3D Printing: Enabler of Social Entrepreneurship in Africa? The Roles of FabLabs and Low-Cost 3D Printers

Tobias Schonwetter and Bram Van Wiele

Working Paper 18
Published: 15 October 2018

openAIR
AFRICAN INNOVATION RESEARCH

Authors

Dr. Tobias Schonwetter
Associate Professor, Faculty of Law, University of Cape Town
Director, Intellectual Property Unit, University of Cape Town
Associate Member, Centre for Law, Technology and Society, University of Ottawa
Co-Founding Director and Researcher, Open African Innovation Research (Open AIR)
tobias.schonwetter@uct.ac.za

Bram Van Wiele
PhD Candidate, Faculty of Law, University of Cape Town
Research Assistant, Intellectual Property Unit, University of Cape Town
Researcher, Open African Innovation Research (Open AIR)
bram.van.wiele@gmail.com

The authors will be grateful for inputs and feedback on the contents of this Working Paper. Please use the authors' email addresses provided above.

Abstract

Recognising the potential of 3D printing technology for facilitating locally relevant innovation and social entrepreneurship in Africa, this case study looks at two promising approaches for increasing access of social entrepreneurs to 3D printing technology in South Africa and Kenya: FabLabs and the availability of low-cost 3D printers. Based on data collected during interviews conducted with key players at FabLabs in South Africa and Kenya, as well as with social entrepreneurs making use of low cost 3D printers, this case study seeks to uncover whether either of these approaches, or both, aid the development and scaling up of social entrepreneurial business models in Africa. In particular, it strives to understand better the role of collaborative problem-solving, follow-on innovation, knowledge-sharing and appropriation in this context.

Acknowledgements

We acknowledge the support provided for this research by Open African Innovation Research (Open AIR), the Social Sciences and Humanities Research Council (SSHRC) of Canada, the International Development Research Centre (IDRC), the UK Department for International Development (DFID), the University of Cape Town, and our interviewees.

Keywords

additive manufacturing, 3D printing, collaboration, knowledge-sharing, knowledge appropriation ,knowledge governance, FabLabs, maker movement, scalability, innovation, intellectual property (IP), openness, open source, social entrepreneurship, high technology hubs, informal sector innovation, South Africa, Kenya

Contents

I. Introduction

The last years have seen a significant hype surrounding 3D printing. The technology was touted to revolutionise manufacturing and entrepreneurship, and for the African context, it was quickly hailed as a tool to help African nations overcome their "resource curse" (Mathers, 2015; Ortolani & Di Bella, 2014) and "leapfrog" the industrial revolution (Mungai, 2015; Jacobs, 2015). While much of the hype is fuelled by media reports on individual success stories that tend to neglect differentiating between consumer, industrial, and research applications of the technology, 3D printing still holds great promise for democratising and fostering locally relevant innovation and entrepreneurship through enabling communities and entrepreneurs to create much-needed, locally relevant products.

One exciting field of application for 3D printing in Africa is the field of social entrepreneurship, in support of those focusing their efforts on achieving positive societal impacts by solving pressing social, economic, environmental, or cultural problems. According to one report, "as has been shown with the Fab Labs, [3D printing] could enable locally designed solutions for local problems, potentially bringing large benefits to these economies" (WIPO, 2015, p. 98).

However, (affordable) access to 3D printing technology and know-how is a key challenge for 3D printing to become a real game changer in Africa. This case study analyses two strategies for facilitating access to 3D printing technology on the continent: so-called "FabLabs" on the one hand, and the manufacture and supply of low-cost 3D printers on the other. This research seeks to improve our understanding of whether these strategies enable one particular type of entrepreneurs, *social entrepreneurs,* in Africa to develop viable business models, grow their businesses and, at the same, address social needs and help alleviate prevalent socio-economic challenges. Particular emphasis is on the role of collaborative problem-solving, follow-on innovation, knowledge-sharing and appropriation in this context. To this end, we researched 15 FabLabs in South Africa and Kenya, and four social entrepreneurial projects in Kenya.

This case study forms part of the Open African Innovation Research (Open AIR) project. In researching knowledge governance and innovation dynamics in Africa, Open AIR aims to answer two overarching research questions: "How can open collaborative innovation help businesses scale up and seize the new opportunities of the global knowledge economy?" and "Which intellectual property policies will ensure social and economic benefits of innovation are shared inclusively?" From the outset, Open AIR's focus on open models of innovation and collaboration seems to align well with some of the core principles underpinning FabLabs, and the open and less profit-driven ethos of social entrepreneurs using 3D printing. This case study speaks to at least two of Open AIR's four themes: "high technology hubs" and "informal sector innovation".[1] While, at least in South Africa, FabLabs are to a large extent formalised through government or institutional involvement and, thus, are best categorised as high

[1] Under the "high technology hubs" theme, Open AIR analyses the extent to which formal intellectual poperty (IP) rights are important to the success or failure of Africa's burgeoning tech initiatives at and around high technology hubs, such as makerspaces and FabLabs. Open research under the "informal sector innovation" theme seeks to appreciate how the formal and informal sectors interact in different contexts, and how IP rights might allow for better policy frameworks to encourage economic growth.

tech hubs, the development and use of low-cost 3D printers in Kenya often happens in informal or semi-formal settings, i.e., in settings that are outside formally regulated structures.

In the next section of this Working Paper, we describe our methods, selection of our sample, and our collection of primary data. The two sections that follow introduce the concepts of, and relationship between, social entrepreneurship and 3D printing. Thereafter, we outline the two approaches to facilitating access to 3D printing that were of interest for our study—FabLabs and low-cost 3D printers—and report and reflect on our empirical findings concerning: in the case of FabLabs, accessibility, use, and knowledge-sharing; and, in the case of social enterprises, accessibility, knowledge-sharing, opportunities for scaling, and the role of FabLabs. We end with some conclusions and recommendations.

II. Methods, Sample Selection, Data Collection

A. Research Methods

Methodologically, our study combines secondary desk research with quantitative and qualitative primary research, with emphasis on qualitative research. The fieldwork component of this research was conducted between February and August 2017, during which we interviewed 10 key informants who either hold positions at FabLabs in South Africa or Kenya at the following FabLabs:

South Africa:

- CDI Product Support Space (incorporating the former Cape Town FabLab), at the Craft and Design Institute (CDI), Cape Town, Western Cape Province;
- Limpopo FabLab, Polokwane, Limpopo Province;
- Ekurhuleni FabLabs (in Ekurhuleni townships of Thokoza, Tembisa, Tsakane, Duduza and Vosloorus), Ekurhuleni, Gauteng Province;
- Bloemfontein FabLab, Central University of Technology (CUT), Bloemfontein, Free State Province;
- North West FabLab, Potchefstroom, North West Province;
- Sebokeng FabLab, Vaal University of Technology (VUT), Sebokeng, Gauteng Province; and
- eKasi Labs (in Lynnwood, Ga-Rankuwa and Soweto), Johannesburg/Pretoria, Gauteng Province.

Kenya:[2]

- FabLab Nairobi; and
- Aro FabLab, Kisumu.

We further interviewed four Kenyan social enterprises that make use of low-cost 3D printing technology:

- African Born 3D (AB3D) Printing, Nairobi;

[2] Gearbox in Nairobi, Kenya, only became part of the FabLab network after the data collection for this study was completed. It was thus not included in our analysis.

- Artisan Hive, Nairobi;
- Happy Feet, Nairobi; and
- Medtech Kijenzi, various locations, Kenya.

Details concerning the above-listed FabLabs and social enterprises are provided later in this Working Paper.

B. Focus on FabLabs

This study complements other makerspace-related Open AIR studies, such as the ones by Kraemer-Mbula and Armstrong (2017), and De Beer, Armstrong, Ellis and Kraemer-Mbula (2017). However, for several reasons, emphasis is placed in this study on FabLabs—a specific type of makerspace. First, the concept of makerspaces is broad and entails collectives that participate in myriad activities that do not always include 3D printing. Second, we saw value in exploring government's role in enabling social entrepreneurial activities that facilitate the production of locally relevant products, and the establishment of FabLabs in South Africa was in large part the result of a government initiative. Lastly, the key characteristics of openness and collaboration as expressed in the FabLab Charter[3]—which underpins the functioning of FabLabs globally—is well-aligned with Open AIR's general research context of open and collaborative innovation.

C. Focus on South Africa and Kenya

The scope of our research is geographically limited to South Africa and Kenya. The reason is that South Africa saw a concerted government effort between 2005 and 2009 to establish multiple FabLabs across the country, with the specific aim of enabling communities to address local needs. Kenya, on the other hand, while also being the home of some FabLabs, hosts several social entrepreneurial projects that make use of low-cost 3D printing technology. While South Africa may host similar projects, the Kenyan projects were chosen because they received significantly more attention by the public and the media. South Africa and Kenya are also most often regarded as key drivers in sub-Saharan Africa when it comes to the use of 3D printing technology.

D. Data Collection and Interview Subjects

We collected our primary data through semi-structured interviews, guided by an interview protocol, with, on the one hand, key individuals working at FabLabs and, on the other, social entrepreneurs using 3D printing technology. The interviewees at FabLabs comprised individuals involved in the management of FabLabs, i.e., FabLab managers, FabLab assistants, or FabLab initiative managers. The interviewees from social entrepreneurial projects were mainly their founders and, in one case, the person currently responsible for the running of the project. These interviewees were best placed, in our opinion, to provide relevant insights, including information on the set-up and day-to-day operation of the FabLabs and projects.

[3] The FabLab Charter lays down key principles and guidelines that FabLabs need to comply with. See http://fab.cba.mit.edu/about/charter/

The semi-structured interview focussed on the following elements:

- accessibility;
- use;
- knowledge-sharing; and
- scaling up.

III. Social Entrepreneurship and its Importance in Africa

While little research attention was paid to the concept of "social entrepreneurship" until the end of the 1990s, myriads of articles and book chapters have since been written on the topic—from different angles. Hand (2016) provides a useful overview of some of the most influential academic articles on social entrepreneurship.

Intriguingly, however, much of the existing research is still concerned with defining social entrepreneurship and describing how that concept relates to traditional business or non-profit work. Scholars have, by now, identified dozens of different definitions for social entrepreneurship (see, for instance: Dacin, Dacin, & Matear, 2010; Zahra, Gedajlovic, Neubaum, & Shulman, 2009). In 2012, Abu-Saifan (2012) compiled the following seven leading definitions of social entrepreneurship:

Table 1: Seven Leading Definitions of Social Entrepreneurship (as compiled by Abu-Saifan (2012))

Source	Definition
Bornstein (1998)	A social entrepreneur is a path breaker with a powerful new idea who combines visionary and real-world problem-solving creativity, who has a strong ethical fiber, and who is totally possessed by his or her vision for change.
Thompson et al. (2000)	Social entrepreneurs are people who realize where there is an opportunity to satisfy some unmet need that the state welfare system will not or cannot meet, and who gather together the necessary resources (generally people, often volunteers, money, and premises) and use these to "make a difference".
Dees (1998)	Social entrepreneurs play the role of change agents in the social sector by: • Adopting a mission to create and sustain social value[;] • Recognizing and relentlessly pursuing new opportunities to serve that mission; • Engaging in a process of continuous innovation, adaptation, and learning; • Acting boldly without being limited by resources currently in hand; • Exhibiting a heightened accountability to the constituencies served for the outcomes created.
Brinckerhoff (2009)	A social entrepreneur is someone who takes reasonable risk on behalf of the people their organization serves.

Leadbeater (1997)	Social entrepreneurs are entrepreneurial, innovative, and "transformatory" individuals who are also: leaders, storytellers, people managers, visionary opportunists and alliance builders. They recognize a social problem and organize, create, and manage a venture to make social change.
Zahra et al. [(2009)]	Social entrepreneurship encompasses the activities and processes undertaken to discover, define, and exploit opportunities in order to enhance social wealth by creating new ventures or managing existing organizations in an innovative manner.
Ashoka [(n.d.)]	Social entrepreneurs are individuals with innovative solutions to society's most pressing social problems […]. They are both visionaries and ultimate realists, concerned with the practical implementation of their vision above all else.

Source: Table contents reproduced from Table 2 in Abu-Saifan (2012, p. 24)

And as far back as 2003, Mair and Noboa (2003) identified the following key definitions for social entrepreneurship:

Table 2: Earlier Definitions of Social Entrepreneurship (as compiled by Mair and Noboa (2003))

Author/s & year	**Definition suggested**
Fowler (2000)	Social entrepreneurship is the creation of viable (socio-) economic structures, relations, institutions, organizations, and practices that yield and sustain social benefits.
Hibbert, Hogg et al. (2002)	Social entrepreneurship is the use of entrepreneurial behavior for social ends rather than for profit objectives, or alternatively, that the profits generated are used for the benefit of a specific disadvantaged group.
The Institute for Social Entrepreneurs	Social entrepreneurship is the art of simultaneously pursuing both a financial and a social return on investment.
Canadian Centre for Social Entrepreneurship	Social entrepreneurship falls into two categories: First, in the for-profit sector it encompasses activities emphasizing the importance of a socially-engaged private sector and the benefits that accrue to those who do well by doing good. Second, it refers to activities encouraging more entrepreneurial approaches in the nonprofit sector in order to increase organizational effectiveness and foster long-term sustainability.

Source: Table contents reproduced from Table 1 in Mair and Noboa (2003, p. 3)

From a developing country perspective, one could perhaps criticise that none of the above definitions were suggested by African scholars, and argue that as a result, most of these definitions do not sufficiently consider that in regions where governments do not meet demands in certain sectors, many start-ups seek to fill the void, and in doing so often carry out social entrepreneurial activity without social impetus.

Cognizant of the ongoing definitional difficulties and intricacies concerning the relatively new and contested concept of "social entrepreneurship", and recognising the limitations of one-size-fits-all definitions in this complex domain that is also influenced by cultural context, the term is used in this case study rather broadly—and perhaps over-simplistically—as a shorthand for: entrepreneurs who are primarily interested in achieving positive societal impacts through developing market-oriented innovative solutions to address (local) social needs and solve pressing social, economic, environmental, or cultural problems.

It should be noted, however, that the focus on social return does not preclude social entrepreneurs from simultaneously seeking financial gain. On the contrary, blending the goal of profitability with achieving positive social impact is often a key characteristic of social entrepreneurship ventures, setting it apart from mere non-profit projects. This said, one key factor for our decision to focus our research on *social* entrepreneurs, rather than on entrepreneurs in general, was our assumption that dynamics of collaboration, sharing and co-creation are more likely to exist in the context of business ventures that are not geared towards profit maximisation at all costs.

A closer look at social entrepreneurship from an African perspective, and some of the key factors that can either promote or impede such activities, makes sense for a variety of reasons. Not only is there a general dearth of empirical research that approaches this important topic from an African viewpoint, but social entrepreneurship activity generally focuses on the "bottom of the pyramid"—the large group of poor people—and can thus be regarded as an important building block for the sustainable development of countries (Mair & Noboa, 2006, p. 121). One must, of course, avoid the mistake of downplaying the diversity of the African continent by treating it as a single country, thereby perpetuating the stereotypes of African homogeneity (De Beer, Oguamanam, & Schonwetter, 2013, p. 5). Yet, some important socio-economic and environmental conditions prevail in a number of African countries which provide opportunities for social entrepreneurs to address social needs and help alleviate socio-economic challenges brought about by these conditions, including poverty, poor governance and infrastructure, resource-constraints, climate change, and ongoing market failures in a variety of areas. Having said this, some of these conditions—including limited internet bandwidth and intermittent supply of electricity—can, at the same time, provide significant obstacles for (social) entrepreneurial activity. Thus, according to Rivera-Santos, Holt, Littlewood and Kolk (2015):

> The African continent is characterized by serious social issues, which can become opportunities for business creation, combined with a lack of resources and poor governance, which are likely to present particular challenges for social entrepreneurs and enterprises. (Rivera-Santos et al., 2015, p. 76)

Santos (2012) argues that situations in which simultaneous market and government failures arise, are the context in which social enterprises can typically be expected to emerge. Finally, and even though this aspect is beyond the scope of the present paper, it promises to be a fascinating undertaking to further investigate possible links between the motivations to engage in social entrepreneurship activities and the values and principles that underlie the African philosophy of *ubuntu*, with its emphasis of interconnectedness, caring for others, human interdependence, reciprocity, and collectivism.

IV. 3D Printing and its Potential for Social Entrepreneurship in Africa

3D printing, also known as additive manufacturing, refers to different manufacturing technologies which physically construct objects by consecutively adding layers of material. The technology allows for the localised, decentralised production of myriads of customised products without the need for expensive equipment and production lines. In a broader sense, 3D printing includes the process of creation, customisation and mass dissemination of digital designs followed by the additive manufacturing of the underlying object. The result is that 3D printing not only requires access to hardware, but manufacturing knowledge, and computer-aided design software literacy.

The International Organization for Standardization (ISO) defines seven groups of technologies that currently make up additive manufacturing (ISO, 2015):

- material extrusion;
- vat polymerisation;
- material jetting;
- binder jetting;
- sheet lamination;
- powder bed fusion; and
- direct energy deposition.

This paper focuses on the most common and recognisable form of 3D printing: material extrusion. Material extrusion consists of building an object from the bottom up by selectively depositing layers of material at high temperatures, allowing the layers to cool and bond together. The process itself, the use of low-cost material—commonly plastics[4]—and the speed of production, make it a preferred type of manufacturing for rapid prototyping and small-scale modelling or manufacturing (Lipson & Kurman, 2013, p. 68). Material extrusion 3D printers can therefore be found in businesses, FabLabs, makerspaces, and in the homes of hobbyists alike.

Much of the current hype concerning the prospects of 3D printing for African countries may not be lived up to, and much of it may also relate to the technology's application in the industrial sector. As far as the basic material extrusion printing technique is concerned, however, it only allows for the production of relatively simple products made out of plastic, and a number of technical limitations apply concerning, for instance, size, resolution, accuracy, and the ability to print overhanging parts. This said, basic 3D printing can nevertheless facilitate quick and increasingly cost-effective local production of much-needed goods, and thus reduce reliance on (expensive) imports and industrial supply chains. Consequently, examples now abound of 3D printing technology being used by social entrepreneurs for end-product manufacturing.

Using various case studies, Birtchnell and Hoyle (2014) demonstrated that 3D printing offers a wide range of applications that empower the interests of various groups in the developing world. This

[4] It is beyond the scope of this paper to address the sustainability implications of plastic-based 3D printed products.

research uses insights from the 3D Printing for Development (3D4D) Challenge, a worldwide competition to produce the most scalable grassroots community action project in the Global South involving 3D printing—in which one of our interviewees participated. It illustrates that the technology enables the production of objects that people use and need in their everyday lives.

Other reported examples include the use of extrusion printers for the localised and customised production of prosthetic fingers, hands, and legs in Sudan and Pakistan (Bashir, 2016; Eskin, 2014), and the manufacturing of a weather station helping developing countries to forecast weather-related disasters (Freitag, 2015; Walker, 2016). In Haiti, a local non-governmental organisation (NGO) identified 16 printable medical tools, including umbilical cord clamps, in an attempt to better meet the demands of local medical professionals in rural areas (Matthews, 2015). A similar project, MedTech Kijenzi, is currently underway in Kenya. In addition to printing medical equipment for Kenyan hospitals, this project also develops low-cost, open source 3D printers and software for use in remote clinics in Kenya. The Medtech Kijenzi project will be looked at in more detail below.

While these examples clearly show that access to 3D printing, even in its most basic form, can provide a useful and essential tool for manufacturing locally relevant tools even in the most rural areas, (affordable) access to this technology remains a major challenge in developing countries. In the following section, this paper examines two different approaches to how access to 3D printing technology can be improved in these countries.

V. Two Approaches to Facilitating Social Entrepreneurs' Access to 3D Printing

In this section, we analyse two key strategies for facilitating affordable access, by social entrepreneurs, to 3D printing technology in South Africa and Kenya: (1) the use of FabLab facilities; and (2) manufacture, and supply, of low-cost 3D printers.

A. FabLabs

In recent years, makerspaces and FabLabs have attracted significant public attention, and several studies have addressed the African maker movement from various angles (see, for instance, Armstrong et al., 2018; De Beer et al., 2017; Kraemer-Mbula & Armstrong, 2017). Both makerspaces and FabLabs typically offer to the public off-the-shelf, industrial grade, digital fabrication tools, including 3D printers. In addition, they typically aim at creating environments that facilitate innovative activity, entrepreneurship, and peer-to-peer learning. While a makerspace can broadly be defined as a workshop for individual tinkering, social learning, and group collaboration on creative and technical projects—generally among adults—through interdisciplinary sharing of resources and knowledge (Schrock, 2014, p. 1), the term FabLab describes a more narrowly prescribed concept that is best regarded as a sub-category of, or a certain type of, makerspace.

The first FabLab was established in the early 2000s at the Massachusetts Institute of Technology (MIT) as part of the outreach component of its Center for Bits and Atoms (CBA). Since then, the concept has grown into a global, collaborative network, and today there are several hundred FabLabs around the world (Fab Labs, n.d.). FabLabs are often located in community resource centres like schools and universities, and to officially qualify as a FabLab, labs must: (1) be open to the public (ideally free of charge); (2) support and subscribe to the FabLab Charter; (3) provide a common set of tools and processes, based on the Fab Foundation's inventory; and (4) participate in the global FabLab network. According to the Fab Foundation, FabLabs are "a global network of local Labs, enabling invention by providing access to tools for digital fabrication" (Fab Foundation, n.d.).

FabLabs are a worthwhile research study object against the backdrop of aforementioned overarching research questions of the Open AIR network because openness is one of their key characteristics. According to the Fab Charter:

> Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programs, [and while] [d]esigns and processes developed in fab labs can be protected and sold however an inventor chooses, [they] should remain available for individuals to use and learn from. (CBA, 2012)

In this paper, we distinguish between FabLabs and FabLab initiatives. This is because, in some cases, several FabLabs are part of a broader initiative. For example, the five FabLabs in the Ekurhuleni Municipality in South Africa are run by the same local government, and indeed overseen by the same person. Similarly, the eKasi Labs initiative consists of multiple local hubs and offers FabLab facilities at three of its hubs.

Interestingly, we also noted in our research that a number of facilities carry the name "FabLab" even though they are not officially affiliated with the FabLab network. Cases in point are the FabLabs of the eKasi Labs. Conversely, the Craft and Design Institute's (CDI's) Cape Town FabLab has been integrated into the CDI's Product Support Space and no longer carries the name "FabLab", even though it is still part of the global FabLab network.

i. South Africa

In 2005, the Department of Science and Technology (DST) started rolling out several FabLabs across South Africa, under a programme called SA FabLab (SA FabLab, n.d.). In providing the infrastructure for entrepreneurs to develop new products and produce small batches of niche products, the aim of this initiative was to empower local communities through science and technology. On its website, SA FabLab cited the labs' intended role in addressing local needs:

> The FabLabs can also be used to enable grassroots inventions by providing a platform where communities can have access to advanced tools that can help people make products to address local needs. (SA FabLab, n.d.)

At the peak of the DST's SA FabLab programme, in 2011, the following seven fixed FabLabs existed in South Africa:

- Cape Town FabLab (at the Cape Craft and Design Institute (CCDI), since incorporated into the Product Support Space of the re-named the Craft and Design Institute (CDI);[5]
- Limpopo FabLab;
- Thokoza FabLab;
- Soshanguve FabLab;
- Kimberley FabLab;
- Bloemfontein Fab Lab; and
- North West FabLab.

In addition, there was one mobile FabLab. The mobile FabLab was used in the Eastern Cape Province to promote science, technology, engineering, mathematics, and innovation (STEMI) for children (Mphuthi, 2013, p. 90). In rotating locations, this FabLab visited various schools in the region, including in the cities of Port Elizabeth, Queenstown, and Grahamstown.

However, in 2009 and 2010 the DST made severe cuts to its funding support for FabLabs, and as a result, three FabLabs have since folded: Soshanguve FabLab; Kimberley FabLab; and the mobile FabLab. The five remaining FabLabs were able to obtain alternative sources of funding and thus remain operational. The FabLabs located at universities were able to secure institutional support to continue their operations, while the other Labs obtained provincial or local government support. Notably, provincial and local government support actually led to a resurgence of FabLabs in certain parts of South Africa, particularly in the Ekurhuleni Municipality, in the Gauteng Province.

At the time of the data collection in 2017, there were 13 operational FabLabs in South Africa, as listed in Table 3 below. Figure 1, also below, provides a visual representation of the FabLab landscape in South Africa.

[5] See earlier footnotes on: (1) integration of Cape Town FabLab into CDI Product Support Space; and (2) re-naming of Cape Craft and Design Institute (CCDI) into Craft and Design Institute (CDI).

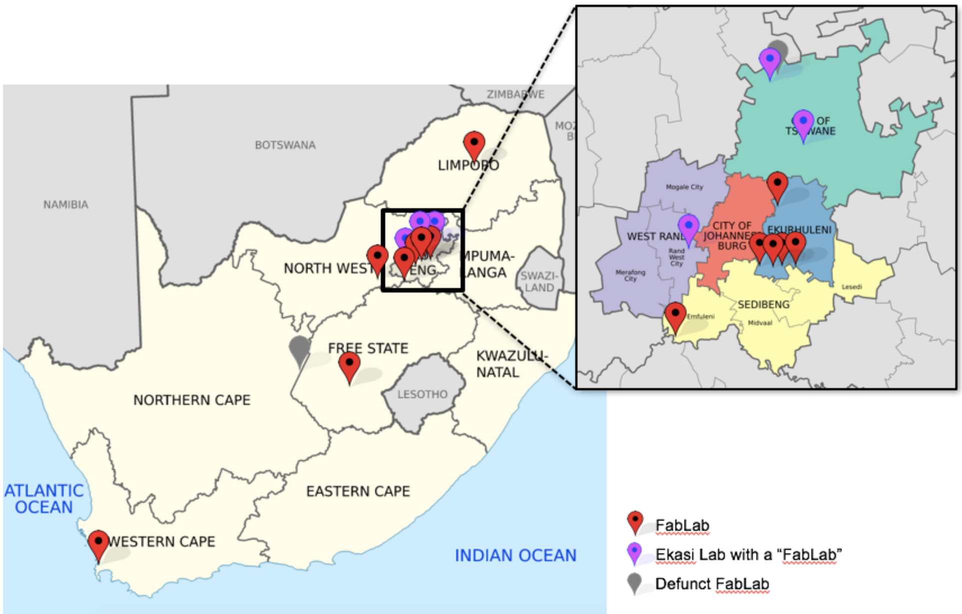
Table 3: FabLabs in South Africa (2017)

Name	Year of establishment	Location	Recipient of initial DST funding	Current funding
CDI Product Support Space (formerly Cape Town FabLab), Craft and Design Institute (CDI) [6]	2006[7]	Cape Town (Centre)	Yes	National, provincial, and local government
Bloemfontein FabLab	2006	Bloemfontein (Centre)	Yes	Central University of Technology, Bloemfontein
North West FabLab	2007	Potchefstroom (Centre)	Yes	North West University, Potchefstroom
Limpopo FabLab	2009	Polokwane (Ga-Mankoeng)	Yes	Limpopo Provincial Government and University of Limpopo
Thokoza FabLab	2011	Ekurhuleni (Thokoza)	Yes	Ekurhuleni Metropolitan Municipality
Tembisa FabLab	2014	Ekurhuleni (Tembisa)	No	Ekurhuleni Metropolitan Municipality
Tsakane FabLab	2015	Ekurhuleni (Tsakane)	No	Ekurhuleni Metropolitan Municipality
Duduza FabLab	2016	Ekurhuleni (Duduza)	No	Ekurhuleni Metropolitan Municipality
Vosloorus FabLab	2017	Ekurhuleni (Vosloorus)	No	Ekurhuleni Metropolitan Municipality
Sebokeng FabLab	2014	Vaal Triangle (Sebokeng)	No	Vaal University of Technology[8]
eKasi Lab Soweto	2016	Johannesburg (Soweto)	No	Gauteng Provincial Government and local government
eKasi Lab Ga-Rankuwa	2014	Pretoria (Ga-Rankuwa)	No	Gauteng Provincial Government and local government

[6] Today's Craft and Design Institute (CDI) was founded in 2001 as the Cape Craft and Design Institute (CCDI).
[7] Today's CDI Product Support Space incorporates what was formerly known as the Cape Town FabLab (which was launched in 2006 at was then still called the Cape Craft and Design Institute (CCDI)).
[8] According to our interviewee at Sebokeng FabLab, the FabLab also has a partnership with the municipality.

eKasi Lab Lynwood	2015	Pretoria (Lynwood)	No	Gauteng Provincial Government and local government

Figure 1: FabLab Landscape in South Africa (2017)



ii. Kenya

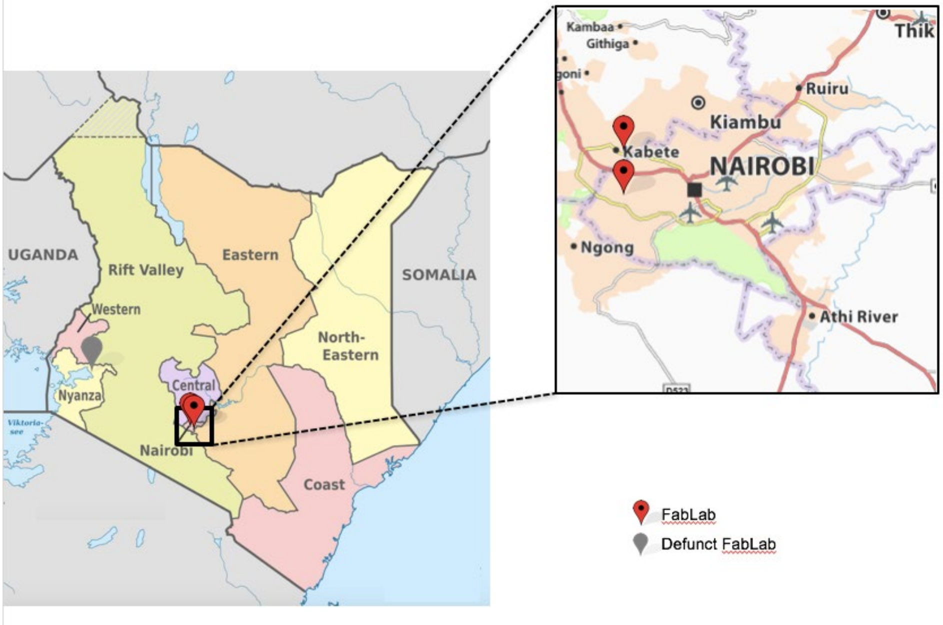
There are, at the time of writing, three operational FabLabs in Kenya, all of which are in Nairobi: FabLab Nairobi, FabLab Kivuli and Gearbox.[9] Aro FabLab, which was located in the city of Kisumu on Lake Victoria, eventually closed down in 2015–16 due to lack of funding.

Table 4: FabLabs in Kenya (2017)

Name	Year	Location	Current Funding
FabLab Nairobi	2009	Nairobi (Upper Kabete)	University of Nairobi and own
FabLab Kivuli[10]	2014	Nairobi (Kivuli)	unknown

[9] As mentioned earlier, Gearbox in Nairobi only became part of the FabLab network after the data collection for this study was completed and was thus not included in our analysis.
[10] The researchers were not able to conduct interviews with FabLab Kivuli representatives and this FabLab has thus been excluded from the analysis.

Figure 2: FabLab Landscape in Kenya (2017)



iii. Our FabLab Typology

FabLabs in South Africa and Kenya can be grouped in various ways, according to, for instance: funding models; governance structures; location; and objectives. In this paper, we differentiate, firstly, between (predominantly and directly) government-based FabLabs, and FabLabs that are based in and supported by institutions other than government ("institution-based")—even if these institutions themselves are recipients of government support and funding.[11] While this distinction appears clear enough at first, it is of course possible that a FabLab falls into both categories—e.g., if the FabLab is at the same time financially supported by government and based at an institution—but we realised that this is typically not the case, and in cases where it is we refer to such FabLabs as hybrids.

Secondly, we were particularly interested in differences and commonalities between FabLabs located in urban centres and those located elsewhere. While countries are typically divided into urban and rural areas, in South Africa we find an important third, peri-urban category, however, that is neither rural nor fully urban: townships and informal settlements (T&IS) (Mahajan, 2014, pp. 1-2). And indeed, many of the FabLabs in South Africa are located in T&IS. We thus categorised the existing active FabLabs in South Africa and Kenya as follows:

[11] Categorisations using similar criteria were developed for makerspaces in Kraemer-Mbula & Armstrong (2017).

Table 5: Typology of FabLabs

	Urban Centres	**Townships[12] and Informal Settlements (T&IS)**	**Rural**
Institution-based (e.g., in these cases, university-based)	• Bloemfontein FabLab • North West FabLab • FabLab Nairobi	• Sebokeng FabLab	• (planned) Limpopo FabLab satellite
Hybrid		• Limpopo FabLab	
Government-based	• CDI Product Support Space (incorporating former Cape Town FabLab)	• eKasi Labs • Ekurhuleni FabLabs	

Institution-Based FabLabs in South Africa and Kenya
This first category ("institution-based") covers FabLabs that are formally or informally connected to an institution. Within this category we identified five existing Labs that are physically located at an institution: three in urban centres and two in T&IS, as well as one planned FabLab in a rural area.

In South Africa, Bloemfontein FabLab and North West FabLab are both located on university grounds in an urban environment. Bloemfontein FabLab is located on the premises of the Central University of Technology (CUT), which currently funds the Lab. The Lab was started in 2006 and is currently run by three people who are each responsible for different sections such as design, electronics, and moulding. North West FabLab is hosted by the Engineering Faculty at North West University. While initially funded by the DST, the Lab is now funded by the university. When DST funding ceased, the FabLab hardware was handed over to the university and the FabLab was incorporated into the university's engineering programme.

While formally a part of the Vaal University of Technology, the Sebokeng FabLab is in fact not located at the urban main campus. Instead, VUT's Southern Gauteng Science and Technology Park, located in the township of Sebokeng, houses the FabLab. Similarly, Limpopo FabLab is located at the Science Education Centre at the University of Limpopo's Turfloop Campus within the Turfloop university township. However, although physically located at the university, Limpopo FabLab is not formally connected to the institution, and funding is provided by the provincial Department of Economic Development and the University of Limpopo. This makes the Limpopo FabLab a hybrid between institution-based and government-based FabLabs.

[12] In the context of this research, township refers to "an urban or peri-urban area occupied predominantly by black South Africans and formerly officially designated for non-white occupation by apartheid segregation laws". See http://www.oed.com/view/Entry/204077

In Kenya, FabLab Nairobi operates from the University of Nairobi's Upper Kabete Campus. In 2009, with support from the Ministry of Science and Technology, the FabLab was initially set up at the University of Nairobi's Faculty of Engineering, at the City Campus. In 2017, the FabLab then moved to the University of Nairobi's Upper Kabete Campus where it became part of the university's Science Park. FabLab Nairobi is largely run by engineering students and three full time staff members. In addition to the day-to-day funding by the University of Nairobi, the FabLab raises its own funds through providing services, including on-demand design and fabrication, and facilitating projects.

Government-Based FabLabs in South Africa

This second category ("government-based") refers to FabLabs that were established as part of a government-led initiative and still rely on government, e.g., for management or funding. We identified three such FabLab initiatives, all in South Africa: Ekurhuleni FabLabs (consisting of five individual FabLabs), eKasi Labs (the three of them that accommodate a FabLab), and the Craft and Design Institute (CDI) Product Support Space in Cape Town, which includes the facilities of the former Cape Town FabLab. Two of these three government-based FabLab initiatives—the Ekurhuleni FabLabs and the eKasi FabLabs—are located in townships.

The CDI, formerly known as the Cape Craft and Design Institute (CCDI), was set up in 2001 in the city centre of Cape Town as a joint initiative between the Western Cape Government and Cape Technikon (now Cape Peninsula University of Technology), with the main aim of enterprise development in the region's craft and design sector. While the DST supported the other initial FabLabs in South Africa, the then-CCDI hosted and managed Cape Town FabLab (which has since become part of the CDI Product Support Space). Currently, the CDI functions as a sector development agency aimed at small, medium and micro enterprises (SMME). Through its business development programme, the CDI assists businesses in developing ideas and prototyping. Other programmes include market and business support during later stages of development. The CDI also offers design support, particularly looking at design solutions that can improve lives and business competitiveness within health, education, agriculture, and housing. The CDI receives national, provincial, and local government support.

Ekurhuleni FabLabs was the first FabLab initiative in South Africa that comprised more than one FabLab in single city, the City of Ekurhuleni next to Johannesburg. In 2001, the Ekurhuleni Metropolitan Municipality set up the first of the city's FabLabs, in Thokoza township. In the following years, the Municipality set up another four—in Tembisa, Tsakane, Duduza, and Vosloorus townships—for a total of five Fablabs in the city. Ekurhuleni considers FabLabs as a platform for job creation, and even has plans to create a "mega FabLab" in the near future. Since all FabLabs under this initiative function in a similar fashion, they will be collectively referred to in the remainder of this paper as "Ekurhuleni FabLabs".

Started around 2014, the eKasi Lab initiative is funded by the Gauteng Provincial Government's Innovation Hub. The eKasi Labs are co-creation and innovation spaces in townships that enable local communities to access services and facilities with the aim of re-industrialising the community. The use of these FabLab facilities is, however, limited to users who are part of the incubation and commercialisation programme. We found three eKasi Labs that house a FabLab: one at the

Innovation Hub—the main eKasi hub located in the industrial zone near the suburb of Lynnwood—and two T&IS-based eKasi Labs in Ga-Rankuwa and Soweto. The FabLabs can be used by users of the other eKasi Labs. While the innovation hub is located in an industrial zone, the eKasi Lab Ga-Rankuwa and eKasi Lab Soweto are located within the respective townships. The three eKasi FabLabs operate in similar ways and therefore are collectively treated in this paper as “eKasi FabLabs”.

(At present, there are no government-funded or institution-based FabLabs located in rural areas in either South Africa or Kenya. However, Limpopo FabLab is planning to set up a satellite FabLab in the rural Vhembe region in the near future.)

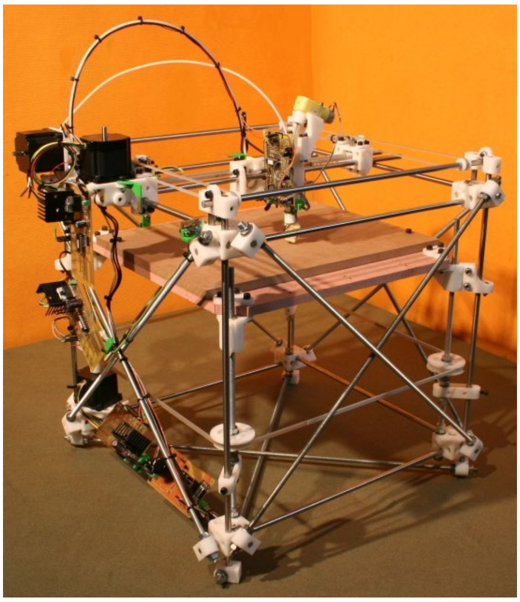
B. Low-Cost (Open Source) 3D Printers and their Use by Four Social Entrepreneurship Initiatives

Making 3D printers more affordable is another key strategy for increasing access to this technology. Low-cost 3D printers are often defined as printers costing less than USD 5,000 (De Beer et al., 2016, p. 18). However, even the cost of these “low-cost 3D printers” must still be regarded as a substantial access barrier for most individuals or SMMEs—particularly in developing countries. Therefore, this case study looked at low-cost 3D printers that cost significantly less than USD 5,000.

Initially, our aim was to focus our investigation on one low-cost 3D printer manufacturer in Nairobi, Kenya—African Born 3D Printing (AB3D). At the time of writing this study, AB3D sells its printers for KES40,000, or about USD400. During our research we became aware, however, of three exciting social enterprises in the region that make use of low-cost 3D printing technology. In order to broaden our evidence-base we thus decided to expand our research. Interestingly, it became immediately apparent that open source 3D printers play a key role in all these initiatives.

While commercial hardware producers play an increasingly important role in the 3D printer consumer market, the rise of consumer 3D printers is in part attributable to the emergence of various open source 3D printer initiatives (Tech, Ferdinand, & Dopfer, 2016). The open source character of these printers generally provides free access to the underlying blueprints, combined with the permission for third parties to freely use and adapt the design. One of the most well-known open source printers is the RepRap, a largely self-reproducing open source 3D printer that has gained popularity in communities of researchers, hobbyist, and hackers alike. RepRap printers use the materials extrusion printing process and are able to manufacture many of their own components (Jones et al., 2011). Currently, there are over 60 different RepRap designs available online for free, either under an open source General Public Licence (GPL) or Creative Commons license (RepRap, 2018).

Figure 3: The First Version RepRap Printer: RepRap 1.0 Darwin



Source: http://commons.wikimedia.org/wiki/File:Reprap_Darwin.jpg

We looked at four social enterprises in Kenya that directly use open source printing hardware, particularly RepRap derivative printers (see Table 6). While three of these social enterprises use their 3D printers to locally manufacture goods, one initiative focuses on the production of open source printers and associated training and support.

Table 6: Social Entrepreneurs using Open Source 3D Printers

Enterprise	Year established	Products	3D printing hardware
AB3D	2015	Affordable 3D printers, education tools	RepRap Derivative
Happy Feet	2013	Medicated shoes	RepRap Derivative
Artisan Hive	2016	No delineated scope	RepRap Derivative
MedTech Kijenzi	2014	Medical equipment	RepRap Derivative

AB3D is a hardware start-up based in Nairobi, Kenya, that aims to provide easy and affordable access to 3D printing technology through the production of low-cost 3D printers. AB3D designs, produces, and sells 3D printers made from electronic waste and locally available materials at a fraction of the price of commercially available machines. Most of the electric and electronic materials, such as wires, motors, and power supplies, are collected from a local Waste Electronical and Electrical Equipment Centre. Other components are either produced by local craftsmen or 3D printed by AB3D using their own machines. In addition to their core activity of providing low-cost 3D printers, they also provide, among other things, 3D printing services, education, and training. Both co-founders, Roy Ombatti and Karl Heinz, are social entrepreneurs who use 3D printing as a tool to create locally relevant goods. In fact, Roy Ombatti realised the need for affordable access to 3D printing technology during his work on the Happy Feet project.

The goal of the Happy Feet project is to create affordable, customised and medicated shoes for people with deformed feet resulting from sand flea infestation, especially in poorer areas. The project is the result of the aforementioned 3D for Development Challenge (3D4D). An international NGO donated a 3D printer to a local FabLab and invited its users to submit ideas for the 3D4D challenge. Having volunteered with an NGO in the field of sand flea infestation before, Roy Ombatti decided to create customised shoes for people with deformed feet.

In 2016, Karl Heinz founded Artisan Hive. Artisan Hive creates social designs to solve or mitigate problems in communities through 3D printing, while at the same time creating a sustainable business model around it. For example, Artisan Hive developed a 3D printed headlamp made from locally available components to solve the problem of insufficient lighting for local fishermen when working very early or very late. In the future, they aim to train and equip local fishermen so that they themselves can produce and sell the product at a profit. Currently in its pilot phase, Artisan Hive makes use of the facilities at FabLab Nairobi where they mainly produce 3D printed microscopes. In the future, however, the goal is to set up 3D printing kiosks to bring manufacturing to the communities. These kiosks would form a hybrid between the two 3D enabling initiatives examined in this paper, namely FabLabs and low-cost printers, by creating a small physical space that enables access to 3D printing knowledge and technology by using low-cost printers. Through education and training in 3D printing, Artisan Hive also aims to have “foot soldiers” that can go to communities to solve everyday problems.

As mentioned earlier, the MedTech Kijenzi project is an initiative aimed at helping mitigating equipment supply shortages faced by rural medical facilities in Kenya. Typically, problems arise from derelict machinery, inadequate supply chains, and limited access to specialty equipment. The MedTech Kijenzi project’s approach is to use 3D printing technology and educate clinic personnel on the use of this technology to function more efficiently and independently. Started in 2014, the project team comprises professors, engineers, students, and makers. In its initial phase, the project assessed eight hospitals in Kenya to establish which items are in store, need replacement, or are difficult to obtain. Thereafter, the team established to what extent these items could be produced locally by using 3D printing technology. At the time of writing this paper, the project was busy analysing their data and research results.

VI. Empirical Findings and Analysis: FabLabs

In this section, we highlight some of our key empirical research findings with regards to accessing and using FabLabs.

A. Accessibility

Based on our interviews, we established three factors that play a key role when determining whether a FabLab can be considered accessible or not. These are:

- openness to the general public;
- fees; and
- location.

i. Openness to General Public

According to the Fab Charter: "Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programs" (CBA, 2012). We found that only one FabLab initiative was not open for use by the general public: The eKasi FabLabs in Soweto, Ga-Rankuwa and Lynwood were only open to those who are part of the eKasi incubator programme. However, these Labs are considering opening their doors to the general public in the future.

ii. Fees

At the time of conducting our fieldwork, none of the FabLabs in South Africa imposed any general *membership fees*. This said however, ad hoc fees applied in Limpopo FabLab, as they charged a small fee, generally ZAR 10 to 15 (approximately USD 1), for learners as part of experimentation programmes. In Kenya, FabLab Nairobi reported that they applied charges on a case-by-case basis. For example, individuals will typically be charged a membership fee; however, experimentation for the purpose of learning may be free-of-charge to the extent that the production is not excessive. Start-ups and other companies, however, are charged a fee for registration, machine use, and services.

In addition to these approaches to membership fees, we observed an interesting difference when it comes to charging *usage fees*. Three FabLabs—Bloemfontein FabLab, North West FabLab, and Sebokeng FabLab—reported that they charge their users for material use and machine time. All other FabLabs did not charge such usage fees. However, it should be noted that the use of FabLabs generally excludes mass production. While this is typically prohibited by internal rules, some FabLabs, such as Limpopo FabLab, have systems in place to charge fees if users exceed an allocated amount. Such charges, even if only at operating cost, could be an access barrier for some (potential) users. For example, interviewee 3 (2017) raised the issue of affordability for poorer users:

> [...] you got a lot of people coming from streets and you also got the school kids and the community also coming in. It's a bit difficult that you have to charge these people because, essentially, they don't have a lot of skills and you are training them and you're showing them how everything works. But the problem is that these people are coming to you to acquire skills and they don't have funding.

iii. Location

We found that location can become a potential barrier for accessing FabLabs, and three factors seem to play a key role in this context:

- availability of transport to and from the FabLab;
- physical access barriers to FabLabs premises located at universities; and
- bias.

Representatives from FabLabs located in urban areas indicated that transport to and from their FabLab is a major problem for those who reside outside of these urban areas. Similarly, interviewees from Limpopo FabLab reported that their location in a township presented an access barrier for users from rural areas. It is for this reason that this FabLab is now setting up a satellite Lab in a rural area in the Vhembe district. Moreover, interviewees from North West FabLab shared with us their perception that people from the community often find it cumbersome and difficult to access university premises.

Similarly, FabLab Nairobi interviewees raised the concern that the FabLab's location on a university campus might negatively affect utilisation of these facilities by the general public. It was pointed out to us that those who are not affiliated with university campuses are usually unfamiliar with, and in some cases intimidated by, their access procedures.

Another concern raised was that FabLab Nairobi is located on a largely female-dominated campus—the College of Agriculture and Veterinary Sciences campus—yet, the typical users of the FabLab are male engineering students. The FabLab was initially housed on the engineering campus, and engineering students might now be reluctant to commute to another campus, while those working or studying at the College of Agriculture and Veterinary Sciences campus typically do not make use the FabLab's facilities, or at least, not yet.

Finally, various FabLab representatives argued that biases towards a FabLab's location may present a formidable access barrier, often associated with assumptions about its users and safety concerns. For instance, FabLabs located in townships indicated that people from urban areas do not typically use their facilities, and that location bias may play a role in this. For instance, according to interviewee 4 (2017):

> the one hindrance factor that we have to look at [is that] people are sometimes a bit sceptical [and] afraid to get into the township to use the Lab.

B. Use

As far as the use of FabLabs is concerned, we distinguished in our investigation between different user groups on the one hand, and general usage patterns on the other. We then analysed in more detail how 3D printing technology in FabLabs is being used generally, and by social entrepreneurs in particular.

i. Users

We found that, according to our interviewees, FabLabs are used by a variety of different user groups, including entrepreneurs, learners, students, and the general public. We noted that two initiatives in particular, eKasi FabLabs and the CDI Product Support Space, are primarily used by entrepreneurs. The reason for this appears to be that these Labs, while targeting different audiences, put emphasis on incubation and SME development. More specifically, eKasi FabLabs have a school learners' programme where learners make use of the facilities; while many of the users of the CDI Product Support Space are craft producers, designers, makers, hobbyists, creative enterprises, entrepreneurs, and the general public.

All other Labs have a rather diverse user base even though the four Labs located at universities—Bloemfontein FabLab, North West FabLab, Sebokeng FabLab, and FabLab Nairobi—are predominantly used by students from their respective universities. Nearby educational institutions generally seem to influence a FabLab's user base. For instance, many of Bloemfontein FabLab's users are students from a nearby high school, as well as students from the neighbouring University of the Free State.

With the exception of Sebokeng FabLab and Ekurhuleni FabLabs, all Labs reported that they were predominantly used by male users. This corresponds with findings of research conducted in relation to makerspaces in the Gauteng Province, South Africa (Kraemer-Mbula & Armstrong, 2017). However, only FabLab Nairobi explicitly mentioned that the under-representation of women is a great concern to them, and that they use specific outreach programmes to better reach out to female users.

We noted that the majority of users at all FabLabs that we investigated were younger than 35 years old, and in the case of Ekurhuleni FabLabs, the majority of users were reported to be even younger (between 6 and 16 years).

ii. Usage

According to our informants, the predominant uses within FabLabs are product development, prototyping, and teaching. Within the institution-based FabLabs, uses also often include school projects. Bloemfontein FabLab, for instance, is mainly used for school projects and to supplement the theoretical teaching the students receive in school. This said, the eKasi FabLabs are predominantly used for promotional and marketing material for the businesses that are part of their incubation programme. Here, the focus seems to be on business development, rather than on prototyping and developing new products.

We were told of only a few cases in which FabLabs were used for manufacturing end products. For South Africa, none of these cases involved 3D printing technology.

iii. 3D Printing

The Fab Foundation has created an inventory of recommended hardware and materials to be deployed in a full FabLab. FabLab core equipment typically includes a variety of cutting and milling machinery, as well as 3D printers. The full list of recommended equipment is available on the Fab

Foundation website (Fab Foundation, n.d.). All FabLabs included in this study provided access to 3D printing hardware and software, as explained in more detail below.

Hardware

Most FabLabs in South Africa and Kenya were equipped with one or two 3D printers. However, the CDI Product Support Space in Cape Town had four such printers, and Sebokeng FabLab had eight. The high number of 3D printers available at Sebokeng FabLab is due to the fact that this Lab hosts the Idea to Product (I2P) initiative. Through providing 3D printing facilities, the I2P initiative aims to empower communities "to locally conceptualize, define, develop and design their own solutions to problems as well as to offer new ways of thinking about and addressing their own local problems" (Maker Station, n.d.). Only two of the FabLabs, Limpopo FabLab and eKasi Lab Soweto FabLab, indicated a low use of their 3D printing machinery.

While all Labs had proprietary material extrusion 3D printers, North West FabLab also had an open source RepRap printer. FabLab Nairobi indirectly provides access to open source 3D printers by housing the Artisan Hive projects which make use of open source 3D printers. Interestingly, managers of FabLab Nairobi complained about the high cost of their proprietary 3D printing hardware. In particular, they argued that filament is very costly and protected by technical protection measures, to prevent the use of cheaper third-party materials.

Software

As far as software is concerned, we were particularly interested in whether FabLabs and their users make use of proprietary or open source software. During our interviews, we noted, however, that the concept of open source software is not well-understood and often confused with free software or freemium software, i.e., software that only offers certain basic features for free.

Having said this, most FabLabs provided access to both open source and proprietary software, and all but two indicated a preference for proprietary software. The reasons given included user-friendliness of the user interface, conformity with industry standards, and the absence of bugs. However, the CDI Product Support Space and Limpopo FabLab mainly use—and encourage the use of—open source software, mainly because their users can get free copies and use these outside their FabLab facilities. At the same time, both the CDI Product Support Space and Limpopo FabLab saw a need to continue using proprietary software at the Lab, too.

One FabLab, Sebokeng FabLab, shared with us that they employ a "use appropriate approach" when it comes to software: for training and introduction to CAD drawing purposes, the Lab uses Autodesk 123Design, under a freemium licence scheme which allows the free use of basic features of the software, with a premium charged for additional functionality. In addition, the Lab provides access to Autodesk Fusion 360, and students can get a 2-year free licence on Autodesk 123D when registering on the Autodesk website. More expensive proprietary software such as Solidworks and Solid Edge is only used for more professional purposes.

C. Knowledge-Sharing

As a next step, we examined the attitude of FabLab users towards knowledge sharing or appropriation.

We found that while all FabLabs offer some kind of formalised training, typically through seminars, workshops or one-one-one training, peer-to-peer learning plays a critical role. All FabLabs indicated a level of peer-to-peer learning, where users teach one another how to use the machinery and improve designs. In many cases, peer-to-peer learning was an integral part of the functioning of the FabLab. For instance, while the participants of the eKasi programme receive training on the machines at the beginning of the programme, many users joined at a later time. That knowledge gap is filled through peer learning from more experienced users. Limpopo FabLab even has a tutoring system in place where experienced users teach and assist new users. This system compensates for the lack of teaching staff at the FabLab.

Most FabLab interviewees reported that the issue of knowledge appropriation, e.g., in the form of intellectual property rights, comes up on a regular basis. Most FabLabs have been asked by some of their users to sign non-disclosure agreements (NDAs) or memoranda of understanding (MOUs). The FabLabs have, however, very different approaches as to how to handle such requests. The CDI Product Support Space, for instance, does not sign NDAs because they are an open access facility where non-disclosure can in their view not be guaranteed. By contrast, Bloemfontein FabLab provides and uses a standardised NDA form.

We observed several approaches that aim to cater for users' needs to access legal advice. The eKasi Labs programme, for example, offers its users a consultation with the Innovation Hub's legal advisors in Tshwane. Sebokeng FabLab refers those who seek intellectual property protection to their Enterprise Development Unit, and users of the FabLab Nairobi have access to the university's Intellectual Property Management Office.

We noted that none of the FabLabs asserts any claims on innovations resulting from the use of their facilities; however, FabLabs Ekurhuleni expects express recognition if a product was developed in their facilities.

More broadly, anecdotal evidence at both Limpopo FabLab and FabLab Nairobi suggests that the sharing of ideas is essential for product development and market success, and users who were reluctant to share typically did not successfully complete their project. According to interviewee 6 (2017), from Limpopo FabLab:

> What I have discovered is that those that do have this problem of opening up their projects and their ideas have always had a problem of actually never completing their projects. And I've also done follow ups just to check how far they would be. But, none of them has ever succeeded with getting a prototype and even moving forward.

Similarly, interviewee 10 (2017), from FabLab Nairobi stated:

> So we do get those people who really want to keep it to themselves. They think they have a brilliant idea, but the problem is they're not designers themselves, so they don't know anything about the drawbacks or loopholes of the designs. That's why we invite you to share your idea with one or two people to further the design, not just keep it to yourself. Because most of the people who have come and told me we need to sign an MOU, all their products have problems.

And interviewee 9 (2017), from FabLab Nairobi stated:

> It's the only way ideas are improved. But there's the culture in Africa, most of the time as I said earlier: 'I have an idea—it's mine. I don't want to share it. I want to get rich and sell it tomorrow.' But it usually doesn't work that way. At least from being in FabLabs, that's what we've learned. You need all these people that are around you to give you different ideas. You need people around you to give you different networks. There are people relevant for your idea to go out. So I think open sourcing most of our ideas is something that needs to be encouraged a lot, especially in an African set-up.

D. FabLabs and Social Entrepreneurs

One focus of our research was on identifying instances in which social entrepreneurs make use of 3D printing facilities in FabLabs, and to get a better understanding of the extent to which this occurs.

Several FabLabs (Limpopo, CDI Product Support Space in Cape Town, Bloemfontein, Ekurhuleni, North West, Sebokeng, and Nairobi) indicated that their facilities are being used for social entrepreneurial activities. Notably, however, only two FabLabs in South Africa, and one in Kenya, saw their 3D printing facilities being used for such activities. In both Limpopo FabLab and North West FabLab, 3D printing was used to create 3D models of sanitary infrastructure for demonstration and pitching purposes. FabLab Nairobi was the only FabLab that saw end product manufacturing of social entrepreneurial goods via the Artisan Hive project it houses. Artisan Hive primarily uses the physical space of the Nairobi FabLab and uses its own low-cost 3D printers. Ken Abwao, from FabLab Nairobi (Interviewee 10, 2017), suggested that 3D printing technology is still relatively new, and especially people in rural areas are often unfamiliar with the technology and how it can be used to their benefit.

In spite of the low numbers of social entrepreneurs using their facilities in general and their 3D printing hardware and software in particular, we found that none of the FabLabs actively reached out to social entrepreneurs. We, in fact, observed that while many FabLabs recognise the importance of outreach and growing their user base, there appears to be a general lack in proactive outreach activities. Various FabLabs, especially those with facilities that are already used to capacity such as Bloemfontein FabLab and North West FabLab, currently take no active steps in growing their user base, and solely respond to user demand. The eKasi Lab Soweto FabLab indicated that it planned to advertise its facilities better in future. Some FabLabs reported that they have or are engaged in outreach activities to grow their user base, but none of these FabLabs had reached out specifically to social entrepreneurs. Instead, the preferred target audience for FabLab outreach activities remains students and learners. It seems that overall outreach activities have had little success. The CDI Product Support Space, for instance, reported that it had tried to reach new users through its outreach programme, yet many of its current users joined as a result of referrals rather than their outreach activities. And managers of Sebokeng FabLab and Ekurhuleni FabLabs admitted that many people are probably not aware of their existence.

In our interactions with social entrepreneurs in Kenya we learned, however, that while social entrepreneurs may make limited use of the FabLabs and their 3D printers to carry out their social entrepreneurial activities, many of them used local FabLabs or makerspaces to acquaint themselves with 3D printing technology. And in some cases, FabLabs have played advisory roles for social enterprises or served as a backup facility when their own 3D printers have broken down.

VII. Empirical Findings and Analysis: Low-Cost 3D Printers and Social Entrepreneurship

While the link between social entrepreneurship and the accessibility of 3D printing technologies at FabLabs in South Africa and Kenya was, perhaps, not quite as pronounced as initially expected, our research suggests a much closer link between the availability of affordable and openly accessible 3D printing technology and social entrepreneurship.

A. Hardware and Software

3D printers are, for instance, the primary manufacturing tool for Artisan Hive and they only resort to other means of manufacturing if it cannot be done by 3D printing. In the words of Karl Heinz (interviewee 11, 2017), founder Artisan Hive, 3D printing is “the easiest and cheapest way”. In using 3D printing as the main production method, Artisan Hive says it is less dependent on supply chains, and the investment cost in a printer repays itself in a short time period. For instance, the initial investment in two 3D printers to enable local fishermen to produce headlamps could potentially repay itself in a month. Similarly, according to AB3D founder, Roy Ombatti (interviewee 8, 2017):

> You give me the printer and we make the shoes and it’s just that simple. Change people’s lives. It’s very direct. As opposed to perhaps what if we didn’t have 3D printers at all, forget even the expensive ones, at all. This project would never proceed because the conventional manufacturing techniques would have involved perhaps injection moulding, which for a certain number is super, super expensive.

All social entrepreneurial projects investigated are based on and indicated a strong preference for their own open source RepRap derivative printers. For example, AB3D printers, used for the Happy Feet projects, are based on one of the open source RepRap hardware designs. We repeatedly heard that the speed and quality achieved by using these printers meets, or even surpasses that of commercial printers. The MedTech Kijenzi project also relies on the open source RepRap design for its printers and uses a customised design that focuses on portability so that it can be easily assembled and transported. Another reason for the project to choose a RepRap design above a commercial printer is the ability to locally repair the printer.

According to interviewee 14 (2017), leading the MedTech Kijenzi project:

> We also wanted a printer that would be very easy to repair. We used commercial printers last year. If something breaks, a lot of the commercial designs are not made for you to fix it yourself. They require some sort of assistance from the company that makes them. As we don't always have that option as we would have to order components from Europe or the States to be able to do that, we wanted a printer that could be easily maintained and repaired without having to rely on anyone else. [...] [Open source 3D] printers are really designed to be used in a community because you can make parts for each other, people can bounce ideas off each other, and their general customisability. They are not meant to be used alone. [...] A well maintained and designed RepRap, in my opinion, can compete with any of the commercial printers, particularly if you had a hand in its design [...].

And according to Roy Ombatti (interviewee 8, 2017):

> We would have never built the first printer if the design wasn't open source.

As far as software is concerned, however, we observed a similar attitude towards open source software as observed in FabLabs. The social entrepreneurs interviewed generally prefer and use proprietary software due to its perceived ease of use and reliability. However, affordability and, as a result, software piracy remains an issue. Interviewee 11 (2017), from Artisan Hive stated:

> I have the chance to have an original copy of Solidworks design software, which is hard to get. So they actually gave a few to makerspaces and start-ups. That is the biggest thing that we have. [But] most of our students [...] can't afford to buy 10,000-dollar software. And most open source software is either difficult to use or not robust enough to design.

B. Knowledge-Sharing

All social entrepreneurial projects investigated in this study were generally committed to the open source sharing of their designs and other data. We observed that products of some of the projects are derived from open source designs. For instance, Artisan Hive's main project, a 3D printed microscope, is based on an open-source-licensed design by Richard Bowman from the Department of Physics at the University of Bath in the UK. Similarly, many designs produced under the AB3D umbrella are based on available open source designs. At the same time, many designs created by these social entrepreneurs—original, customised, or improved—are shared back with the public. Artisan Hive, for example, makes all its designs available under an open source licence on its website.

Karl Heinz (interviewee 11, 2017):

> As of now we don't really focus on [knowledge appropriation] because we want first of all to open a framework to just encourage creativity and design in our communities. [...] We believe in open collaboration [...] and so we try as much as possible to open our designs. On our website you would have the files for anything we make. Anything we make is open source.

And according to Roy Ombatti (interviewee 8, 2017):

> It's ethical, to be fair and give back.

MedTech Kijenzi is similarly dedicated to open source and aims to eventually share its data, printer, and object designs through open source licencing.

AB3D's Roy Ombatti also stated that he widely shares his technical knowledge through teaching and other activities. And while he was also in favour of sharing, in the context of his AB3D initiative, he adopted a somewhat different approach towards his Happy Feet project, for which he aims to seek strong formal intellectual property protection in order to preserve its original vision. Roy Ombatti (interviewee 8, 2017):

> It's less that others cannot copy, but more so that my initial vision to why I created it can remain as it is. I wouldn't want someone with more muscle and more money to come in, take it up and perhaps make more money out of that and exploit the people. I want to retain that control or initial vision as to why we started this. It's less to block out those who want to copy, but more to protect its original mission and see it through.

C. Sustainability and Scaling Up

As mentioned earlier, one of Open AIR's overarching research questions is how open collaborative innovation can help businesses scale up and seize the new opportunities of a global knowledge economy. While a broad definition of scaling often involves expanding the size of an organisation and/or the reach of products and services, Open AIR recognises that scaling up can, or must, mean different things in different sectors and contexts. Against this background, Open AIR seeks to develop its own innovation-focused and context-sensitive definition of scaling up; at least partly built on what our research subjects consider as scaling up in their respective fields. We therefore sought input from our interviewees as to whether and how their innovations are scalable, and what this means for them.

It seems that for the social entrepreneurs we interviewed, the issue of scaling up is mainly linked to: (a) becoming (more) sustainable; and (b) increased impact of their work and products.

In the absence of external funding, Artisan Hive aims to make their projects sustainable through also offering training for a fee. At the same time, however, they are committed to keeping their designs open as their current focus is "to inspire and create". This said, they consider looking into a formal form of intellectual property protection at a later stage, once people have been exposed to their designs and creative efforts.

For Artisan Hive, scaling up means making 3D printers, knowledge, and locally relevant products more available in remote areas. More specifically, interviewee 11, from Artisan Hive, described his idea of scaling up as follows:

> The scale up for us is access to funding that we can set up for space to train local artisans in 3D printing, manufacture the printers locally and then open up to more digital tools. For example, if we need to incorporate CNC [computer numerical control] machinery into 3D printing, I want to get one [CNC machine]. [...] But I'd like to have a physical space, like a FabLab, where I also train artisans.

While the project in its current phase is funded by Artisan Hive's founder, external funding is considered essential for Artisan Hive to scale up.

For AB3D, scaling up would result in a broader platform offering. Roy Ombatti envisions a hardware-based and hardware-driven umbrella platform, which offers health care, educational, and agricultural solutions. Yet, such a platform would include alternative manufacturing methods to supplement its current offerings, including the use of CNC machines and laser cutters. AB3D would aim to build these machines themselves, making them also low-cost. According to Roy Ombatti, interviewee 8 (2017):

> That is my vision of scaling [for AB3D]: Touching more lives, but not just with one thing, but with different things.

Interestingly, for none of the social entrepreneurs using low-cost printers did scaling up involve moving away from their current open source 3D printer designs towards using commercial printers. Karl Heinz from Artisan Hive, interviewee 11 (2017), expressly stated:

> We only refine the design for sale of our printers. [...] I will not invest 2,000 dollars in printers. I would make multiple printers.

VIII. Conclusions

Recognising 3D printing's potential for facilitating locally relevant innovation and social entrepreneurship in Africa, this case study looked at two promising approaches for increasing the access of social entrepreneurs to 3D printing technology in South Africa and Kenya: FabLabs and the availability of low-cost 3D printers. In doing so, we sought to uncover whether either of these approaches, or both, aid the development and scaling up of social entrepreneurial business models in Africa. In particular, we wanted to understand better the role of collaborative problem-solving, follow-on innovation, knowledge sharing, and appropriation in this context.

We started off by mapping the current FabLab landscape in the two study countries and proposing a typology of FabLabs, based on where they are located and how they are supported.

We then investigated, whether FabLabs are generally accessible to the public, and which user groups typically make use of FabLabs, and for what purposes. As far as the general accessibility of FabLabs is concerned, we identified three key factors that determine whether a FabLab can be considered accessible: openness to the general public; fees; and location. In keeping with international FabLab standards as set out in the Fab Charter, all FabLabs were open to the public, and none of the Labs investigated charged a membership fee; only a few Labs charged usage fees. Most FabLabs allowed free usage of their facilities as long as the use did not exceed development and prototyping purposes. The locations of the FabLabs influenced their utilisation in various ways: cumbersome or costly transport options were seen as a deterrent for using FabLabs, and university access procedures were held to negatively affect the usage of FabLabs located on university premises. In one case, we took note of a perceived gender dimension when accessing FabLabs in that its location on a more remote and largely female-dominated campus made it difficult for the customary type of user—male engineering students—to reach that particular FabLab. We also noted that due to biases concerning user base and safety, urban users steered clear of FabLabs located in townships. We established that the FabLabs studied are used by a variety of different user groups and that, in most cases, the Labs are predominantly used by male users. The majority of FabLab users was younger than 35 years. Typically, FabLabs are used for product development, prototyping, and teaching, and not for manufacturing end products.

As far as our overall research question is concerned, two things became apparent: first, different dimensions of collaboration, knowledge sharing, and openness can be found within the FabLab ecosystem. Peer-to-peer learning among FabLab users, for instance, plays a crucial role in knowledge transfer and training. And while some users are interested in exploring knowledge appropriation mechanisms with regards to their final innovations, it appears that the sharing of ideas still remains essential for product development and market success. Put differently, we heard that users who were reluctant to share did typically not successfully complete their project. As for the 3D printing hardware and software typically used in FabLabs, we found that while emphasis is generally on proprietary material extrusion 3D printers, some managers complained about the high costs associated with proprietary 3D printing hardware—an issue that could arguably be tackled by making increased use of open hardware solutions. Similarly, FabLabs usually provide access to both open source and proprietary software, and we heard some criticism regarding the affordability of proprietary software solutions. Yet, most users still prefer the proprietary software due to the user-friendliness of their user interface, the conformity with industry standards, and the absence of bugs.

Second, and somewhat surprisingly, we noted that few social entrepreneurs make use of FabLab facilities in general and their 3D printing hardware and software in particular when conducting their social entrepreneurial activities. Even so, none of the FabLabs actively reaches out to social entrepreneurs to increase their numbers. This said, social entrepreneurs in Kenya told us that oftentimes social entrepreneurs use local FabLabs or makerspaces to generally acquaint themselves with 3D printing technology. In some cases, FabLabs play advisory roles for social enterprises or serve as a backup and servicing facility when their own 3D printers break down or cannot be accessed by those in need.

Our research suggests a closer link between the availability of affordable and openly accessible 3D printing technology and social entrepreneurship. All social entrepreneurial projects we studied expressed a strong preference for their own open source printers, because the speed and quality of these printers is often seen as equal or superior to that of commercial 3D printers. An added benefit is that these open source printers can be repaired locally more easily. In spite of being critical of the cost for proprietary software, the social entrepreneurs interviewed generally favoured such software over its open source counterpart due to the user-friendliness of the user interface and reliability.

Social entrepreneurs using 3D printing for their social entrepreneurial activities also reported that they share their technical knowledge through teaching and other activities. The social entrepreneurial projects studied used open source designs created by third parties and shared back their new, customised or improved designs, as well as other data, with the public. One social entrepreneur even told us that he feels he has an ethical obligation to do so. At the same time, however, one social entrepreneur aims to seek strong formal intellectual property protection for one of his projects, not in order to maximise profits but to ensure that its original vision is preserved.

As mentioned earlier in this paper, Open AIR seeks to develop its own innovation-focused and context-sensitive definition of scaling up, based on the feedback received from our informants. In summary, social entrepreneurs interpret scaling up as, mainly, becoming more sustainable and increasing their impact, rather than increasing size, profit, and budget. While formal types of intellectual property protection could become relevant in the future, emphasis was for now on:

- keeping designs open to inspire and facilitate creativity;
- making 3D printers, knowledge, and locally relevant products more available in remote areas; and
- developing broader platform offerings.

For none of the social entrepreneurs did scaling up involve moving away from their current open source 3D printer designs towards using commercial printers. Meanwhile, additional income could be generated through external funding or the provision of add-on services such as, for paid training sessions.

Broadly, we feel that our study provides some valuable insights into how collaborative and open approaches can indeed facilitate problem-solving and benefit-sharing in African countries. And in light of Open AIR's overarching research questions, we hope that this paper contributes— especially when read together with the findings of other Open AIR case studies—to an improved understanding of the term "scaling" generally and, more importantly, in the specific and topical context of technology-enabled social entrepreneurship with links to the maker movement. While this study already presented some interesting strategies, more work is needed, however, to better address the all-important question of how to make open, collaborative, and socially-desirable endeavours more sustainable.

References

Abu-Saifan, S. (2012). Social entrepreneurship: Definition and boundaries. *Technology Innovation Management Review*, February 2012, 22–27.

Armstrong, C., De Beer, J., Kraemer-Mbula, E., & Ellis, M. (2018). Institutionalisation and informal innovation in South African maker communities. *Journal of Peer Production (JoPP), 12*(1), 14–42. Retrieved from http://peerproduction.net/wp-content/uploads/2018/07/jopp_issue12_vol1of3.pdf

Ashoka. (n.d.). Social entrepreneurship. Retrieved from http://www.ashoka.org/en/focus/social-entrepreneurship

Bashir, O. (2016, May 14). How 3D prosthetics change lives in Pakistan. *Dawn*. Retrieved from http://www.dawn.com/news/1254750

Birtchnell, T., & Hoyle, W. (2014). *3D printing for development in the Global South: The 3D4D challenge*. Basingstoke, UK: Palgrave Macmillan.

Bornstein, D. (1998, January). Changing the world on a shoestring. *The Atlantic*. Retrieved from www.theatlantic.com/magazine/archive/1998/01/changing-the-world-on-a-shoestring/377042

Brinkerhoff, P. C. (2009). *Mission-based management: Leading your non-for-profit in the 21st century* (3rd ed). Hoboken, NJ: John Wiley & Sons.

Canadian Centre for Social Entrepreneurship. (2001). *Social entrepreneurship discussion paper no. 1*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.194.4683&rep=rep1&type=pdf

Center for Bits and Atoms (CBA). (2012). The fab charter. Retrieved from http://fabfoundation.org/index.php/the-fab-charter/index.html

Dacin, P. A., Dacin, M. T., & Matear, M. (2010). Social entrepreneurship: Why we don't need a new theory and how we move forward from here. *Academy of Management Perspectives*, *24*(3), 37–57.

De Beer, J., Armstrong, C., Ellis, M., & Kraemer-Mbula, E. (2017). *A scan of South Africa's maker movement*. Open AIR Working Paper No. 9. University of Cape Town and University of Ottawa: Open African Innovation Research (Open AIR). Retrieved from http://www.openair.org.za/wp-content/uploads/2018/02/WP-9-A-Scan-of-South-Africas-Maker-Movement.pdf

De Beer, D., Du Preez, W., Greyling, H., Prinsloo, F., Sciammarella, F., Trollip, N., & Vermeulen, M. 2016. A South African Additive Manufacturing Strategy. Retrieved from http://site.rapdasa.org/wp-content/uploads/2017/02/South-African-Additive-Manufacturing-Strategy.pdf

De Beer, J., Oguamanam, C., & Schonwetter, T. (2013). Innovation, intellectual property and development narratives in Africa. In J. De Beer, C. Armstrong, C. Oguamanam, & T. Schonwetter (Eds.), *Innovation and intellectual property: Collaborative dynamics in Africa* (pp. 1-31). Cape Town: UCT Press.

Dees, J. G. (1998). *The meaning of "social entrepreneurship"*. Research Paper. Retrieved from http://centers.fuqua.duke.edu/case/wp-content/uploads/sites/7/2015/03/Article_Dees_MeaningofSocialEntrepreneurship_2001.pdf

Eskin, B. (2014, January 30). Makerbot stories: Project Daniel takes robohand to Sudan. Retrieved from www.makerbot.com/media-center/2014/01/30/project-daniel-takes-robohand-sudan

Fab Foundation. (n.d.). Fab Lab Resources. Retrieved from http://www.fabfoundation.org/index.php/fab-lab-resources/index.htmlFabLabs. (n.d.). Labs. Retrieved from http://www.fablabs.io/labs

Fowler, A. (2000). NGDOs as a moment in history: Beyond aid to social entrepreneurship or civic innovation? *Third World Quarterly*, *21*(4), 637–654.

Freitag, H. (2015, 16 March 16). How 3D printing can help save lives. [Blog post.] Retrieved from http://blog.usaid.gov/2015/03/how-3d-printing-can-help-save-lives

Hand, M. (2016, May 24). The research gap in social entrepreneurship. *Stanford Social Innovation Review*. Retrieved from http://ssir.org/articles/entry/the_research_gap_in_social_entrepreneurship

Hibbert, S. A., Hogg, G., & Quin, T. (2002). Consumer response to social entrepreneurship: The case of the Big Issue in Scotland. *International Journal of Nonprofit and Voluntary Sector Marketing*, *7*(3), 288–301.

Institute for Social Entrepreneurs. (n.d.). Social enterprise terminology. Retrieved from http://www.socialent.org/social_enterprise_terminology.htm

International Organization for Standardization (ISO). (2015). ISO/ASTM 52900:2015 (ASTM F2792): Additive manufacturing – general principles – terminology. Retrieved from http://www.iso.org/standard/69669.html

Jacobs, S. (2015, March 13). A 3D revolution in Africa? *This is Africa*. Retrieved from http://www.thisisafricaonline.com/Business/A-3D-revolution-in-Africa

Johnson, R. B., Onwuegbuzie A. J., & Turner, L. A. (2007). Towards a definition of mixed method research. *Journal of Mixed Methods Research*, *1*(2), 112–133.

Jones, R., Haufe, P., Sells, E., Iravani, P., Olliver, V., Palmer, C., & Bowyer, A. (2011). RepRap – the replicating rapid prototyper. *Robotica*, *29*(1), 177–191.

Kraemer-Mbula, E., & Armstrong, C. (2017). *The maker movement in Gauteng Province, South Africa*. Open AIR Working Paper No. 6. University of Cape Town and University of Ottawa: Open African Innovation Research (Open AIR). Retrieved from http://www.openair.org.za/wp-content/uploads/2017/06/WP-6-Maker-Movement-in-Gauteng-Province-South-Africa.pdf

Leadbeater, C. (1997). *The rise of the social entrepreneur*. London: Demos. Retrieved from http://www.demos.co.uk/files/theriseofthesocialentrepreneur.pdf

Lipson, H., & Kurman, M. (2013). *Fabricated: The new world of 3D printing*. Hoboken, NJ: John Wiley & Sons.

Mair, J. & Noboa, E. (2003). *Social entrepreneurship: How Intentions to create social enterprise get formed*. IESE Working Paper No. D/521. Barcelona: IESE Business School. http://dx.doi.org/10.2139/ssrn.462283

Mair, J. & Noboa, E. (2006). Social entrepreneurship: How intentions to create a social venture are formed. In J. Mair, J. Robinson, & K. Hockerts (Eds.), *Social entrepreneurship* (pp. 121–135). Basingstoke, UK: Palgrave Macmillan.

Mahajan, S. (Ed.). (2014). *Economics of South African townships: Special focus on Diepsloot*. Washington, DC: World Bank.

Maker Station. (n.d.). Website. Retrieved from http://makerstation.co.za/i2plab

Mathers, I. (2015, August 17). 3D printing can revolutionise emergency healthcare. *SciDev.Net*. Retrieved from http://www.scidev.net/global/design/multimedia/3d-printing-emergency-healthcare-haiti-maternity.html

Matthews, K. (2015, May 29). Disaster relief in three dimensions. *3DPrint*. Retrieved from http://3dprint.com/68527/medical-3d-printing-in-haiti/

Mphuthi, L. (2013). *FabLab, a technology transfer platform for technical empowerment through science and technology education: A South African FabLabs impact evaluation*. Master's thesis, Da Vinci Institute, Modderfontein, South Africa.

Mungai, C. (2015, August 8). "Guerrilla manufacturing": This 3D printing thing might just be Africa's industrial magic wand. *Mail & Guardian*.

Ortolani, G., & Di Bella, P. (2014, 20 January). Building low-cost tools to bridge the digital divide. *SciDev.Net*. Retrieved from http://www.scidev.net/global/digital-divide/multimedia/building-low-cost-tools-to-bridge-the-digital-divide.htm

RepRap. (2018). RepRap options. Retrieved from http://reprap.org/wiki/RepRap_Options

Rivera-Santos, M., Holt, D., Littlewood, D., & Kolk, A. (2015). Social entrepreneurship in Sub-Saharan Africa. *Academy of Management Perspectives*, *29*(1), 72–91.

SA FabLab. (n.d.). Welcome to SA FabLab. Retrieved from http://www.fablab.co.za

Santos, F. M. (2012). A positive theory of social entrepreneurship. *Journal of Business Ethics, 111*(3), 335–351.

Schrock, A. (2014). "Education in disguise": Culture of a hacker and maker space. *InterActions: UCLA Journal of Education and Information Studies*, *10*(1). Retrieved from http://escholarship.org/uc/item/0js1n1qg

Tech, R., Ferdinand, J.-P., & Dopfer, M. (2016). Open source hardware startups and their communities – the case of desktop 3D printing. In J.-P. Ferdinand, U. Petschow, & S. Dickel (Eds.), *The decentralized and networked future of value creation* (pp. 129–146). Heidelberg: Springer.

Thompson, J., Alvy, G., & Lees, A. (2000). Social entrepreneurship – a new look at the people and the potential. *Management Decision*, *38*(5), 328–338.

Troxler, P. (2016). Fabrication laboratories (Fab Labs). In J.-P. Ferdinand, U. Petschow & S Dicket (Eds.), *The decentralised and networked future of value creation* (pp. 109–128). Heidelberg: Springer.

Uvin, P., Jain P.S., & Brown D.L. (2000). Think large and act small: Toward a new paradigm for NGO scaling up. *World Development, 28*(8), 1409–1419.

Walker, K. (2016, July 12). 3D-printed weather stations help rural Zambian communities. *Design Indaba*. Retrieved from http://www.designindaba.com/articles/creative-work/3d-printed-weather-stations-help-rural-zambian-communities

World Intellectual Property Organisation (WIPO). (2015). *World intellectual property report: Breakthrough innovation and economic growth*. Retrieved from http://www.wipo.int/edocs/pubdocs/en/wipo_pub_944_2015.pdf

Zahra, A. S., Gedajlovic, E., Neubaum, D. O., & Shulman, J. M. (2009). A typology of social entrepreneurs: Motives, search processes and ethical challenges. *Journal of Business Venturing*, *24*(5), 519–532.

Research interviews

Interviewee 1. (2017). In-person interview, 23 February.

Interviewee 2. (2017). Interview via phone, 6 April.

Interviewee 3. (2017). Interview via phone, 6 April.

Interviewee 4. (2017). Interview via phone, 6 April.

Interviewee 5. (2017). Interview via Skype, 7 April.

Interviewee 6. (2017). Interview via phone, 19 April.

Interviewee 7. (2017). Interview via phone, 15 May.

Interviewee 8. (2017). In-person interview, 4 July.

Interviewee 9. (2017). In-person interview, 5 July.

Interviewee 10. (2017). In-person interview, 5 July.

Interviewee 11. (2017). In-person interview, 5 July.

Interviewee 12. (2017). Interview via Phone, 12 July.

Interviewee 13. (2017). Interview via Skype, 19 July.

Interviewee 14. (2017). Interview via Skype, 30 August.

Recognizing Africa's role in the global knowledge economy.

http://openair.africa

Open African Innovation Research (Open AIR) is a unique collaborative network of researchers investigating how intellectual property (IP) systems can be harnessed in open, participatory ways that have the potential to maximise knowledge access, innovation, and the sharing of benefits from innovation inclusively.

For more Information about Open AIR, please visit our website: www.openair.africa
or contact one of our Program Managers:
capetown@openair.africa
ottawa@openair.africa

Open AIR is carried out with financial support from the International Development Research Centre, Canada, the Social Sciences and Humanities Research Council of Canada, UK Department for International Development, and Queen Elizabeth Scholars Program. More information about Open AIR's current and previous supporters can be found at http://www.openair.org.za/supporters/. The views expressed herein do not necessarily represent those of Open AIR's funders.