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Democratizing the adoption and use of advanced digital production technologies

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List of abbreviations

AI	artificial intelligence
BISU	Bohol Island State University
CAD	computer-aided design
CNC	computer numeric control
DIY	do it yourself
DTI	Department of Trade and Industry, Government of the Philippines
DOST	Department of Science and Technology, Government of the Philippines
FabLab	Fabrication Laboratory
FOSS	free and open source software
GIST	Global Innovation through Science and Technology
ICFOSS	International Center for Free Open Source Software
IoT	Internet of Things
IPR	intellectual property right
JICA	Japan International Cooperation Agency
KJSCE	K.J.Somaiya College of Engineering
MIT	Massachusetts Institute of Technology
MS	MakerSpaces
MSMEs	micro, small and medium enterprises
MSU-IIT	Mindanao State University-Iligan Institute of Technology
NGO	non-governmental organization
NPO	non-profit organization
PhP	Philippines pesos
R&D	research and development
SDGs	Sustainable Development Goals
STEM	science, technology engineering and mathematics
STEAM	science, technology, engineering, art and mathematics
Tech hub	technology hub
TVET	technical and vocational education and training
USAID	United States Agency for International Development

Table of Contents

List of Figures

List of Tables

Abstract

Industry 4.0 offers new opportunities for industrial development in emerging and developing countries, introducing new technologies, including Internet of Things (IoT), artificial intelligence (AI), 3D printing, among others. These technologies are expected to trigger societal transformations. While positive impacts on productivity and welfare are evident, some negative side effects are expected as well, namely an unbalanced distribution of benefits from technological development. In view of the United Nations' Sustainable Development Goals (UN SDGs), the overarching goal being to "leave no one behind," technological solutions should address specific local problems and be accessible to all.

This study addresses the critical issue of mitigating an unbalanced distribution of technological benefits by analysing MakerSpaces (MS) and its role in facilitating access to advanced digital technologies in developing countries. MS is a space created to share advanced digital equipment, such as 3D printing technology, among a community of users. It supports modern day "Do It Yourself (DIY)" activities that facilitate user-led innovations to solve individuals' daily problems by either creating or revising existing products to suit their needs. Furthermore, the use of digital technology enables the sharing of knowledge and innovation generated in MS, accelerating the diffusion of innovative solutions to many.

This study explores how MS can serve as a foundation for the adoption of capabilities necessary to use Industry 4.0 technologies in developing countries. After presenting MS and discussing its potential role in promoting new technologies from a conceptual perspective, the paper focusses on how MS exercises its role in developing countries based on existing cases. Finally, the paper reviews the challenges MS faces and concludes with a discussion on policy implications.

Keywords: MakerSpaces, FabLab, hackerspace, Industry 4.0, inclusive innovation, 3D printing technology, free innovation, user-led innovation

1 Introduction

Industry 4.0 offers new opportunities for industrial development in emerging and developing countries. New technologies associated with Industry 4.0—Internet of Things (IoT), artificial intelligence (AI), 3D printing, among others—are expected to trigger successive changes in institutions, leading to a dynamic socio-economic transformation. While positive impacts in terms of enhanced productivity and welfare are expected, there may be negative side effects, such as an uneven distribution of benefits from technological progress. In view of the United Nations Sustainable Development Goals (UN SDGs) that aim to "leave no one behind", inclusiveness under Industry 4.0 requires careful consideration.

MakerSpace (MS) is a common space (either cyber or physical) where individuals—either alone or collectively—can create or revise existing products to suit their needs, using advanced digital equipment as well as hard tools, by meeting, socializing and sharing ideas related to technology, science and arts (Anderson, 2013, Gershenfeld et al., 2017). MS has become popular since the mid-2000s against the backdrop of advanced digital equipment—such as 3D printers—spreading at decreasing costs. By making advanced digital equipment more accessible, user-innovators can enhance the equipment's ability to solve their daily problems using innovative solutions that are not provided by the public or the private sector. Moreover, as MS creates a communal space for "sharing" among a diverse set of actors beyond borders, it extends the reach of positive externalities. The positive impacts generated by MS boost the transformation of production activities towards a sustainable path under Industry 4.0.

MS plays a crucial role and can be a useful tool for governments to tackle the challenges associated with Industry 4.0, namely inclusivity and sustainable development.

First, as originally intended, MS offers solutions to daily problems at the local level and to societal challenges at the global level, including those the Sustainable Development Goals (SDGs) aim to address (Anderson, 2013; Gershenfeld et al., 2017). These may not always involve the core technologies of Industry 4.0; nevertheless, MS provides a space for the broader population, including individuals and micro, small and medium enterprises (MSMEs), to access advanced digital technologies for innovation and means to diffuse them among the community. By employing 3D printing technology, in particular, rapid prototyping and low-cost, small lot production for smaller producers is possible. This helps start-ups that are at an early stage to establish their business and increase their odds for survival (Anderson, 2013; Gershenfeld et al., 2017).

Secondly, MS provides an alternative approach to strengthening science, technology engineering and mathematics (STEM) education among the younger generation by heightening their awareness of these subjects, enhancing their capabilities and eventually preparing them for the job market under Industry 4.0 (Benjues-Small et al., 2017).

Third, MS creates a hub or community to nurture early stage entrepreneurs or start-ups by connecting them with key stakeholders, such as venture capitalists, accelerators and angel investors (Mulas, 2019; De Beer et al., 2017). MS can gather a critical mass of relevant actors and establish a community that stimulates the transformation of production activities.

To summarize, MS has the potential of serving as a new policy tool for promoting alternative production activities targeting smaller players, helping them meet their needs, supporting large segments of the population in acquiring the necessary capabilities and generating employment by stimulating entrepreneurial activities. MS fulfils the emerging policy needs of developing countries in the Industry 4.0 era, namely providing access to new technologies, building capacity to use these technologies, raising awareness of new technologies and promoting entrepreneurship to increase innovation and generate employment based on these new technologies. Current industrial policies do not fully embrace MS activities as possible policy tools to meet the challenges posed by Industry 4.0; however, the above observation suggests possible complementarities that merit further exploration.

This study examines MS and the potential role it can play under Industry 4.0. More specifically, it addresses the question how MS can serve as a foundation for the adoption of capabilities in developing countries required in the Industry 4.0 era. To determine the contributions of MS, this study first reviews the existing literature on the following topics: types of MS (FabLab, hackerspace, creative space, innovation/tech hub), the underlying concept of MS (long tail, user-led and free innovations), empirical studies on MS (surveys and case studies) and on 3D printing technology, one of the most representative technologies in the context of MS and developing countries. Second, a website search on ongoing MS activities of various types is conducted to understand the current coverage of MS and its role based on practical examples. This search uncovered various types of secondary information (blogs, web-based magazines and reports). Third, actual visits to MS or online interviews with managers of MS were carried out (Tokyo, Japan; Lima, Peru; Bohol, the Philippines, Kerala, India; Maastricht, the Netherlands; see Appendix 1). Interviews were conducted to verify and complement the secondary information (literature and websites) and to deepen the understanding of current challenges in a more practical setting. Despite the efforts undertaken to better understand MS by evaluating diverse sources of information, there are shortcomings when relying on information from secondary sources.

The following section describes the existing types of MS and discusses MS's functions in detail. In the next section, we focus on the conceptual underpinning of MS. It is complemented with existing cases to highlight the role of MS. Finally, the challenges and possible policy space for MS are discussed. Under Industry 4.0, the digital divide—the disparities between those who are able to take advantage of the new technologies and those who are not able to—is expected to intensify. Under such circumstances, an effective policy mechanism is urgently needed to facilitate a smooth transformation without "leaving anyone behind", and MS may contribute as a policy instrument if effectively implemented to support existing production activities.

2 What is MakerSpaces?

MakerSpaces (MS) is a space that supports collective do it yourself (DIY) activities using digital technologies under the Maker Movement that began around the mid-2000s in the United States (see Anderson, 2010; Eakin, 2013; Hatch, 2013; Maker Media, n.d.). The movement introduced changes to innovation, culture and education, diffused through media (e.g. Maker Media, a website) and Maker Fairs, where individual participants can present and share their work (Anderson, 2010). This movement initially emerged as communities of hobbyists creating and sharing knowledge in specific areas.

There are different variations of MS in the form of governance and financing models, and an emphasis on core activities, but all of them provide a common space with access to digital and hard tools and equipment for individuals to create or adapt existing products to suit their needs. Other common names associated with MS are FabLab, hackerspace, creative space and innovation/tech hubs, to name a few. The next section provides a brief description of more representative MS.

2.1 Different types of MakerSpaces

This study uses MS as a generic term to represent different types of common space. These include FabLab, hackerspace, tech/innovation hub and creative space, among others. Each has a slightly different focus and business model depending on historical origin. Since the mid-2000s, the number of MS has increased rapidly in both developed and developing countries. The following section briefly describes the existing types of MS.

a) FabLab

FabLab refers to Fabrication Laboratory. It is a small-scale workshop or space offering digital equipment and tools for individuals to fabricate "almost anything." Such labs were initially established by Massachusetts Institute of Technology (MIT) Professor Neil Gershenfeld at the Center for Bits and Atoms in MITs Media Lab in 2001, as a platform to create technical prototypes to stimulate innovation among local entrepreneurs (Gershenfeld et al., 2017). It is a platform for learning and innovation, "a place to play, to create, to learn, to mentor, to invent" (Gershenfeld et al., 2017). FabLab may be the only MS with a charter on the principles of their activities (see below) that all certified FabLabs must agree to.

In 2002, the first FabLab outside of MIT was established in India. In 2009, the FabLab foundation was created to expand the FabLab network even further. As stated in the mission statement, the FabLab foundation aims to provide better access to equipment, knowledge and finances by diffusing digital fabrication equipment and providing space for capacity-building so anyone can create (nearly) anything, and thus have the opportunity to improve their livelihood by solving their daily problems. The primary beneficiaries of the foundation are community organizations, educational institutions and non-profit organizations (FabLab foundation, 2019)[1].

A unique feature of FabLab is its open creative network of diverse professions and ages. All FabLab innovators are free to exchange innovations or collaborate in creating them. FabLab: 1) provides democratic access to tools for producing technological inventions; 2) establishes a manufacturing network; 3) contributes to the diffusion of technological campuses; and 4) to research laboratories on digital fabrication. The FabLab ultimately aims to become an experimental lab of the next generation of production activities, including personal fabrications (FabLab foundation, 2019)[2].

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[1] website: http://www.fabfoundation.org/index.php/about-fab-foundation/index.html (accessed March, 2019)
[2] website: http://www.fabfoundation.org/index.php/about-fab-foundation/index.html accessed March, 2019)

Box 1 The FabLab Charter

What is a FabLab?
FabLabs are a global network of local labs, enabling invention by providing access to tools for digital fabrication

What's in a FabLab?
FabLabs share an evolving inventory of core capabilities to make (almost) anything, allowing people and projects to be shared

What does the FabLab network provide?
Operational, educational, technical, financial, and logistical assistance beyond what's available within one lab

Who can use a FabLab?
FabLabs are available as a community resource, offering open access for individuals as well as scheduled access for programs

What are your responsibilities?
Safety: not hurting people or machines
Operations: assisting with cleaning, maintaining, and improving the lab
Knowledge: contributing to documentation and instruction

Who owns FabLab inventions?
Designs and processes developed in FabLabs can be protected and sold however an inventor chooses, but should remain available for individuals to use and learn from

How can businesses use a FabLab?
Commercial activities can be prototyped and incubated in a FabLab, but they must not conflict with other uses, they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs, and networks that contribute to their success
Source: http://www.fabfoundation.org/index.php/the-fab-charter/index.html accessed March, 2019

b) Hackerspace

Hackerspace is a community-operated, not-for-profit workspace, where individual with common interests, often in computers, machining, technology, science, digital art or electronic art, can meet, socialize and collaborate. It is comparable to FabLab; however, its origins go back to Berlin, Germany, in 1995, where a community of computer programmers worked and shared infrastructure to "hack" technology. Today, hackerspace activities are organized through fundraising from crowd funding like kick-starters. The use of "hack" later expanded to physical objects, naturally evolving into a physical space as was the case of FabLabs. This shift was facilitated by the declining price of maker tools, such as 3D printers, desktop laser cutters and computer numeric control (CNC) routers.

c) Creative space

Creative space boosts creativity, allowing people to connect and collaborate. This space does not only emphasize digital technology or digital tools. It can be an open space for artistic and cultural collaboration and exploration as well, which may lead to innovative outcomes.

d) Innovation/tech hubs

Innovation/tech hubs promote entrepreneurship, which differs from the previously mentioned concepts that focus on digital fabrication among communities of hobbyist. Innovation/tech hub is a physical space (city, suburb or office), but caters to technology start-ups by supporting a scale-up of their activities by providing access to digital technology to generate innovation.

These hubs aim to stimulate creativity within a community of diverse actors with an emphasis on openness. The hubs not only stimulate such communities to engage in innovation activities, but also to improve the condition of existing "tech communities" or "ecosystems" of innovation and entrepreneurship. Moreover, by way of creating such communities, hubs aim to generate positive social impacts in addition to economic development by being an interface for diverse actors not limited to entrepreneurs but including government representatives, investors, experts from the Global North, NGOs, training providers, artists and others (Friederici, 2019). MS usually play an integral part in innovation/tech hubs (as shown in Table 5) by providing low cost access to advanced digital equipment for rapid prototyping of products and tools, which are critical for start-ups that are suffering from a shortage of capital. Moreover, innovation/tech hubs assume a similar role as incubators, which essentially 1) help in establishing a business, 2) create networks, 3) support marketing, 4) help conduct market research, and 5) provide fast and reliable internet access[3].

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[3] Natalie Chirchietti (2017), "The role of Innovation Hubs taking start-ups from idea to business. The case of Nairobi, Kenya" IZNE Working Paper Series No. 17/7 https://pub.h-brs.de/frontdoor/deliver/index/docId/3362/file/N_Chirchietti_The_role_of_Innovation_Hubs.pdf

Innovation/tech hubs are booming in Africa. As of early 2018, 442 active tech hubs had been established in Africa alone (GSMA.com, 2019 accessed, March 2019). This number had increased by over 50 per cent since 2016, with tech hubs expanding most rapidly between 2016-18 in the Democratic Republic of Congo, Zambia (by 200 per cent), Côte d'Ivoire (160 per cent), Togo (150 per cent) and Nigeria (139 per cent). Cities with numerous tech hubs in Africa include Lagos, Nigeria with 31 tech hubs, Cape Town, South Africa with 26 hubs, Nairobi, Kenya with 25 hubs, Cairo, Egypt with 23 hubs and Accra, Ghana with 16. Of all the hubs present in Africa, almost half (47 per cent) also function as incubators and accelerators.

2.2 Function of MS

The common features of MS are the provision of a space for individuals to come together for creative purposes and to solve personal problems or challenging societal issues. The four types of MS mentioned above have a differentiated emphasis but share the following key functions: 1) promoting access to machines and equipment; 2) sharing knowledge among communities of innovators and creators or creating learning and capacity-building communities; 3) establishing communities to connect critical stakeholders in supporting and promoting entrepreneurship.

First, MS provides access to equipment and tools that are expensive for individual innovators, early stage entrepreneurs and micro, small and medium enterprises. MS are typically installed with tools and equipment needed for digital fabrication such as CNC; computer-controlled vinyl-cutters, also known as sign-cutters; CNC milling machines, woodworking routers, electronic components, microcontrollers and microcontroller software, low-cost microcomputers, PCs and/or laptops for programming and controlling other hardware via computer assisted design (CAD) software, 3D printers and other software packages (Anderson, 2013; Gershenfeld et al., 2017). The above equipment is generic and applicable to various areas of production. Such advanced digital equipment allows for rapid prototyping and low-cost, small lot production. This creates benefits, in particular, for smaller producers and early stage start-ups (Anderson, 2013; Gershenfeld et al., 2017). For start-ups, shortening the time to produce a viable prototype is critical for increasing the chances of survival. Having access to equipment without having to invest in purchasing it, accompanied by training on its usage from communities through peer-to-peer learning lowers the entry barriers for start-ups. Moreover, low-cost prototyping and small lot custom production business models may bring back manufacturing activities to the market (from small island states, for example), which are considered too small to have manufacturing facilities under the mass production paradigm (see Case 4 of FabLab Mindanao and Case 6 FabLab Bohol).

The application of new technologies changes the conventional fabrication process. For instance, the use of laser cutters in crafts amplifies an artist's skills by complementing designs that would be difficult to execute by hand. Enabling a user to fabricate customized furniture and design unique-shaped housing is made possible by the equipment made available by MS. These tools help replicate relatively high-tech products from their design concepts, anywhere in the world. For instance, a drone can be fabricated using FabLab equipment in Rwanda, Costa Rica and Barcelona, each executing different functions, as is the case with navigation systems for transportation or surveillance systems to combat pests (Gershenfeld et al., 2017). Another example is the creation of means of communication, such as internet terminals, in Afghanistan and South Africa, which have limited internet access (Gershenfeld et al., 2017). These examples demonstrate that providing the public with access to equipment within a shared knowledge community can impact their livelihood by enhancing their ability to learn and solve problems, which was previously not possible.

The second function associated with MS is capacity-building, education and learning. Access to MS evidently provides an opportunity for capacity-building. For instance, FabLab installs the same equipment globally, so that every member of the extended community of peer-to-peer learning can seek support in overcoming technical problems. Some MS also offer courses and workshops and organize events to exchange knowledge to help diffuse skills; some are shared on the internet (Anderson, 2013; Gershenfeld et al., 2017; De Beer et al., 2017; Kraemer-Mbula and Armstrong, 2017; EL Houssamy and Rizk, 2018).

The literature on MS in developed countries focusses on its effective use to enhance STEM education at schools. In fact, in the United States, MS are located in various libraries of schools at primary and secondary level. This was the result of policy implemented during the Obama administration (www.obamawhitehouse). These educational activities using MS are considered effective in preparing the younger generation for the new digital age. This trend is gradually spreading in developing countries (see Case 1, Case of Makers' Asylum).

For instance, Vigyan Ashram in India—the first FabLab established outside MIT—asserts that "craft should be the medium of education." FabLabs support "local problem solving" by applying knowledge from software and hardware as a form of education and capacity-building (Gershenfeld et al., 2017, Case 3). In developing countries, many MS are often located within higher education facilities, such as technical schools (TVET) and universities. At these facilities, MS can provide equipment and trainers, preparing students with hands-on experience using advanced digital equipment to increase their chances in the job market and of becoming entrepreneurs. Furthermore, MS often organize workshops on specific topics on technology and beyond, some even covering the management of business and intellectual property rights.

Third, MS can serve as a network hub for early stage entrepreneurs or start-ups to meet and connect with key stakeholders, venture capitalists, accelerators and angel investors (Mulas, 2019: De Beer et al., 2017). For instance, the FabLab in the State of Kerala in India is located next to the Kerala Start-up Mission, a state-run programme for start-ups (World Bank, 2016). In such a setting, FabLab can support the prototyping of start-up firms, as the location facilitates the free exchange of ideas, connecting with venture capitalists. iHub in Kenya is a similar model. These business-inclined hubs have access to mentorship, professional counselling and advise individuals and businesses. They also have exposure to a network of potential financial providers and support through grants and loans, or even opportunities to participate in acceleration activities, intensive mentorship with resource opportunities (capital, technology, hardware) to boost start-up business growth within limited periods. In such a context, MS becomes an integral support mechanism in creating innovation, capacity-building, new business and employment.

FabLab establishes a network of collaborators beyond national boundaries. Each FabLab must agree with the Fab Charter (see Box 1) and is a node in the collaboration network. The unique feature of this Charter is its emphasis on "sharing" knowledge and networks. Peer-to-peer learning and knowledge sharing are easier within this network, as each hub is equipped with the same equipment. Currently, there are about 2,000 FabLabs in 78 countries[4], although this number is increasing. These external linkages can become an important alternative knowledge source for developing countries. For instance, the FabLab in Kerala has been collaborating with the FabLab in Barcelona to develop a drone for geographical surveillance (interview, Feb 2019). The have also sought international support in learning practical surveillance using the networks (see Case 3 FabLab Kerala).

2.3 Spread of MS in developing countries

MS has spread rapidly in developed countries since the 2000s (Gershenfeld et al., 2017). However, the diffusion of MS in developing and emerging countries has been gradual. Today, MS is present throughout Asia, Latin America, the Middle East, North Africa and sub-Saharan Africa. It is difficult to determine the exact numbers, as there are many ways to count and classify diverse types of MS. Table 1 presents the regional distribution of FabLabs, hackerspaces and creative

[4] https://www.FabLabs.io/ [accessed March 2019].

spaces, as of April 2019 (based on website information). This demonstrates that most MS (over 80 per cent) are located in developed countries. It is worth mentioning that the United States alone hosts 16 per cent (1,015) of MS worldwide. In addition to the large gap in the number of MS between developed and developing countries, there are variations across countries in each region.

In Africa, the top three countries with MS are: 1) Egypt and South Africa (both 25), and 3) Morocco (22). In Asia and the Pacific, these countries are 1) India (120), 2) China (73), and 3) the Philippines (25). In the Middle East, these countries are 1) Israel and Saudi Arabia (15), and 3) Iran (10). In developing Europe, they are 1) Georgia (27), Turkey (23), and 3) Latvia (17). In Latin America and the Caribbean, the top three countries with MS are: 1) Brazil (178), 2) Mexico (68), and 3) Argentina (40). The general trend shows that countries with more manufacturing activities and higher levels of income tend to host more MS than other countries. Table 1 does not include innovation/ tech hubs which have expanded considerably in Africa (GSMA.com, 2019, accessed March 2019).

Table 1: Number of existing FabLabs, hackerspaces and creative spaces by region

	Developing countries					Total Developing	Developed countries	Total of the world	% of developing
	Africa	Asia and Pacific	Latin America and Caribbean	Middle East	Europe				
Fablab	81	172	196	50	62	561	2183	2744	20.4
Hackerspace	49	151	179	16	67	462	2445	2907	15.9
Creativespace	22	32	40	12	7	113	553	666	17.0
Total	152	355	415	78	136	1136	5181	6317	18.0

Source: www.FabLab.io; www.hackerspace.org, http://creativespaceexplorer.org/

Note: The data is based on web listings; the listed dates differ significantly between countries.

3 Conceptual background of the role of MS

In this section, the underlying concepts of MS are discussed. There are three slightly overlapping strands of literature. The first strand deals with innovators' (or users') behaviour in solving their problems (von Hippel, 2006) utilizing digital technology at MS (Anderson, 2013; von Hippel, 2016). The literature emphasizes MS's potential to amplify the ability of innovators to solve individual problems and share their solutions within the extended community based on a bottom-up approach. Studies that examined 3D printing technologies find that MS has the potential of making distributed customized manufacturing a viable business model (Berman, 2012; Ranya and Striukova, 2016). The second strand of literature focusses on capacity-building and learning, especially on STEM education and responding to the need to accelerate and catch up with accelerating technological change. The third strand reviews the establishment of networks of complementary stakeholders to scale up the impacts of MS. It examines how the business model offered at MS complements conventional production systems based on the long tail of demand (Anderson, 2007) and the Free Innovation Paradigm (von Hippel, 2016). The existing empirical literature and case studies (Mulas et al., 2015, Table 5) confirm MS's role in increasing innovation, its spillover effect (Halbinger, 2018) and in converting innovation into business creation, implying that MS is perceived as a builder of an innovation ecosystem (Adner, 2017; Jacobides et al., 2018; Gawer and Cusmano, 2013). The following section discusses these three strands of literature in detail.

3.1 User-led innovation and 3D printing technology

a) User-led innovation and the long tail of demand curve

Solving daily problems and addressing societal challenges are considered non-commercial activities. As mentioned, MS provides a physical space to exercise a modern day DIY to find solutions to personal problems for non-commercial, personal use. MS formalizes informal personal activities to fix problems within a defined physical space (city, province, office, etc.) where people meet and form a community of peer-to-peer learning using shared digital equipment (Anderson, 2013). These collective, personal and "creative" activities by users are considered "user-led innovation" or user-centred innovation (von Hippel, 2006). This concept, which differs from that of manufacturers' profit-seeking innovation, asserts that users develop what they want/need and share their innovations freely among the community members without much consideration of profit (von Hippel, 2006). User-led innovation shares similarities with grass root innovation (Gupta, 2013) where the disadvantaged, whose needs are not fulfilled by the market or public sector, initiate bottom-up innovation. The difference between original user-led and grassroots innovation and innovation within the scope of MS is the application of digital technology and the creation of a broader community. Digital technology, combined with MS, make it possible to share and diffuse knowledge across an extended geographical area, in addition to establishing a network of peer-to-peer learning and capacity-building mechanisms that enhance the ability to generate innovation.

A survey-based empirical study by Halbinger (2018) confirms the role MS plays in facilitating innovation and diffusion with quantitative evidence. The data used by innovators in MS are compared with those from existing comparable studies on user-led (household) innovation[5] (de Jong et al., 2015; von Hippel et al., 2011; von Hippel, 2016). The results indicate a higher rate of

[5] Here, household sector innovation is almost equal to user innovation. However, household innovation excludes entrepreneurial user innovators who want to become entrepreneurs. In other words, they are more similar to tinkerers who innovate in their backyards.

innovation (53 per cent compared to 1.5-6.0 per cent) and of diffusion (18 per cent compared to 2-6 per cent) for innovators at MS than those at household level (Halbinger, 2018) (see Tables 2 and 3). These results substantiate that MS, by providing access to digital equipment and a community of peer-to-peer learning, generates positive externalities resembling a *"sharing economy" business model*.

Table 2: Percentage of consumers innovating in the household sector and in MakerSpaces

	Innovation rate
Household sector*	1.50-6.10%
MakerSpaces	53.23%

**de Jong (2013); de Jong et al. (2015); Kim (2015); von Hippel et al. (2011, 2012).*

Source: Halbinger, 2018.

Table 3: Percentage of consumers diffusing and protecting innovation

	Diffusion rate overall	Commercial diffusion rate**	Protected with IPR
Household sector*	5.00-21.20%	2.00-6.00%	0.00-9.00%
MakerSpaces	n.a.	18.18%	3.70%

**de Jong (2013); de Jong et al. (2015); Kim (2015); von Hippel et al. (2011, 2012).*

***Commercial diffusion rates in national consumer innovation surveys only reported in Finland (6%) and the Republic of Korea (2%).*

Source: Halbinger (2018)

The samples used in this survey comprise 588 MS participants from developed countries, namely Europe, the United States, Canada, Australia and New Zealand (Halbinger, 2018). As developing countries have lower levels of institutional maturity in supporting access to technology, capacity-building and entrepreneurship promotion, it is possible to expect that the impact of MS on innovation and its diffusion would be higher in developing countries than that observed in this particular empirical study.

b) 3D printing manufacturing technology and MakerSpace

3D printing is a digital technology commonly used in MS. It employs "additive" manufacturing, whereby products are built by injecting material in layers. It is similar to a 2D inkjet printer; however, a 3D printer uses materials to construct the image in three dimensions aided by 3D digital design. "Additive" manufacturing is often compared with conventional, "subtractive" manufacturing, when an object is carved out of a block of raw materials, or to moulding/die-casting (Berman, 2012).

Since its emergence in the 1980s, 3D printing technology has successively improved in quality at reduced prices. The interaction of these two factors—quality and price—has influenced the levels of adoption[6] (Rayna and Striukova, 2016). Although it is generally assumed that the broad diffusion of 3D printers may disrupt the conventional manufacturing process (Garret, 2015), recent case studies indicate that such disruptive impacts may vary by: 1) the level of adoption (Berman, 2012); 2) how the industry responds to new competitive advantage generated by 3D printing technology (Rayna and Striukova, 2016), and 3) the type of ecosystem the firm or industry is embedded in (Rayna and Striukova, 2016; Sandstrom, 2016; Bogers et al., 2016). Improving the quality and decreasing the cost of 3D printing has helped popularize MS, which

6 These levels of adoption are identified as rapid prototyping, rapid tooling, direct manufacturing and home fabrication (Rayna and Striukova, 2016).

shortens the time and lowers the costs for prototyping products and production tools[7] for smaller producers and individual entrepreneurs (Berman, 2012; Rayna and Striukova, 2016). Further reductions in the cost and improvements in the quality of 3D printing technology will open an opportunity for greater transformation in production methods through the adoption of a distributed manufacturing business model (Rayna and Striukova, 2016; Berman, 2012; Bogers, et al., 2016). For this stage of application to materialize, however, accompanying production networks are necessary—such as computer aided software (CAD), designers sharing design concepts, shared platforms—that are crucial in forming a type of ecosystem (Adner, 2006). This aspect of expanding the production network's platform is explored in section 3-3.

Anderson (2007) describes the transformative production process with the introduction of digital technology (such as 3D printing technology) as a "long tail of demand curve". According to Anderson, first, digital technology allows producing (printing) a variety of products at a constant unit cost. This unit cost of production decreases with the reduction in the price of 3D printers as well as the increase in access through MS. Second, by sharing the design in a platform or network created at MS, the externality of knowledge can be fully utilized. Third, by digitally printing products on-demand, the risk and cost of inventory can be reduced. Fourth, the creation and modification of designs can be done at a lower cost and within a shorter time span. Fifth, by not having to mass produce at one location, production sites can be set up close to consumers, thereby reducing the environmental impact.

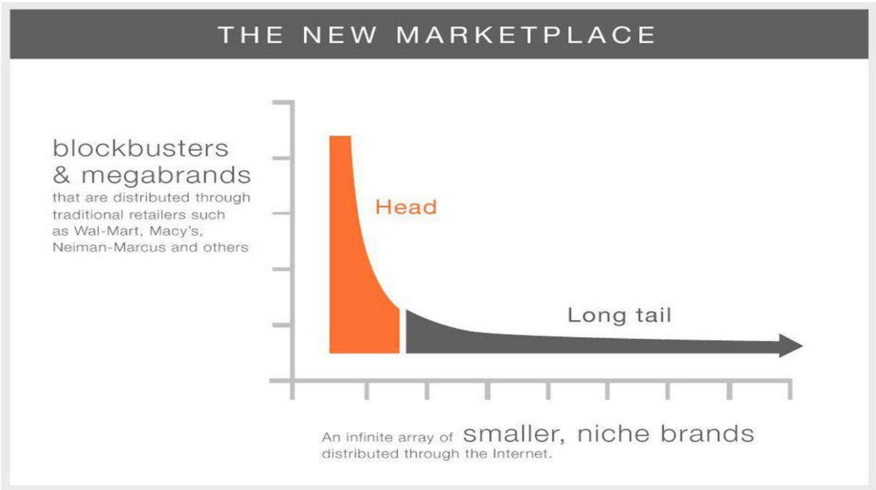
This new production rationale enables firms to respond to the currently unmet demand for niche (tailor made) goods that are crucial in solving societal problems, but are not yet economically feasible under the current economic paradigm. Typically, these represent small lot products such

7 Earlier, these tools required moulding and die-casting and were associated with higher costs and qualified human resources.

as dental/medical products (e.g. dental crowns, bone replacements, prostheses), replacement parts for machines, products that do not yet meet the mass production threshold ("bridge manufacturing") and the production of tools used for manufacturing (e.g. mould, specialized tools etc.) (Berman, 2012).

By making customized (tailor made) production equally cost effective along "the long tail of demand curve", the model complements the conventional model based on "economies of scale" (see Figure 1).

Figure 1: Long trail of niche products vs. hit products



Source: Based on Anderson (2007). Figure is from https://www.forbes.com/sites/robinlewis/2016/05/31/the-long-tail-theory-can-be-reality-for-traditional-megabrands/#1047e25f6372

Anderson (2007, 2013) views this emerging production system as *complementary* to the "conventional" production system, not a replacement of it (see Figure 1). In this approach, user-led innovation aided by 3D printer manufacturing via MS are considered an expansion of production styles suitable for smaller producers that cater more to consumers, and co-existing producers who manufacture conventional products in the mass production paradigm of large corporations.

This implies that MS, in combination with digital technology, enables the generation of different types of externalities, namely increasing people's well-being by fulfilling unmet needs (e.g. low cost prostheses), reducing waiting times and decreasing environmental degradation by reducing transport of products and enhancing the potential for mass customization and strengthening the distributed production business model.

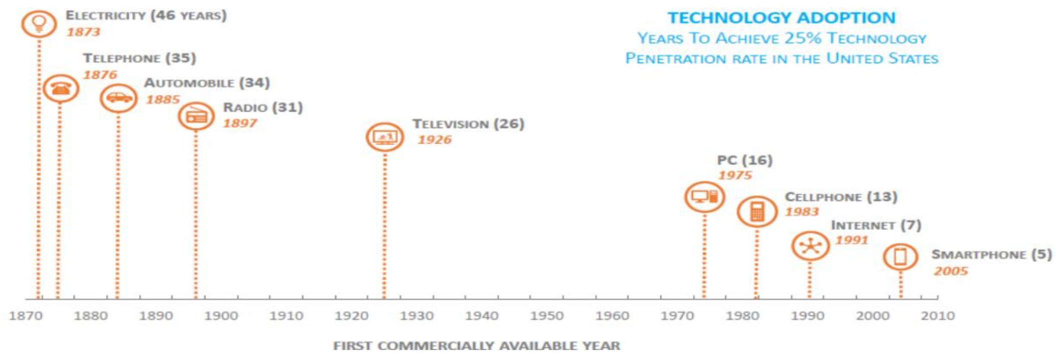
c) MS and 3D printing technology for solving daily problems and transforming manufacturing

The literature suggests the following: 1) MS offers solutions to daily problems following the logic of user-led innovation, whereby the user him-/herself solves problems using advanced digital tools; 2) Using 3D printing technology in MS enables the production of prototypes and lowers the cost of production of tailor made products (Gershenfeld et al., 2017); 3) Digital connectivity transforms the manufacturing process by expanding the community of users sharing knowledge beyond borders, including smaller producers (Gershenfeld et al., 2017). Thus, the combination of MS and digital technology has the potential of transforming industry to take an alternative trajectory. At the same time, for such a trajectory to take shape, a network of user communities beyond borders needs to be established, which share designs, production facilities and know-how (Berman, 2012).

3.2 Enhancing learning activities, complementing STEM education, preparation for employment

For Industry 4.0, digital literacy is increasingly becoming a *sine qua non* for anyone who want to fully capitalize from frontier technology. Various literature mentions that the speed of technological progress is increasing (e.g. Moore's law); however, the rate of adoption of new technology is even faster (see Figure 3). For instance, in the United States, it took electricity and the telephone 46 and 35 years, respectively, to achieve a penetration rate of 25 per cent of the entire population in the 19th century, whereas the internet and smartphones took only 7 and 5 years, respectively, to achieve a penetration rate of 25 per cent in the 1990s and 2000s. This indicates that learning and building capabilities do not only need to be accelerated, but a change in approach needs to also be introduced.

Figure 2: The pace of technology adoption is accelerating: from 46 years to 5 years and speeding up…



Source: Adapted from Singularity University, Comin, D and Mestiere, M. and Asymco data.

Institutions such as MS provide for a physical space to experiment with new technologies for digital fabrication for the public, in particular, the youth. Furthermore, MS enables the establishment of peer-to-peer communities that can provide external sources of knowledge, thus facilitating learning by providing access to technology to solve daily problems. For instance, in rural India, FabLab provides a wide variety of skills for solving problems and learning through the design process, even for those who dropped out from formal education (see Case 3 on Vigyan Ashram). The case study demonstrates that after exposure to learning by fabricating products at FabLab, some youth returned to their villages and designed a hydroponic watering system, adapting the knowledge they had acquired to their local context. Others purchased laser cutters and set up a local service business, motivated to become entrepreneurs, while some set up their own FabLabs (Gershenfeld et al., 2017). In other words, MS can empower local communities through capacity-building by exposing potential users, especially youth, to new technologies, external ideas and access to wider external networks.

Developed countries view MS as a potential space for enhancing STEM capabilities among youth to better prepare them for the new digital era. For instance, the FabLab network in the United States launched research in collaboration with Stanford University to evaluate teaching instruments to enhance the effectiveness of STEM education[8]. The underlying concept of the research was that an individual learns most effectively when using tangible objects in the real world. Hence, the idea of FabLab, namely to connect the digital with the physical world—"atoms into bits and bits into atoms" as described by Gershenfeld et al. (2017)—is well in line with improving learning efficiency. Moreover, the research concludes that knowledge sharing is a crucial component of learning. This corresponds with the FabLab Charter mentioned earlier. Interest in the educational aspect of MS is also evident in the EU, where STEM education is included in the Horizon 2020, a 5-year development plan. Newton FabLab, an educational programme in the EU, aims to evaluate the impact of using digital fabrication as a support tool to raise students' interest in STEM (Potstada et al., 2018; Togu et al., 2018). A similar experimental policy is also being implemented in Russia to boost interest in STEM education among the population aged 15 years and younger (Rayna and Struikova, 2019).

There are fewer examples in developing countries of MS use as a tool to promote STEM education among youth. However, this does not mean that the notion of using MS for educational purposes is absent (see Case 1 on Maker's Asylum). Existing cases seem to suggest that MS is viewed as an opportunity to acquire technical training in the use of digital equipment to rapidly produce prototypes at technical schools and universities (De Beer et al., 2017; Kraemer-Mbula and Armstrong, 2017; ElHoussamy and Rizk, 2018). In other words, the aim of MS in education is more closely associated with employment and technical education. Information collected in Africa; for instance, demonstrates that many MS are located within universities (Kraemer-Mbula

[8] See https://www.FabLabconnect.com/stem-school-FabLab/

and Armstrong, 2017). This may be an indication that MS provides unique opportunities of entrepreneurial learning.

3.3 Enhancing business opportunities by establishing a network of communities

a) Complementary model to the conventional business model

MS strengthens the network community beyond borders. This allows for a broader social impact by transforming a creative activity at the individual and household level to a larger scale. This is possible due to the sharing of equipment, knowledge and know-how through the extended community network created via an MS. This community of knowledge sharing is strengthened by the extended network and by the eco-system the MS is embedded in.

In fact, several of the concepts described in section 3.1 emphasize the complementary characteristics of manufacturing activities that are emerging from MS based on a conventional production paradigm. Anderson (2017) considers that the "long tail of demand" generated by the application of 3D printing allows for a diversity of goods and services, creating a space for smaller producers to meet the needs of users that are unmet by creating small lot customized goods. This would not replace the existing model of mass production but rather complement it. Similarly, von Hippel (2006, 2016) emphasizes the complementarity of user-led-innovation to conventional producer (firm) -led innovation due to the lack of scalability of the former.

This complementarity is discussed in depth by von Hippel (2016) in his "Free (of cost) innovation", which is an evolved version of user-led and household innovation. He defines "free innovation" as innovation without the intention of gaining any profit and differs from conventional ones as shown in Table 4 (von Hippel, 2016). Moreover, free innovation picks up the untapped needs of potential users/consumers at the early stage. This is possible because these innovations are made by users who do not hesitate to implement them for their own personal use.

Free innovation is limited in its capacity to scale up and diffuse because innovators (users) are only interested in their own needs and are not generally driven by commercialization of the innovation to generate a greater impact. Here, the innovation of conventional producers can play a role. Producers, who invest to make a profit, can scale up potential innovation seed if this meets market demand. Naturally, producers are slower in picking up potential innovation seeds because they try to monitor and evaluate market demand before engaging in production at a massive scale. Hence, these two can be complementary and beneficial when they collaborate, especially in the design and scaling up phase (Fig 3).

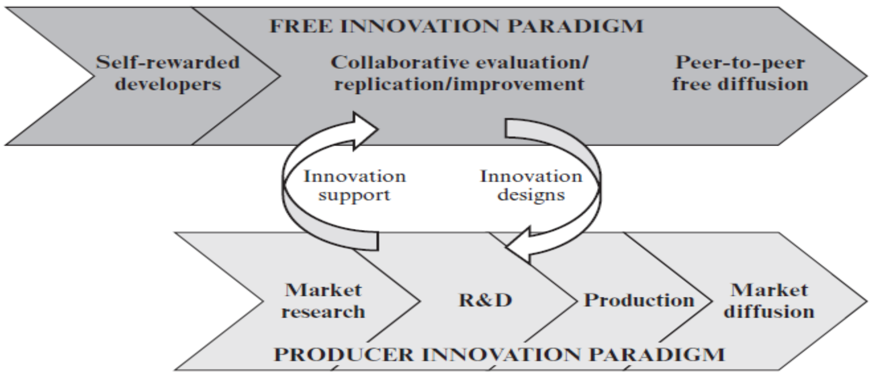
Table 4: Comparison of free innovation and producer innovation

	FREE INNOVATION	PRODUCER INNOVATION
Main actor	Individual user/ household	Firm and producers
Motivation	Self-rewarding, problem solving	Profit-seeking, market appeal
Capital/resource	Discretionary time, no cost	Investment
Innovation	Product design, improvement in community	Product development and diffusion to market
Main consumers	Household, self-need, members of community	Market, unfilled market needs
Diffusion method	Peer-to-peer	Market
Time of inception to consumer	Short after needs identification and product design	Long-time lag until market assessment is over
Intellectual property right	Not interested/unprotected free to share in the network	Very important/ protected, not to be shared freely
Scale	Small, because specific needs not covered by the mass market, but potential long tail	Large, because of the mass production needed to gain from economies of scale
Impact on social welfare	High (potentially) because it is what users need. However, because of limited scalability, its impact may also be limited	Unknown because its marketability is evaluated by firms/producer

Source: Authors, based on von Hippel (2016)

Free innovation shares characteristics with MS. The complementarity model presented by von Hippel (2016) suggests that MS can meet societal needs quickly; however, on its own, its impact may be limited. MS needs to be incorporated into the innovation process of conventional firm activities or some form of collaboration may serve mutually beneficial results. In fact, some large corporations have created similar entities like FabLab in-house (e.g. Sony and Fujitsu), while others allow engineers to use external entities (e.g. DMM corporation, a privately owned MS, interview, 2018).

Figure 3: Free innovation paradigm and producer innovation paradigm



Source: von Hipple (2016:18)

b) Scaling up the impacts through the creation of an ecosystem

MS generally supports innovation at the individual and household level by providing much needed access to equipment, know-how and knowledge generated in the community. This is not motivated by profit. MS provides more than just access to digital tools and know-how – it goes far beyond this.

Some MS are located within the innovation/tech hub, whose main activities include supporting start-ups in scaling up their business by connecting with key stakeholders who provide access to finance (investors and venture capitalists), skills, market channel and advice (mentors and angel investors) that start-ups need if they are to become full-fledged businesses. The ecosystem is choreographed by the innovation/tech hub that organizes events and trainings and provides space for innovators in which the MS plays an integral part, as providers of rapid prototypes, tools or small lot production, all of which are customized to meet users' needs. In other words, an integrated MS in a well-managed ecosystem allows for a scaling up to generate a broader social impact by stimulating entrepreneurship and start-ups.

Several studies find that the following five elements are important for a start-up to be successful. 1) People: human talent or skills (e.g. human resources generated from universities and industries); 2) Economic assets or finance; 3) Infrastructure provisions (e.g. transportation, housing, water and sanitation, telecommunications); and 4) Enabling environment: overall ecosystem to coordinate the stakeholders and policies on innovation and entrepreneurship (Shapiro and Glicksman, 2002; Marchant et al., 2011, Mulas, Minges and Applebaum, 2015). Networking assets are crucial for start-ups. These assets include, for example, expertise, mentorship, tacit knowledge, access to markets and funding. However, an exchange between these assets is not effective unless the social capital is shared within the community. Hence, the emphasis on the hub should not only be on the shared physical infrastructure but rather on those factors that support the building of a social community comprised of networking assets that facilitate "sharing" and learning. More specifically, via activities such as: 1) community building events, such as meetups, 2) skill training events, such as boot camps and hackathons, 3) collaboration spaces as co-working spaces, 4) collaboration space and networks of mentors as accelerators, 5) network of mentors as angel investors (Mulas, Minges and Applebaum, 2015) (Figure 4). MS can play a role in ecosystem building in such contexts by promoting collaboration, capacity-building and skill development, in addition to providing digital tools, know-how and rapid prototyping services in a more dynamic way. To make such activities even more effective, coordination beyond MS, namely introducing policy, is necessary.

Recent research on ecosystems emphasizes its importance as a source of complementary suppliers of services and inputs (Gawer and Cusmano, 2013), leading/strategic intermediary or coordinating entity (Jacobides et al., 2018; Gawer and Cusmano, 2008; Gawer and Cusmano, 2013; Iansiti and Levien, 2004; Adner and Kapoor, 2010) and shared value or social capital, allowing collaboration among stakeholders to build sustainable and competitive business activities (Porter, 2011; Mulas, Minges and Applebaum, 2015; Adner, 2017; Jacobides et al., 2018; Gawer and Cusmano, 2013). As these features resemble those of an MS, it can serve as part of a larger ecosystem to support capacity-building, if relevant policy is in place to encourage such integration.

Figure 4: Key elements of an ecosystem for successful start-ups

Community-Building Events	Skills Training Events	Collaboration Spaces	Collaboration Spaces/Networks of Mentors	Network of Mentors
Meetups	Bootcamps and technology training linked to community building	Collaboration and community-building spaces (e.g., coworking spaces, makerspaces, fab labs)	Accelerators (network value)	Angel investors (network value)
Tech community events/conferences	Rapid technical and entrepreneurial skills programs		Incubators (network value)	Venture capital (network value)
				Networks of mentors and start-up "alumni" networks (if different from accelerators, incubators, angel investors, and venture capital)

Source: World Bank. 2017. Tech Start-up Eco-system in Beirut: Findings and Recommendations. Washington, DC. World Bank. https://openknowledge.worldbank.org/handle/10986/28458 License: CC BY 3.0 IGO.

A web-based review of notable innovation/tech hub cases in Africa shows that MS and FabLab are embedded with other facilities that allow building secure ecosystems (Table 5). This demonstrates that MS is an integral part of the ecosystem of these innovation/tech hubs, where a series of functions are in place. Moreover, auxiliary functions related to MS help connect users with extended services that facilitate the scaling up of their activities, namely accelerators, incubators, venture capital or manufacturers to subcontract the production of products; access to improve logistics and channels beyond national boundaries are also important. Innovation/tech hubs are perhaps better equipped for such “exposure” and networking functions that facilitate the extension of business linkages for innovators.

Table 5: Summary of notable examples in African continents

Organization	Community Building Events	Skill Training Events	Collaboration Spaces for information idea& prototyping	Collaboration Spaces / Networks of Mentors	Networks of Mentors and funding opportunities
Antwork **(Beirut, Lebanon)**	○ Networking events	○ e.g. Intro Blockchain Workshop / 3D design workshop	○ Hot desks meeting rooms event spaces MakerSpace hackerspace e.g. Lamba Labs	○ Accelerator and incubator e.g. SMART ESA / STARTUP SCOUTS	○ e.g. US AID / touch
Berytech **(Beirut, Lebanon)**	○ Workshop / events / Berytech meetups / industries exhibition	○ e.g. start-Up Booster Track / Global Social Venture Competition	○ Meeting Facilities / Co-working Space / Berytech FabLab Innovation Factory / Living Lab	× No accelerator / incubator	○ e.g. Berytech Fund I / Berytech Fund II / IM Capital
hbr creative platform **(Beirut, Lebanon)**	○ e.g. Design Expo / Design Award. Design Congress/ young designers' exhibition	○ Professional courses / workshops / seminars / creative strategies	○ MakerSpace	× No accelerator / incubator	× No VC
icecairo **(Cairo, Egypt)**	○ Meetup with inventors, hackers, entrepreneurs	○ Entrepreneurship training / workshops on machine use / technical training in green buildings for graphic facilitation	○ Co-working space FabLab	○ Incubator e.g. NM incubates icecairo	○ Cooperation with international and local VC and impact investors

Gearbox **(Nairobi, Kenya)**	○ Community projects	○ Training tech – support	○ Rent space / hot desk / shared workshop / boardroom / event space / MakerSpace	○ Incubation and acceleration programmes network of ihub	○ e.g. The Lemelson Foundation, AUTODESK FONDATION, SILICON VALLEY community foundation participate as partners
Chandaria Business Innovation and Incubation Centre **(Nairobi, Kenya)**	○ Networking activities	○ Mentoring programmes / presentation/ pitching skills / marketing assistance / links to higher education resources	○ MakerSpace CIC Space (interactive online forum)	○ Incubator	○ Access to bank loans, loan funds and guarantee programmes / angel investors or venture capital
GreenLab Micro-Factory **(Ibadan, Nigeria)**	○ Maker exhibition	○ Summer camp	○ FabLab	×	×
Clintonel Innovation Centre (CIC) **(Aba, Nigeria)**	×	○ Training courses / invitation to SKILL UP ABIA graduation / CAD trainee / STEM excursion	○ MakerSpace	○ Technology incubation start-up incubation	×

Source: See Appendix 2, Case 7 for sources of each case.

Overall, the existing evidence concurrently demonstrates that MS can potentially be a useful institution in preparing developing countries for Industry 4.0, by providing not only access to technology for rapid prototyping, capacity-building on using digital technology, know-how and a peer-to-peer network, but also by nurturing effective interactions with stakeholders to build ecosystems. At the same time, the cases examined thus far suggest some potential shortcomings of MS, which are discussed in the following section.

c) Challenges of MakerSpaces to generate broader impacts

The above sections have extensively discussed the potential for MS as a viable institution to mitigate the challenges Industry 4.0 pose in developing countries. In the previous sections, each potential role of MS—providing access to advanced digital technology, capacity-building, especially in STEM education, and generating a network of actors to create an ecosystem—has been discussed based on "successful" cases collected from secondary and primary sources. The cases demonstrate the advantages but also challenges MS faces, reflecting the idealistic vision of early proponents of MS (Gershenfeld et al., 2017; Anderson, 2013; Anderson, 2007, among others).

The challenges MS faces are the following: 1) difficulties finding a sustainable business model (De Beer et al., 2017; Kraemer-Mbula and Armstrong, 2017; ElHoussamy and Rizk, 2018, among others); 2) limited scalability of impacts (Rayna and Striukova, 2019; Watanabe and Tokushima, 2016); 3) lack of complementary assets to fully capitalize on the benefits of MS (importance of ecosystem) (JICA, 2016; Mulas et al., 2015); and 4) potential conflicts with intellectual property rights in the future (Kraemer-Mbula and Armstrong, 2017).

Existing studies on MS reveal that different management styles are implemented across the cases (De Beer et al., 2017; Kraemer-Mbula and Armstrong, 2017; ElHoussamy and Rizk, 2018; Watanabe and Tokushima, 2016; Rayna and Striukova, 2019). Three main criteria characterize the business model (Table 6). The first is ownership pattern. They vary from educational institutions (universities, TVET institutions, high schools, libraries), non-profit organizations (NPOs, community), and private businesses (firms, large corporations, multinationals) to the government (national, regional, local). The second criterion is sources of financing; some charge user fees on a monthly basis or on a use basis. Others receive subsidies from different sources, such as government subsidies (national and regional), private sector funding (local firms, multinationals), educational institutions (universities, technical schools, training institutes, secondary and primary education and public libraries) and third parties (philanthropic organizations, NPOs and aid agencies) or a combination of all of the above. The third criterion is the business model's main purpose; again, this can vary from the simplest form of supporting a community of hobbyists, strengthening STEM education to supporting entrepreneurship.

Table 6: Diverse management styles of MakerSpaces

OWNERSHIP		FINANCIAL SOURCE		MAIN PURPOSE
Educational institutions		User charge		Support for hobbyists
Non-profit organization		Government		Strengthening STEM education
Private sector	X	Educational institutions	X	Promoting entrepreneurship/ start-ups
Government (national, regional and local)		Private sector		
Community, private person		Third parties (aid agencies)		

Source: Authors.

In fact, the interviews indicate that a combination of the above three criteria demonstrate that MS are required to flexibly adapt to the local context to sustain their activities. For instance, FabLab Mindanao (Case 4), FabLab Bohol (Case 6) (both Philippines) and Maker's Asylum (Case 1) (India) are supported by bilateral cooperation from the United States, Japan and France, respectively. Mindanao and Bohol are also supported by government entities such as the Department of Trade and Industry (DTI) of the Government of Philippines. Some FabLabs are located at universities, which lowers the cost of rent, helps secure access for clients, such as training or school projects, and access to low-cost labour from the educational institutions to sustain operations (interview, Lima, May 2019). FabLab Kerala (Case 2), for instance, is fully owned by the regional government. This facilitates coordination with government policy, such as initiatives taken on entrepreneurship promotion, STEM education, technical skill training and employment generation. For instance, India's International Center for Free Open Source Software (ICOFOSS) and FabLab Kerala are aligned with the overarching regional policy, Start-Up Kerala Mission.

The reasons behind the diversity of the business models reflect the difficulties in maintaining financial sustainability. In fact, many FabLabs employ a charging system (Watanabe and Tokushima, 2016); however, this alone is insufficient to generate profits to run the basic operation. MS that do not receive funding from external entities (government, private and third parties) sustain their operations by diversifying their sources of income. Their sources of income vary from subcontracting fabrication work to making prototypes and small lot production for private firms and individuals to teaching at educational institutions and to user charges for the provision of services to the public. These diversified sources of finance are very close to the original business model suggested by the founders of FabLab (Gershenfeld et al., 2017); however, interviews conducted with several independent MS revealed that sustaining a business is not an easy task and MS are sometimes forced to compromise on their original "purpose". For example, one MS interviewed stated that although they backed the FabLab Charter, they find it "too academic or idealistic" to be implemented in practice without stable sources of income (interview, Lima, May 2019; interview, Tokyo, January 2019). An existing case study on government support for MS in Russia to enhance STEM and engineering education among youth (under 15 years of age) confirms this observation by pointing out some trade-offs between the sustainability of business and pursuing the intended objective (Rayna and Striukova, 2019).

Although MS may provide for better access to technology and establish a network of key actors to expand innovation and its diffusion than individual household innovation (Halbinger, 2018), without scaling up of activities, its impact remains limited. For MS to be fully functional in creating societal impact, it needs to be embedded as part of the ecosystem involving relevant stakeholders to enhance the activities through entrepreneurship. This notion is in line with that of "complementarity" expressed in both Anderson (2007) and von Hippel (2017). Both claim that new business models–either the "long tail of demand curve" or "free (cost) innovation"—require close integration of MS with conventional manufacturing activities to scale up and generate greater impacts. Thereby, the integration of the MS into an ecosystem would make its business model more sustainable and generate a greater impact. Nevertheless, to fully capitalize on the role MS plays—access to technology, education and learning, and the establishment of a network of critical stakeholders for promoting entrepreneurship—in meeting the challenges of Industry 4.0, complementary assets need to be provided. These include overarching government policy, innovation clusters, funding agencies, capable entrepreneurs, investing private firms, venture capitalists, mentors, angel investors as well as accelerators, incubators or any space enabling a scaling up of the innovation generated in the MS (Table 5).

The management of intellectual property rights (IPRs) may potentially be an important policy agenda, especially in relation to the promotion of start-ups. Most MSs place less importance on IPR because of their emphasis on "open", "sharing" and "building on" knowledge creation processes as a community for peer-to-peer learning. As the early entrepreneurs become full-fledged start-ups, conceptual designs and prototypes increasingly become subject to IPR. While some case studies in Africa indicate that this is only problematic at the level of personal trust but does not reach critical levels to hold back start-ups (De Beer et al., 2017; Kraemer-Mbula and Armstrong, 2017; ElHoussamy and Rizk, 2018), an increasing number of developing countries are aware of IPR and are taking necessary measures to improve the enforcement capacity of IPR. Hence, it is only a matter of time for IPR to emerge as a challenge to "free innovation" (von Hippel, 2017) (Case 4 and 6).

Recently, the importance of distribution-sensitive innovation policies, investing into overcoming societal challenges over economic gain, is being recognized as the pathway towards long-term prosperity (Zehavi and Breznitz, 2017Christiansen et al., 2019). Likewise, new financial resources, such as social impact investments, environment, social and governance (ESG) investments, crowd financing for public works, had emerged to support such policies. These tendencies are consistent to resources seek to balance economic returns and social impacts. Hence, they can be effectively utilized to roll out more MS in remote areas or provide complementary services to existing ones to enhance their impact in the near future.

4 Conclusion

The spread of digital technology under the auspices of Industry 4.0 is transforming our lives while concern about the digital divide is growing. This paper examined the role of MS in preparing developing countries for the Industry 4.0 era by democratizing the use of advanced digital production technologies such as 3D printing. MS has become popular in a number of countries coinciding with the advent of digital technologies. Three functions of MS have been identified in this context: first, MS makes digital technology accessible to a large amount of user innovators and small scale producers who solve their daily problems; second, MS provide capacity-building and strengthen STEM education by supporting peer-to-peer interaction and exposing advanced digital technology to younger generations and the general public to better cope with Industry 4.0; third, MS generates a greater social impact if integrated into an entrepreneurship and start-up ecosystem. MS is an institution that has the potential to prepare society for Industry 4.0 and meeting societal challenges such as the SDGs, which aim to transform society towards a sustainable path and “leaving no one behind.”

MS has the potential to expand the business horizons of smaller producers, opening the possibility of low-cost, tailor made products in the form of prototypes, tooling and direct manufacturing. The combination of digital technology and networks of peer-to-peer learning provided by MS enables the generation of positive externalities of knowledge which is increasingly far-reaching due to the power of the internet. These positive externalities also open up possibilities to employ business models such as sharing economy, while transforming production activities by adopting distributive manufacturing and mass customization.

Nevertheless, MS faces difficulties in terms of scaling up and practical implementation; it is also facing problems in finding a sustainable balance of financial means to remain in operation. This brings us back to the importance of embedding MS in the entrepreneurial ecosystem with complementary assets, opening space for policy interventions. Many of the issues MS currently faces need to be tackled from a systemic level. To embed MS in the entrepreneurial ecosystem, policy must generate dynamic interactions with MS and conventional production systems to consolidate a sustainable production model.

MS plays an important role in preparing countries for Industry 4.0 by introducing alternative pathways to small producers under the new innovation paradigm (free innovation) and production logic (long tail). It is also clear, however, that such initiatives need to be supported by means of policy so that MS can generate synergies and prepare countries for Industry 4.0.

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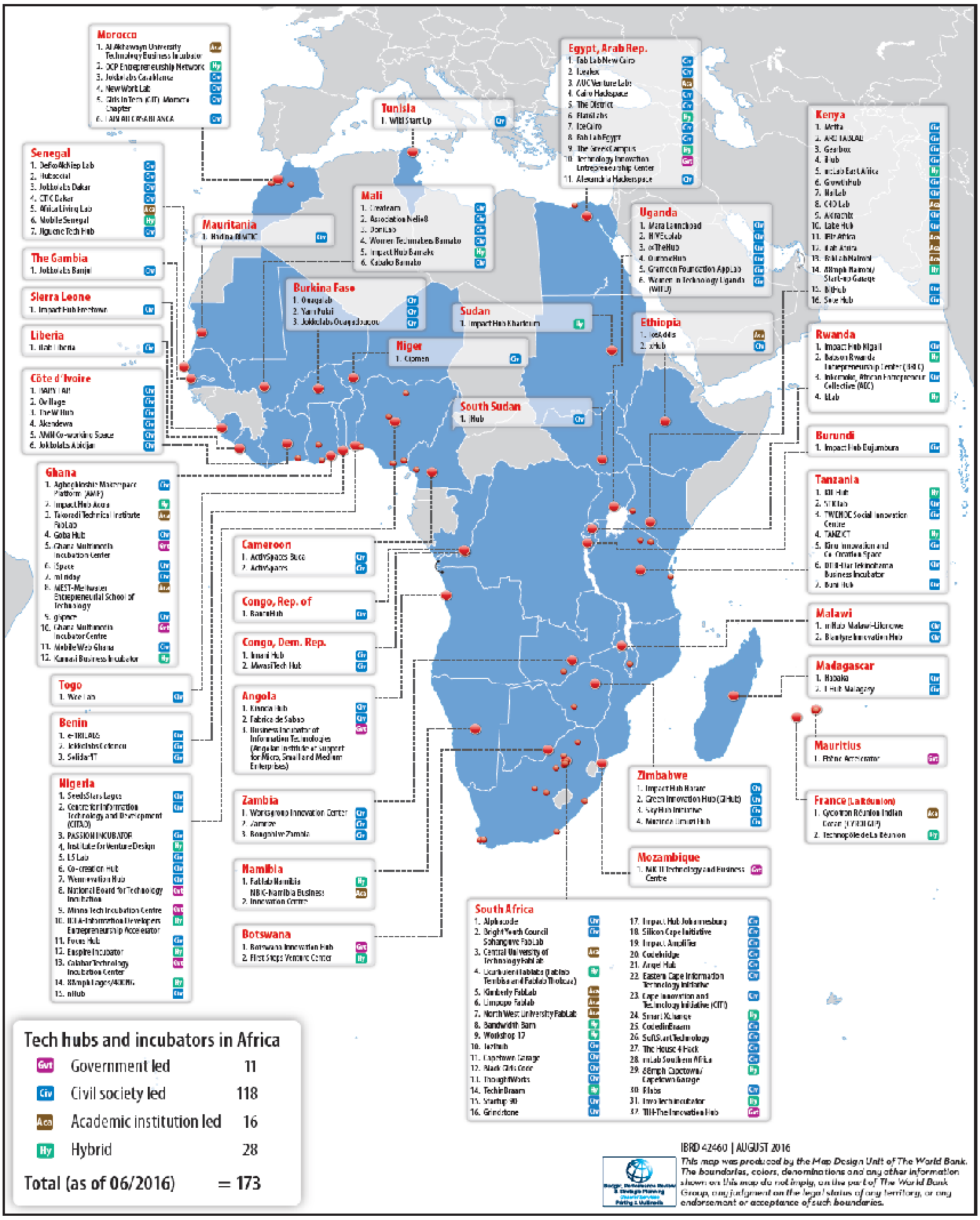
Interviews conducted at FabLab

City, Country	Type of interaction	Date
Tokyo, Japan Digital fabrication DMM Akiba	 Interview in person Site visit and questions	 3 April 2019 29 March 2019
Trivandrum, India	Site visit and questions in person and follow up online	6 May 2019 19 May 2019
Maastricht, the Netherlands	Online exchange	April-May, 2019
Lima, Peru	Visit and interview in person	10 May 2019
Bohol, the Philippines	Site visit, interview in person and online	Sept-Oct, 2019

Appendix 1 Locations of tech hubs in Africa



Source: World Bank, 2016

Appendix 2 Case studies of MakerSpace

Case 1: Case of Maker's Asylum – inclusive and sustainable opportunities of STEAM education

Maker's Asylum is a community MakerSpace based in Mumbai and Delhi. Maker's Asylum wants to promote a maker culture as part of the educational curriculum; namely it brings together interdisciplinary activities covering science, technology, engineering, art and math (STEAM) to foster a culture of innovation, exploration and learning (STEAM School). They organize unique and inclusive projects. For example, "Maker Auto" is a Mobile FabLab in a car with tools and materials to demonstrate the joys of fabrication to the public in the streets.

STEAM School

Maker's Asylum has run the STEAM School as a project-based experimental learning programme for the past two years in collaboration with French partners, the Center of Research & Interdisciplinarity and the French Embassy in India. The programme focusses on bringing together various stakeholders, including entrepreneurs, students, universities and corporate organizations, to work on solving problems that address SDGs. This 10-day programme provides insights into the processes of design, learning, prototyping and creation. In addition, "STEAM Fabrikarium", a spin-off project of the STEAM School, is a fabrication project that aims to develop products that improve the lives of the physically impaired by actually working with them. Under this programme, airplane compatible wheelchairs for paraplegics are designed, and are now undergoing testing in other countries. Other examples include bionic hands, braille printers and cosmetic prosthetic hands.

Maker Auto

Maker Auto is a Mobile FabLab, a van with equipment and tools. Its vision is to improve "access to infrastructure" (with tools and equipment) and "access to education" for the local community. Maker Auto focusses on alternative learning for kids by holding street workshops. Their vision is to eventually become an Open University where eccentric ideas can thrive and break the barriers of traditional ideas of education.

Source: "A Community Makerspace." Maker's Asylum, https://www.makersasylum.com/. Accessed 30 May 2019.

Case 2: International collaboration for capacity development: Drone and photogrammetry in FabLab Kerala, India

A combination of drone and photogrammetry is increasingly being applied to surveying, precision mapping and 3D modelling. These technologies and software are made available free of charge to the digital community, making the technology accessible to a broad range of users.

Despite the growing popularity of drone technologies and free and open source software that diffuses the knowledge further, the lack of practical and hands-on experience limits its applications. To resolve this problem and promote the development of open drone communities, the International Center for Free Open Source Software (ICFOSS) and FabLab Kerala collaborated with the Kerala State Electricity Board to organize a workshop on drone surveillance in 2018.

The training covered broad aspects of drone use in photogrammetry: introduction to open source flight controllers and hardware options, drone assembly and testing, flight planning and data collection and image processing in open drone maps (ICFOSS, blog, 2018). The workshop also covered engagement with relevant government stakeholders to ensure that the regulatory framework is supportive of their activities. The two trainers, Mr. Stephen V Mather and Mr. Frederick Mbuya, are international experts and advocators of the Free and Open Source Software (FOSS) community from the United States and Tanzania, respectively, and were invited by ICFOSS, a government institution established in 2008 to support the FOSS community in collaboration with FabLab Kerala. These experts promote the use of open source software, especially mapping with low-cost drones.

This example entails several unique features. First, FabLab Kerala is a fully government-owned FabLab in India. This allows close collaboration with other government-owned agencies, such as ICFOSS. Although government-owned, FabLab Kerala can still leverage the international network of FabLab to obtain practical knowledge by tapping into its network, ultimately democratizing surveying technology using drones and FOSS.

Source: Information based on three blogs and interaction with Mr. Rahul Rajan, Officer, ICFOSS.

Case 3: Vigyan Ashram – innovation in meeting rural needs

The first FabLab outside of MIT

In 1983, 90 per cent of the Indian population did not complete school and 75 per cent lived in rural areas lacking any form of formal education. Vigyan Ashram is an Indian organization dedicated to education, located in a rural part of India. It advocates learning by doing, and has developed a programme called “Rural Development through Educational System”. This involves interdisciplinary projects and a living (farming, food processing,) and non-living (engineering, energy environment) syllabus incorporating the use of new technologies. Vigyan Ashram is the first FabLab outside of MIT. It was established when Neil Gershenfeld, the founder of FabLabs, visited Vigyan Ashram in 2002.

Frugal innovation to solve local problems

Most of Vigyan Ashram's innovations are low-cost and intended for practical use in rural settings. Product development initiates imitations of existing products. This leads to local adaptations by replacing inputs that are available locally. For example, their "resistance meter" is a copy of an existing product used to detect water. "Mechbulls" is a tractor made from spare Jeep parts. Vigyan Ashram was successful in innovation, but lacked access to tools. Hence, the incorporation of FabLab was complementary. Vigyan Ashram conducts research directly related to practical use to improve the livelihood of rural areas. The following are some of its ongoing projects:

Real-time soil monitoring to improve agricultural production

Monitoring parameters such as soil moisture, temperature and humidity in a greenhouse is critical for maintaining the healthy growth of plants. A device to measure these parameters is available on the market, but at a high cost, and is often not suitable for small scale farms in rural settings. FabLab has developed a device that controls temperature, humidity and soil moisture at an affordable cost. This device can also send data to mobile phones using Bluetooth.

(Left: Real-time soil moisture, temperature, humidity monitor/ Right: Aquaponics)

Aquaponics (RAS)

Vigyan Ashram has researched and developed technologies for the Aquaponics (RAS) system. Aquaponics combines aquaculture and hydroponics agriculture to neutralize nutrients from both activities, preventing them from reaching harmful levels for the environment. This is an efficient and sustainable method of food production. Currently, Vigyan Ashram is conducting a trial system with grass carp fish combined with hydroponics of tomatoes, aloe leaves and rose cultivations in the greenhouse.

Source: "Vigyan Ashram (DST Core supported) Blog." Vigyan Ashram(DST Core supported) Blog, https://vigyanashram.wordpress.com/. Accessed 30 May 2019.

Case 4: FabLab Mindanao: Supporting micro, small and medium enterprises (MSMEs) as drivers of economic development

Around 97 per cent of all businesses in the Philippines in 2015 were micro, small and medium enterprises (MSMEs)[9]. FabLab Mindanao was established with the aim of making local MSMEs more competitive. This is a collaboration between Mindanao State University – Iligan Institute of Technology (MSU-IIT) and the Department of Trade and Industry (DTI) of the Government of Philippines with the support of the United States Agency for International Development (USAID). Today, FabLab Mindanao provides digital fabrication facilities and fabrication education to students. Moreover, they have a unique business model consisting of 1) collaboration with MSMEs, 2) financial model, and 3) utilizing patents.

1) Collaboration with MSMEs

FabLab Mindanao's Technology Access Center and Training provides services to MSMEs. The Technology Access Center is a shared facility that enables MSMEs to develop early stage products such as prototypes of souvenirs with a reduced time lag between product design and commercial

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9 Republic Act No. 9178 known as the Barangay Micro Business Enterprise Act of 2002 defines MSMEs as businesses with asset sizes between PhP 3 million (USD 60,292) and PhP 100 million (USD 2.007,267).

production. Access to this facility improves product quality and enhances industry competitiveness in Mindanao. FabLab Mindanao's vision is to play a role as a local R&D hub. The training provider offers capacity-building for MSME employees by offering trainings on how to use digital fabrications and computer tools. The training provider works on many projects with local firms, including engineering companies.

2) Financial model

Aside from fabrication machines provided by DTI and the management staff of university faculties, FabLab Mindanao is supported by Global Innovation through Science and Technology (GIST), Department of Science and Technology (DOST), USAID and private funding agencies. Compared to other FabLabs in the Philippines, which usually rely on university funds, FabLab Mindanao has ample resources due to its diverse sponsors.

While they successfully obtain financial resources from various actors, they try to yield added value on their own. More specifically, they started commercializing the inventions made in the FabLab. A manager at FabLab Mindanao explained that they measure their projects' effectiveness based on the extent to which they have been commercialized. This approach is unique since a lot of FabLabs in the Philippines focus primarily on non-profitable projects like STEM education.

3) Utilizing patents

The most unique aspect of FabLab Mindanao is its patent utility model. Within this model, MSU-IIT becomes a licenser of inventions created in FabLab Mindanao. The MSU-IIT obtains a license fee when the inventions are used in industry.

It has made FabLab Mindanao more economically sustainable than most other FabLabs in the Philippines, which are part of university facilities. In many cases, however, no contract on intellectual property is concluded between universities and FabLabs. As their activities are closely linked with business, there is a possible conflict of interest between FabLab and entrepreneurs who wish to use the facilities at FabLabs for business purposes. Though the underlying concept of FabLab is based on open source technologies, allowing free access to anyone within the FabLab networks, it is also true that intellectual property rights are an incentive to innovate. Within this context, FabLab Mindanao's patent utility model is very challenging and progressive.

FabLab Mindanao has unique features: it collaborates with MSMEs, has a financial model in place and utilizes patents. Its model is more business-like, as it seeks long-term benefits and bigger industrial impacts. While FabLab Mindanao faces challenges in pioneering new frontiers, its initiatives are worth paying close attention to.

Source: Fab Lab Mindanao MSU-Iligan Institute of Technology. MSU, https://www.msuiit.edu.ph/offices/fablab/index.php. Accessed 30 May 2019.

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Case 5: RiiDL FABLAB: Evolving FabLab

FabLab RiiDL is located in K. J. Somaiya College of Engineering (KJSCE), Mumbai, India. When the FabLab was established in 2010, its users were mainly university students. However, RiiDL gradually acquired machines and tools and began organizing workshops and research projects, turning into an innovation centre. Today, its students are involved in teams in thematic projects such as drones, water quality measurement, etc.

In 2015, RiiDL became an official business incubator, benefiting from a government grant. It hosts start-ups in activity areas such as social, mobile, analytics, cloud and embedded electronics. RiiDL's ambition is to become a premier centre for ground-breaking research and a breeding ground for start-ups. They have produced over 70 start-ups, raised over three million dollars in funding, created over 200 full-time jobs, with 25 firms being incubated.

The following are some examples of start-ups incubated by RiiDL

- **My Cute Office** is a service-based start-up, which allows users to share their office space and facilities to reduce their individual rental costs. This helps start-ups, entrepreneurs and professionals to obtain fully furnished working spaces at a fraction of the cost. (https://mycuteoffice.com/)

- **Kustard** is a design and technology company founded in 2016 in KJSCE. They offer platforms where users' ideas are materialized and where products are improved by digital analytics. (https://kustard.io/)

- **AITOE** offers security services using digital technologies. They help a large range of customers from small and medium enterprises, schools, hospitals and houses. By utilizing data from Digital IP CCTV cameras with authentication technologies and AI, they provide real-time alert and emergency messages.(http://aitoeva.com/)

Source: "Fab Lab." Riidl, https://riidl.org/fablab. Accessed 5 October 2019

Case 6: In-depth focus on FabLab Bohol

FabLab Bohol is the first FabLab in the Philippines. It is located in a remote part of the country with limited access (the Central Visaya Islands, Philippines; two hours from Manila by plane and two hours from Cebu by ferry). This case attracted attention because it involved social problems that typically exist in rural areas, such as low access to technology or education and lack of competitive industry due to small market size and logistic difficulties owing to geographic location. Most of these challenges are common to rural areas; nevertheless, they require solutions specific to local contexts.

FabLab Bohol was founded in 2014 based on the idea of a volunteer from a Japanese International Cooperation Agency (JICA). It is located at the main campus of Bohol Island State University (BISU) in Tagbilaran, the capital of the Bohol Province. It receives financial support from JICA, Department of Trade and Industry (DTI), Department of Science and Technology (DOST) of the Government of Philippines and BISU. Like other FabLabs around the world, it is equipped with digital fabrication machines such as 3D printers, CNC-milling machines, laser cutters and vinyl cutters. It also organizes workshops to make the equipment accessible to locals.

A unique feature of this FabLab is its balanced contribution in three areas: 1) promoting science, technology, engineering and mathematics (STEM) education; 2) supporting micro, small and medium enterprises (MSMEs); 3) producing new products and developing new projects to meet social needs. Its activities are expected to contribute to a decrease in the digital divide that exists between Bohol and the central part of the Philippines. With regard to STEM education, the FabLab provides students with access to technologies through classes on fabrication at BISU. Its presence as a supportive learning environment inspires students to create innovative products. FabLab Bohol also functions as a facility where quick, low-cost and better prototypes can be produced for local MSMEs. Exposure to such equipment has resulted in a change in the mindset of local producers. For instance, one of the producers decided to introduce digital fabrication machines in the production process. Thereby, FabLab has contributed to closing the technological gap between large and small firms, especially those located in rural areas.

Furthermore, FabLab Bohol has generated innovative solutions to local social problems. Some noteworthy products that have emerged from FabLab Bohol are prosthetic legs and plastic recycled products. In 2014, the first prototype of an artificial leg using a 3D printer was created at FabLab Bohol. 3D printing technology can be used to make tailor-made products, like artificial legs, at drastically lower costs and in a comparatively less time. 3D scanning and artificial intelligence technologies were developed, specifically to produce artificial legs. Consequently, this product received ample investments and support, leading to the creation of a start-up called Instalimb (Instalimb Solutions Philippines, Inc.) in 2019. Another project carried out by FabLab Bohol includes the upcycling of plastic products made by women in Tagbilaran. The products are made from disposed plastic bags using heat press machines available at FabLab Bohol. This project offers a solution to the twin social problems of reducing plastic waste and generating jobs for local women. Although the project is currently being supported by JICA and Keio University, it is expected to become an independent venture soon.

Following the gradual establishment of the fabrication culture in Tagbilaran, FabLab Bohol recently acquired an important role – it will expand its activities as the leading FabLab at the national level. This move was endorsed by the government under the former president, Aquino, who declared that FabLabs would be expanded all over the Philippine Islands, upon witnessing the success of FabLab Bohol. FabLab Bohol, together with the Regional and Provincial Office of DTI, made a proposal to improve networking among the 20 existing FabLabs located across the Philippines, with FabLab Bohol as the headquarter. This proposal was made to maximize the impact of existing FabLabs. The proposal also promotes the collaboration of MSMEs with the national network of FabLabs to expand research and development (R&D) activities. Furthermore, it also aims to empower local entrepreneurs in the Visayas, turning Cebu into an innovation hub. Apart from functioning as a catalyst at the national level, FabLab Bohol plans to open Digifab centres, which are half the size of FabLabs, at three other campuses of BISU by the end of next year. The purpose of this is to expand service coverage in Bohol City.

Despite having more than a fair share of achievements, FabLab Bohol also faces challenges. These challenges are as follows:

Adapting to local needs: FabLabs provide services and solutions adapted to local needs. As FabLab Bohol's manager explains, "all FabLabs in the Philippines do not need to have similar machines and services because industrial demands around each of them vary." FabLab Bohol has already started developing its own projects such as using plastic waste and pineapple fibre to make area-specific products. Such products are genuinely "made in Bohol" and will contribute to local production for local consumption.

Setting future visions and road mapping: So far, FabLab Bohol has been providing local users (students and MSMEs) with education and prototyping opportunities. As new initiatives are undertaken, FabLab needs to expand its services to sustain its business and contribute to regional development in the Philippines. To achieve that goal, a clear vision and roadmap are necessary.

To sum up, FabLab Bohol's achievements are commendable because they have contributed to closing the technological gap between the rural (Bohol) and central part of the Philippines. By developing new projects, it provides solutions to local problems; such experiences need to be shared across the Philippine Islands via enhanced collaboration among existing FabLabs. However, there are some challenges that need to be overcome, such as adaptation to local needs and the setting of future visions and road mapping.

The case of FabLab Bohol proves that innovation can be more than mass production in a global market or incubation of large companies. It can also offer solutions that correspond to niche markets or are customized for individual consumption. FabLab Bohol has provided opportunities to those who were left behind, such as people living in rural areas, women and potential entrepreneurs. It has been five years since FabLab Bohol was launched; thus, after having invested personal efforts in developing the project, the management is now at a crossroads of transitioning to a more established working model.

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Manager of FabLab Bohol organizing technical staff and counterpart for FabLab community on

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Person in charge of FabLab at DTI and industry development in Bohol on 1 October 2019.

Case 7: Cases of FabLab in co-working space and of i-hub (background information for Table 5)

1. Antwork (Beirut, Lebanon)[10][11]

- Description:

Antwork provides co-working spaces for businesses that are in the start-up stage. They provide several types of office rooms, including co-working spaces, private workspaces, meeting rooms, event spaces and specialized studios. Antwork provides not only co-working spaces but also networking events, knowledge building programmes, health and lifestyle programmes, event planning and production services, on demand IT and accounting services. Through these activities, they have sought to develop a launch pad for growth and success in emerging entrepreneurial ecosystems. MakerSpace is one function of Antwork within its specialized studios.

- Founded: 1 February 2016
- Founders: Zina Bdeir Dajani (F)
- Sector: private for profit
- Target or users: Freelancer, solo-preneurs, freestylers or business owners[12]
- Partners: LAMBA LABS (hackerspace), NUQAT (NPO, education platform), SMART ESA (accelerator and incubator), STARTUP SCOUTS (training and support programme), touch (mobile telecommunications and data operators in Lebanon), US AID and YARAQA (cultural enterprise) participate with Antwork as partners.
- Products and services:

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[10] Antwork. https://www.antwork.com/ (accessed 31 August 2019).
[11] crunchbase searching antwork. https://www.crunchbase.com/organization/antwork#section-overview (accessed 31 August 2019).
[12] Ministry of Economics and Trade, "Republic of Lebanon, Guidebook What's in Lebanon for SME's 2017" https://www.economy.gov.lb/media/10309/whats-in-lebanon-for-smes-180105-20.pdf (accessed 31 August 2019).

Antwork introduces its services on its website as follows:

- ✓ Smart agile workspaces

Antwork provides meticulously designed workplaces to facilitate the growth of start-ups. Users pay depending on the service they use (pay as you go). This includes equipment rentals and furniture, and virtualized servers and storage as well as event and exhibition space booking. Equipment includes printers, scanners, photocopiers, 3D printers and projectors[13]. Depending on services and user choice, the starting cost is set at USD 249.00 per month.

- ✓ Local and global networking

Antwork provides networking and growth programmes, including happy hours to easily find business partners and employees. Examples of networking events are workshops, community drinks, mentorship programmes, pitching events, incubator programmes and accelerator programmes.

- ✓ On-demand tools and services

Antwork offers on-demand tools for businesses, such as IT services and retainers, trademark registration, accounting and bookkeeping, recruitment services, mail programmes, financial advice, legal services, templates, etc.

- ✓ Opensource marketplace

Antwork helps find clients, mentors, funds, accelerators.

- ■ Business model: Room rental fee

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[13] Coworker – work outside the box- searching antwork. https://www.coworker.com/lebanon/beirut/antwork (accessed 31 August 2019).

■ Images:

(Co-working spaces. Available at https://www.coworker.com/lebanon/beirut/antwork [accessed 31 August 2019])

(MakerSpace inside Antwork. Available at https://www.heydesk.com/rent-desk/Antwork---Maker%27s-space-in-Beirut--Lebanon-Spears--Beirut--Lebanon.1hls.htm [accessed 31 August 2019]).

2. Berytech (Beirut, Lebanon)[14][15]

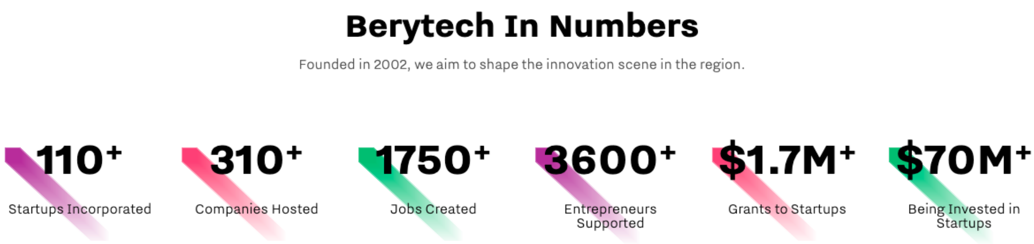
Berytech
The Ecosystem
for Entrepreneurs

■ Description:

Berytech was founded to create a better environment for the establishment and development of start-ups to foster innovation, technology and entrepreneurship at the Saint-Joseph University in 2002. Berytech provides a wide range of services, such as business support, renting office spaces and facilities (meeting spaces, internet access, co-working spaces, FabLab, etc.), programmes,

14 Berytech- The Ecosystem for Entrepreneurs. https://berytech.org/ (accessed 31 August 2019).
15 crunchase searching "Berytech." https://www.crunchbase.com/organization/berytech#section-overview (accessed 31 August 2019).

obtaining funds and holding competitions and events. Their website states that over 250 entities have used offices, and they have produced over 3,150 entrepreneurs, over 1,750 job opportunities, and granted more than USD 600,000+ to start-ups in Lebanon since 2002.



(Berytech output from the website. Available at https://berytech.org/ [accessed 31 August 2019])

FabLab is one of the functions of the facility called “Berytech Fab Lab”. It provides tools such as laser cutters, 3D printers, SLA 3D printers, 3D scanners, vacuum forming machine, bench drill and power tools. In terms of capacity-building, it offers workshops and the Fab Academy, which is an education programme for makers certified by MIT’s Center for Bits and Atoms.

- Founded: 2002
- Founders: Maroun N. Chammas (M)
- Sector: private for profit
- Target or users: students, professionals, artists, techies, entrepreneurs and makers
- Partners: shareholders, supporters and programme partners participating as partners of Berytech.
    - Shareholder: 15 (e.g. Bank Audi, Bank of Beirut, Bank Med, Banque Bemo, Bybols Bank and Credit Libanais)
    - Supporters: 12 (e.g. ebn, in bia, USJ, Beirut Digital District, World Bank, UNDP and

Tomson Reuters)

- ➢ Programme partners: 10 (Agence universitaire de la Francophonie, WeHubs, INJAZ Lebanon, GrowthWheel and ESSEC business school)

- ■ Products and services:

  - ➢ Office space and facilities

Berytech provides several offices inside innovation parks, and facilities such as internet access, meeting spaces, maker spaces, co-working spaces, sports gyms and corporate partnerships (Microsoft® Bizspark, amazon, MAGNiTT, HubSpot and VBOUT)

  - ➢ Mentoring and access to international markets:

Mentoring is a key factor in growing businesses. Mentor advice and guiding start-up teams by sharing knowledge and experiences. Through the mentorship programme, start-up teams can solve specific problems and receive advice on networking opportunities.

Key Benefits Of Mentorship

- Enhanced likelihood of achieving business success through increased confidence
- Guidance during key transitions and decisions in growing a business
- An opportunity to gain access to new markets
- Learning about oneself and broadening one's perspective on life
- Learning new approaches and skills from the mentor and fellow mentees
- Building contacts with a broad array of like-minded fellow professionals

(Key benefits of mentorship from the Berytech website. Available at https://berytech.org/business-support/mentoring-coaching/ [accessed 31 August 2019]).

  - ➢ Workshops, events and competitions:

Berytech organizes and partners in local, regional and international competitions that are open for students, professionals and entrepreneurs. They also hold several exhibitions in specific technology fields such as agriculture, nutrition and the food industry, and workshops for business support.

- Funding advice and counselling:

Berytech own their funds and venture capital. They run a second-round investment fund called Berytech Fund II, which as of 2019, succeeded in raising USD 51 million in capital.

- Job opportunities:

As Berytech has a community of over 200 companies, some undertake recruitment within the community.

3. hbr creative platform[16]

- Description:

hbr is a creative platform and design lab in Lebanon, which provides co-working spaces, a FabLab, education to develop and facilitate design, events, meetups and exhibitions for users, and collaboration with corporate industries. They aim to "provide a space where design awareness and understanding of various disciplines and qualities are explored, developed, and celebrated

[16] hbr creative platform and design lab – Lebanon. http://www.hbrcp.com/(accessed 31 August 2019).

through collaboration between creative individuals, innovative events, activities, and products[17]."

- Founded: 2014
- Founders: Nelly Baz and Halim Choueiry
- Sector: Private
- Target or users: creative individuals (designers, innovators)
- Products and services:
  - Co-working space and FabLab: the company provides individual spaces for rent to members. Individual members can set up a start-up with other members of hbr, such as designers. Through collaboration with other members, it reviews production and marketability.
  - Education: developing and facilitating design educational workshops and symposiums. Hbr provides an opportunity for creative individuals to prototype their ideas. It offers design thinking courses involving three main elements: 1) theoretical courses (creative strategies, design process, design research methodologies, and strategic design thinking), 2) practical courses (service design, data visualization and design innovation), and 3) technical courses (technical software, service design tools, innovation tools and technical prototyping).
  - Retail products: promoting local and international design through the sale of innovative products and literature.
  - Exhibitions: hosting exhibitions that celebrate local and regional designs.

[17] hbr creative platform's mission. http://www.hbrcp.com/(accessed 31 August 2019).

- Support for corporate industries: facilitating academic exchange to support enterprises to conduct research and development. It also provides services, such as plotting, laser machines, silicon moulding and sawing machines and materials.

(FabLab and image of an event from YouTube "hbr creative platform" channel. Available at https://www.youtube.com/channel/UC0t12Cik8t08ZSrwHbysSOA [accessed 31 August 2019]).

4. Icecairo (Cairo, Egypt)[18]

- Description:

icecairo promotes collaboration in innovation and entrepreneurship, focussing in particular on the green-tech segment. icecairo supports innovators to work with different communities to solve complex social challenges using innovation techniques[19]. icecairo is a space where people come together to turn the sustainability challenges the Egyptian community faces into opportunities for green business in Egypt. It implements two main programmes. One of the programmes is a green tech product prototyping programme and the second is a start-up and entrepreneurship programme. Through the second programme, icecairo seeks to support young entrepreneurs in building a business model. icecairo works as a pre-incubation leader of Egyptian incubators, VC and impact investors. As regards MakerSpace, icecairo is a member of the MIT International FabLab network and provides 3D printers, laser cutters and CNC machines for making prototypes. icecairo is a social enterprise, and part of the international icehubs network, which was launched with iceaddis in Ethiopia and ice Bauhaus in Germany.

- Founded: 2012
- Founders: Adam Molyneux-Berry (M)
- Sector: private

[18] Icecairo. http://www.icecairo.com/ (accessed 31 August 2019).
YouTube "icecairo" channel. https://www.youtube.com/user/icecairo (accessed 31 August 2019).
crunchbase searching icecairo. https://www.crunchbase.com/organization/icecairo#section-overview (accessed 31 August 2019).
[19] YouTube "icecairo" channel "What is iccairo?" https://www.youtube.com/watch?v=ZjfhmPN0Lhs&t=5s(accessed 31 August 2019).

- Target or users: innovators, collaborators and entrepreneurs
- Partners: Nahdet El Mahrousa (incubator), GIZ (technical training), FAGNOON (art school), Nawaya (community building), EECA (trainings related to green building), Oasis Renewable Energy (hackathon).
- Products and services:
  - Co-working space: it provides flexible and modular spaces to bring together those with innovative ideas. Objectives: 1) to share resources and skills, 2) to share common objectives, and 3) facilitate dialogue with others. Providing high-speed internet, adjustable furniture, printers, copiers, PCs, networks of green tech enthusiasts and experts.
  - FabLab: 3D printers (1 x Stratasys Dimension SST 1200ES), laser cutters (1 x Universal Laser System VLS4.60 Laser Cutter & Engraver and 2 x LaserPro C180 Laser Cutter & Engraver), power tools (circular saws, grinders, fixed drills, etc.) and hand tools (hammers, chisels, etc.).
  - Events: Organizing several events for users to acquire tech skills, such as entrepreneurship training, machine use training, technical training in green building and graphic facilitation training.
  - Products
    - Low-cost solar water heater (tank)
    - Low-cost biogas digester

(Low-cost solar water heater created by icecairo from YouTube "What is icecairo?" Available at https://www.youtube.com/watch?v=ZjfhmPN0Lhs&t=147s [accessed 31 August 2019]).

(Low-cost biogas digester created by icecairo from YouTube "What is icecairo?" Available at https://www.youtube.com/watch?v=ZjfhmPN0Lhs&t=147s [accessed 31 August 2019]).

5. Gearbox (Nairobi, Kenya)[20][21]

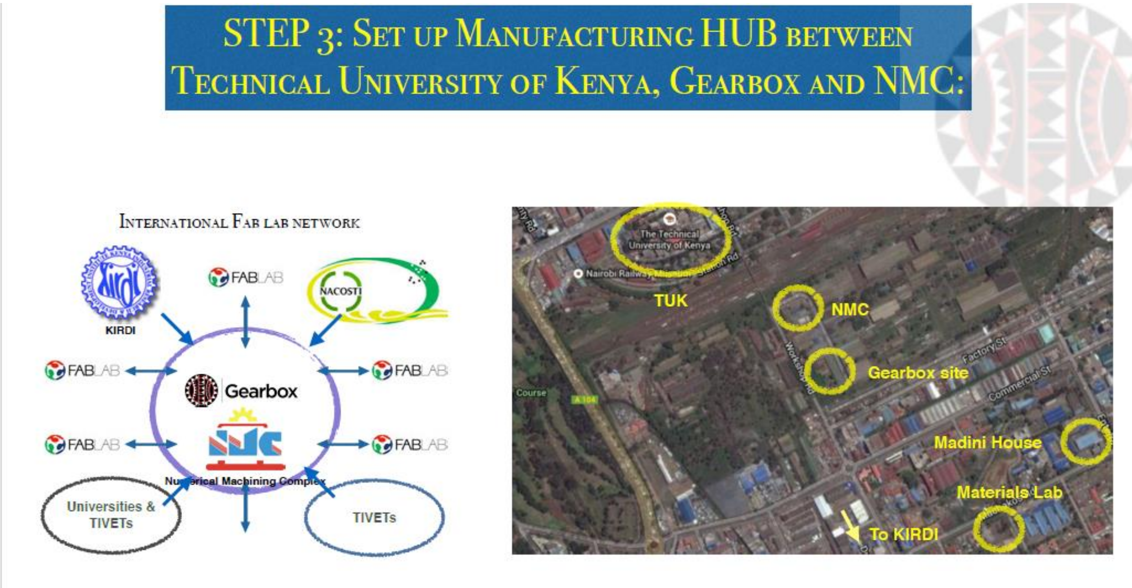
■ Description:

Gearbox is the first MakerSpace in Kenya. Gearbox's vision is "improving the ecosystem for hardware entrepreneurship by providing flexible working space, shared prototyping facilities, training in manufacturing, fabrication and design as well as mentorship, investment opportunities and community development[22]." They provide 1) tech support, 2) training, and 3) co-working spaces, and MakerSpace to integrate hardware skills with their extensive software expertise. As Gearbox aims to be a "manufacturing hub" in Kenya, it is located in Nairobi's industrial area next to the Technical University of Kenya and Numerical Machining Complex. Such an environment helps members build a strong network to take their products or services to the market.

[20] Gearbox. http://www.gearbox.co.ke/ (accessed 31 August 2019).

[21] crunchbase searching Gearbox. https://www.crunchbase.com/organization/gearbox#section-locked-charts (accessed 31 August 2019).

[22] Gearbox. http://www.gearbox.co.ke/ (accessed 31 August 2019).



(Slides from Dr. Kamau Gachig "An Infrastructure for Industrialisation" 2015. http://siteresources.worldbank.org/EDUCATION/Resources/BBL-FabLabsKenya-KamauGachigi-17Sep2015.pdf [accessed 31 August 2019]).

One interesting initiative at Gearbox are "community projects." Community projects attempt to solve challenging issues around Nairobi. Essentially, the project term is around two months, starting with a meeting and designing, prototyping and creating a solution.

- Founded: 1 February 2010
- Founders: Dr. Kamau Gachig (Mr.)
- Sector: private
- Targets and users: designers, engineers, and entrepreneurs
- Partners: The Lemelson Foundation, AUTODESK Foundation, Silicon Valley community foundation, PHILIPS and GE participate as partners.
- Products and services:

Gearbox offers "training in design, prototyping, and manufacturing, along with low-cost access to world class facilities[23]." It offers technical experts to support users and training courses that teach industry-leading tools for design including Autodesk software, automated (CNC) machining, 3D printing, and wood and metalworking.

- Tech – support: offering technical experts who are industry professionals, artists, designers, inventors, entrepreneurs, engineers, makers and fabbers. They have several computer controlled machines, such as a four-axis CNC mill, a hybrid plasma cutter, a 120 watt 36" x 24" laser cutter and Ultimaker 3D printers.

(MakerSpace in Gearbox. Available at http://www.gearbox.co.ke/tech-support [accessed 31 August 2019]).

- Training: Gearbox offers training courses that teach industry-leading tools for design, including Autodesk software, automated (CNC) machining, 3D printing, wood and metalworking. Gearbox's website states that they provide 1) "a platform for innovators graduating from technical institutions with hands-on training to allow them be market-ready and apply already acquired knowledge", and 2) "non-academic technicians, craftsmen and tinkerers to utilize tools that aid their innovation/products improve in quality and save on time and resources[24]".

[23] Nairobi Design Week. http://www.nairobidesignweek.com/listing/gearbox/(accessed 31 August 2019).
[24] Gearbox Training. http://www.gearbox.co.ke/training1(accessed 31 August 2019).

Title	Machine	Contact Hrs	Prerequisites	Cost
Mechanical				
Fundamentals of CAD	N/A	14	N/A	18750
CAM 101	N/A	10	Fundamentals of CAD	12500
3D Printing	3D Printer	5	Fundamentals of CAD, Workshop Safety	6250
Laser Cutting and Engraving	P series Pro 36X24 series	5	Fundamentals of CAD, Workshop Safety	6250
4 axis CNC Mill	PCNC Tormach	4	Fundamentals of CAD, Workshop Safety	6250
Manual Lathe	Granville Senior	2	Workshop Safety	3750
Welding	Arc Welder	2	Workshop Safety	3125
Welding	MIG Welder	2	Workshop Safety	3125
CNC Plasma	Hybrid CNC	5	Fundamentals of CAD, Workshop Safety	6250
CNC Router	Hybrid CNC	5	Fundamentals of CAD, Workshop Safety	6250

(Mechanical Training at Gearbox. Available at http://www.gearbox.co.ke/training1 [accessed 31 August 2019]).

Title	Machine	Contact Hrs	Prerequisites	Cost
Electrical				
Electronics CAD	N/A	28	Basic computer skills	21000
			Basic knowledge in electronics	
PCB fabrication	Hot roller laminator	8	Knowledge in Electronics CAD/	12000
	UV exposure		Workshop Safety	
	CCD			
Electronics Assembly and Testing		12	Knowledge in Electronics CAD/	14000
	Pick and Place		PCB fabrication skills/Workshop Safety	
	Refow			
	Rework			
	Soldering/Hot air station			
	E-bench tools/Equipment			

(Electrical Training at Gearbox. Available at http://www.gearbox.co.ke/training1 [accessed 31 August 2019]).

- Co-location / MakerSpace: It provides rent space, hot desks, shared workshops, boardrooms and event spaces. Those spaces enable networking and the sharing of ideas and provide opportunities for mentorship and incubation.

■ Cases of products

- Lumbrick: Lumbrick is a clean energy social enterprise that recycles organic waste from Kenya and sub-Saharan Africa to produce clean cooking fuel for charcoal users. The briquettes burn twice as long as traditional charcoal without emitting any smoke.

- Vending machine for sanitary towels: Ms. Esta, in her mid-20s, invented a vending machine for sanitary towels, helping girls go to school despite the high cost of sanitary towels.
- Usafi Comfort: This is an onsite wastewater management solution provider for the Eastern African market. It has partnered with global engineering research and product development companies to develop, manufacture and distribute water-saving devices and wastewater recycling products, which are uniquely suited to the Eastern African market.

- Business model: membership-based fee and room rental fee.

6. Chandaria Business Innovation and Incubation Centre (Nairobi, Kenya)[25]

- Description:

Chandaria Business Innovation and Incubation Centre fosters a culture of innovation and entrepreneurship at Kenyatta University. The Centre provides innovation and entrepreneurship programmes that have strong links with industry. It was elected "Most Promoting Africa University Business Incubator, 2014."

- Founded: 2011
- Director: Dr. George Kosimbei (M)
- Sector: university business incubator
- Targets and users: students

[25] Chandaria Business Innovation and Incubation Centre http://www.ku.ac.ke/iiuil/(accessed 31 August 2019).

- Partners: Kenyatta University
- Products and services:
    - Facilities: it provides 3D printing and lasers, water jet cutters, high-speed internet access.
    - Mentoring programmes: assistance with business basics, networking activities, marketing assistance, help with accounting/financial management, presentation/pitching skills, access to angel investors or venture capital, technology commercialization assistance, assistance with regulatory compliance.
    - Funding: it provides access to bank loans, loan funds, guarantee programmes and access to angel investors or venture capital.
    - Networking: links to strategic partners, management team identification.
    - MakerSpace: it provides a place to implement ideas and innovations in the form of prototypes and small batch production. It offers machines, metal and woodworking shops and training and consulting services, including events for members with any level of knowledge, providing them with support and networking options.
- Outcomes:

The Centre provides nine start-ups. The following examples are some of the typical outputs.

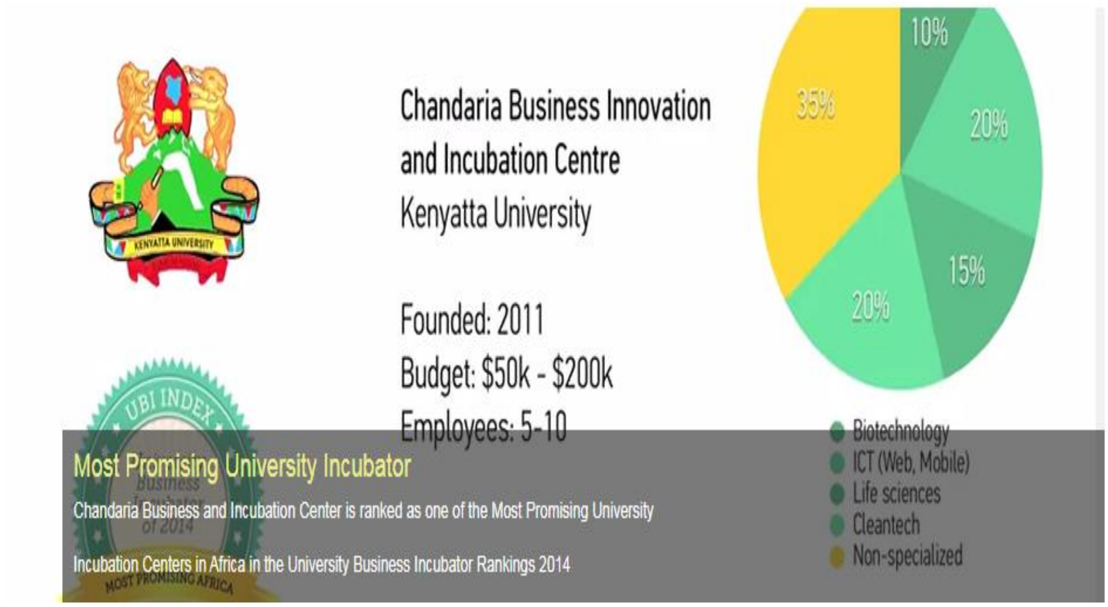
1) **Ecodudu**[26] is an agriculture-based start-up aiming to solve problems associated with food waste and nutrient shortages by up-cycling discarded food to create animal fertilizer and animal feed.

[26] Ecodudu. http://www.ecodudu.com (accessed 31 August 2019).

2) **FlexPay Technologies**[27] enables customers to purchase goods and services through convenient flexible payment options.

3) **Zalisha**[28] is a Swahili word that means growth. This company was established to help farmers grow and market their produce.

4) **AfricarTrack**[29] International is a security company that uses mobile phones and PCs to solve transport-related problems.



[27] FlexPay Technologies https://www.flexpay.co.ke/(accessed 31 August 2019).
[28] Zalisha. www.zalishafrica.com (accessed 31 August 2019).
[29] AfricarTrack www.africartrack.com (accessed 31 August 2019).

(Images from Chandaria Business Innovation and Incubation Centre)

7. GreenLab Micro-Factory (Ibadan, Nigeria)[30]

- Description:

GreenLab Micro-Factory is the first MakerSpace in Nigeria. GreenLab Micro-Factory aims not only to provide digital fabrication but also to foster social innovation, engineering and entrepreneurs. They focus on the green-tech field promoting "a green, eco-friendly, and sustainable environment, through research and development, education and training, technological and innovation awareness, and other human capital development projects."[31] A unique characteristic of GreenLab Micro-Factory is that it encourages small-scale development and sustainable practices using digital fabrication and technologies and provides sustainable and simple solutions to social problems. GreenLab Micro-Factory provides 1) workshops and events, 2) open sourced digital fabrication equipment (e.g. laser cutters, 3D printers, milling machines).

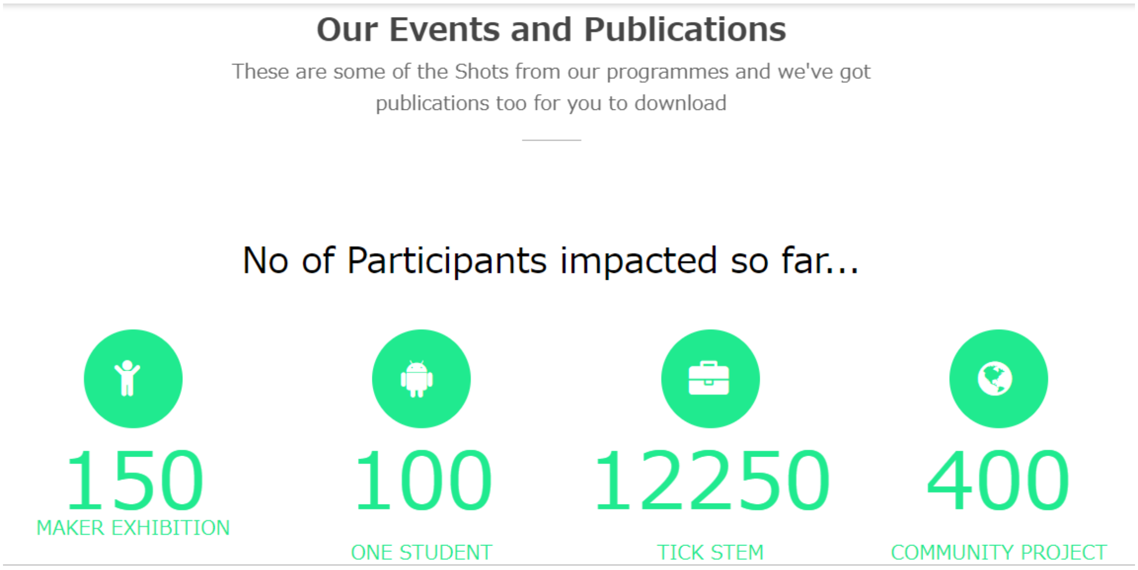
- Founded: 2017
- Founders: Babasile Daniel (M)
- Targets and users: mainly students (from primary to tertiary)
- Partners: undescribed in GreenLab Micro-Factory website
- Products and services:
  - Workshops and events:

[30] GreenLab Micro-factory. http://greenlab-microfactory.org/ (accessed 31 August 2019).
[31] https://www.greenlab-microfactory.org/ (accessed 31 August 2019).

- TICK STEM programme: TICK, which stands for "Talk is Cheap Kit" is a STEM kit developed by GreenLab Micro-Factory to effectively propagate and educate primary and junior secondary school students in science and technology. Using FabLab and other digital fabrication laboratories, GreenLab Micro-Factory provides STEM education at elementary schools in Nigeria.
- Tekly Children Summer Camp: the summer camp is for children to study the basics of programming, including web development, basic design, electronics and robotics programming.
- AJUMOSE open source solar power and 3D printer workshop

➢ Publication: It publishes several reports and publications; all materials are available for download.

- Cartooino Project Book for One Student One Arduino project
- Ajumose Report
- LaFT FabLab research report June 2015 - Babasile Daniel
- Ajumose Summary



(Output of GreenLab Micro-Factory. Available at https://www.greenlab-microfactory.org/events.php [accessed 31August]).

8. Clintonel Innovation Centre (CIC) (Aba, Nigeria)[32]

■ Description:

Clintonel Innovation Centre (CIC) is Nigeria's first MakerSpace established by the University of Nigeria Nsukka (UNN). CIC includes a solar-powered STEM Centre, MakerSpace and Hardware Business Incubator. CIC aims "to transform Nigeria into a technology producer creating massive employment for millions of young Nigerians" and" build capacity in Nigeria for technology development and manufacturing[33]". CIC provides 1) skill training programmes for unemployed

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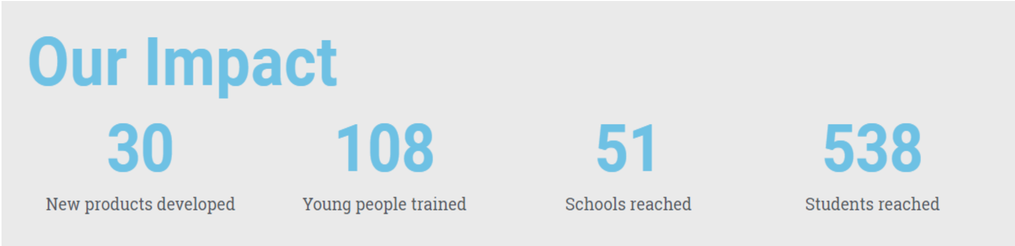
[32] Clintonel Innovation Centre. https://cic.clintonel.biz/ (accessed 31 August 2019).
Youtube TEDx Talks "Why We Need Makerspaces in Nigeria | Tochukwu Clinton Chukwueke TEDxOguiRoad." https://www.youtube.com/watch?v=rPO1wui6Fc8(accessed 31 August 2019).
Youtube "Clintonel Innovation Centre (CIC)" channel. https://www.youtube.com/channel/UChMBoXV7KE3PXWPdK5TXY0g (accessed 31 August 2019).
[33] Clintonel Innovation Centre About. https://cic.clintonel.biz/about/ (accessed 31 August 2019).

young people in Nigeria, 2) STEM education for young people, 3) product design and prototypes using 3D printing, 4) technology incubation, and 4) a MakerSpace. Through those activities, users can develop new products and realize their creative ideas.

- Founded: October 2017
- Founders: Tochukwu Clinton (M)
- Sector: private
- Target or users: mainly students
- Partners: not mentioned on CIC website
- Products and services:
  - Product design: it supports customers in transforming their ideas into three- dimensional models (digital prototypes) through computer aided design.
  - MakerSpace and 3D printing (prototype development)
  - STEM excursion: providing STEM education for young individuals to learn about the latest technologies and encourage them to pursue a STEM career.
  - Training: it develops training courses for youth to become inventors, scientists and engineers.
  - Technology incubation: it provides guidance and support to inventors and innovators, helping them develop their ideas into market-ready products.
- Outcome



(CIC outcome from the website. Available at https://cic.clintonel.biz/about/ [accessed 31 August 2019]).

- One of the main CIC activities is implementing education and training projects. CIC has already launched eight projects to realize its vision. CIC focusses in particular on education and training programmes for youth, such as the “STEM Excursion Center,” “Vision 5000in5” and “CIC Tech Clubs.” CIC is building a school network and offers the above education programmes. CIC’s programme has trained 108 youth and reached 51 schools and 538 students.

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