machines), which allows entrepreneurs to locally produce small batches of some components, and provides facilities where to assemble them into products. However, these facilities are typically used only transitorily, due to limited equipment availability/performance, conflicting demands on machinery and limited labour capacity (Mortara and Parisot, in press).

This work suffers from several limitations. Firstly, many Fab-spaces at the earliest stages of their set-up, or in emerging countries, were excluded from the classification (due to difficulties in their identification). Further, our analysis aimed to evaluate the typology of Fab-spaces rather than their prevalence (we are aware that the sample is biased towards certain types of Fab-spaces – such as TechShops or FabLabs, which follow approximately the same BM and provide similar competences. Hence, certainly there are redundancies in the sample, likely due to their longer history and growing popularity). Further, the perspective of the entrepreneurs was deduced from a limited number of entrepreneurs, who managed to reach the commercialisation stage of their ventures. This selection of case studies implies that this research has only reviewed the use and characteristics of Fab-spaces in the eyes of a very narrow group of current users (Moilanen and Vadén 2013). Future work should consider analysing the potential role of Fab-spaces, and their available models, for other types of users. Finally, it is important to remark that this work is exploratory, and depends on information gathered at a specific time. Hence, although the analytical framework is robust and rooted on a broad academic literature review, further work should be directed to validate, correct and expand the mapping of Fab-spaces.

Acknowledgements

A warm 'thank you!' goes to those who helped developing this paper. In particular, our colleagues Dr. Tim Minshall and Dr. Simon Ford for their support during the work, Prof. Howard Aldrich, Prof. Gianni Lorenzoni and the anonymous reviewers for the extremely helpful support and welcome suggestions on the manuscript.

Disclosure statement

The characterisation data for Fab-spaces is available at http://dx.doi.org/10.17863/CAM.56. Interview data in this paper have been anonymised to protect authors' confidentiality. Additional raw data related to this publication cannot be openly released; the raw data contain transcripts of interviews, but the interviewees did not consent to open data sharing.

Funding

This project has been carried out within the UK - EPSRC - ESRC-sponsored project "Bit-by-bit: Capturing value from the digital fabrication revolution" (EP/K039598/1).

Notes

1. https://www.opendesk.cc/
2. http://videos.airbus.com/video/94b511d91dcs.html
3. http://3dprintingindustry.com/2014/12/11/magneti-marelli-thefablab-3d-printed-dashboard-hackathon
4. http://makezine.com/2013/05/22/the-difference-between-hackerspaces-makerspaces-techshops-and-fablabs/
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6. https://www.3dhubs.com/hd

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