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THE AFRICAN JOURNAL OF INFORMATION AND COMMUNICATION (AJIC)

ISSUE 26, 2020

THEMATIC ISSUE: COLLABORATIVE INNOVATION IN AFRICAN SETTINGS



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Published by the LINK Centre
University of the Witwatersrand (Wits)
Johannesburg, South Africa
https://www.wits.ac.za/linkcentre

ISSN 2077-7213 (online version)
ISSN 2077-7205 (print version)

AJIC 26 - 20-Aug-21 - small fixes to issue naming in Abrahams item.indd 1 8/21/2021 6:21:30 AM

The African Journal of Information and Communication (AJIC)

Issue 26, 2020

Thematic Issue: Collaborative Innovation in African Settings

Published by the LINK Centre, School of Literature, Language and Media (SLLM)
Faculty of Humanities, University of the Witwatersrand (Wits)
Johannesburg, South Africa
https://www.wits.ac.za/linkcentre/ajic

Published since 2000, *The African Journal of Information and Communication (AJIC)* is a peer-reviewed, interdisciplinary, open access academic journal focused on information and communication ecosystems in Africa, elsewhere in the developing world, and at global level. Accredited by the South African Department of Higher Education and Training (DHET), *AJIC* pursues its open access objective by publishing online, free to the user, under a Creative Commons licence, and by not imposing article processing charges on its contributors. *AJIC* is archived and indexed by Scientific Electronic Library Online (SciELO) SA, Sabinet African Journals, the Directory of Open Access Journals (DOAJ), and Wits University WIReDSpace.

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Acknowledgements

AJIC acknowledges with gratitude the following contributions to this thematic issue:

Guest Editors
Dr. Tobias Schonwetter, University of Cape Town
Prof. Jeremy de Beer, University of Ottawa

Peer Reviewers
Olufunmilayo Arewa, Mark Burke, Barry Dwolatzky, Geci Karuri-Sebina, Theko Makhoalibe, Uche M. Mbanaso, Caroline Wanjiru Muchiri, Nixon Muganda Ochara

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Editorial and financial support for this *AJIC* thematic issue were provided by the Open African Innovation Research (Open AIR) network, https://openair.africa. Open AIR receives funding from the Social Sciences and Humanities Research Council (SSHRC) of Canada and the International Development Research Centre (IDRC).

Production
Sub-editing: LINK Centre
Proofreading: Linda Van de Vijver
Desktop-publishing: LINK Centre

AJIC is published by the LINK Centre, School of Literature, Language and Media (SLLM), Faculty of Humanities, University of the Witwatersrand (Wits), PO Box 601, Wits 2050, Johannesburg, South Africa. The LINK Centre is located at the Wits Tshimologong Digital Innovation Precinct, 41 Juta St., Braamfontein, Johannesburg, https://www.tshimologong.joburg

ISSN 2077-7213 (online version)
ISSN 2077-7205 (print version)

Past issues of *AJIC*, and its precursor *The Southern African Journal of Information and Communication (SAJIC)*, are available at https://www.wits.ac.za/linkcentre/ajic and https://www.wits.ac.za/linkcentre/sajic

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Introduction to Thematic Issue: Collaborative Innovation in African Settings

Jeremy de Beer, Erika Kraemer-Mbula, Caroline Ncube, Chidi Oguamanam, Nagla Rizk, Isaac Rutenberg and Tobias Schonwetter
Steering Committee Members, Open AIR

This *AJIC* Thematic Issue: Collaborative Innovation in African Settings features findings from research conducted by members of the Open African Innovation Research (Open AIR) network.[1] With researchers spread across more than 20 African countries, Canada, and elsewhere, Open AIR has for more than a decade been playing a leading role in exploring and uncovering the work of Africa's knowledge-based innovators.

The two overarching questions currently driving Open AIR's research are: How can open, collaborative innovation help businesses scale up and seize the new opportunities of a global knowledge economy? And which knowledge governance policies will best ensure that the social and economic benefits of innovation are shared inclusively? These questions are approached through research work organised into five (often overlapping) thematic orientations: technology hubs, informal innovation, Indigenous entrepreneurs, innovation metrics, and laws and policies. Open AIR's core research methods are situational analysis via case studies; action-based research; and grounded theory-building. The researchers come from a wide range of disciplines, including law, economics, management, political science, and public policy.

The six articles in this thematic issue reflect the diversity of the Open AIR network, of its approaches to understanding collaborative innovation in African settings, and of its conceptions of the social, economic, technological and policy dimensions that impact, and are impacted by, innovation. Also reflected in the articles is the geographical range of the network. Two of the articles include detailed reflections on international and African continental realities, and the four articles grounded primarily in African national and sub-national realities draw on data from the continent's North, East, and Southern regions. The articles' authors include researchers from five of Open AIR's institutional hubs: The American University in Cairo, Strathmore University in Nairobi, the University of Johannesburg, the University of Cape Town, and the University of Ottawa.

The opening article, by Gwagwa, Kraemer-Mbula, Rizk, Rutenberg and De Beer, explores one of the most pressing matters, in both practical and policy terms, facing African knowledge-based innovators: deployments of artificial intelligence (AI) on the continent. Framing their analysis in terms of socio-economic inclusion, the authors argue that if AI is to be of true benefit to the continent, African policymakers will need to craft enlightened responses to matters of gender empowerment, cultural and linguistic diversity, and shifts in labour markets.

1 https://openair.africa

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The second article, by Oguamanam, interrogates a topic that is poised to take on growing urgency in African settings in the years to come: the quest for Indigenous data sovereignty. The focus of this sovereignty movement is on Indigenous peoples' right to control the collection and use of data that is drawn from their communities, so that these communities can exercise full self-determination and full control over their socio-economic development.

In the third article, Nzomo, Mwangi, Matu-Mureithi, Muchiri and Rutenberg provide findings from their survey of collaborative innovation dimensions present in the activities of Nairobi's numerous start-ups engaged in mobile tech innovation. They find that openness, networking, and informality are central elements of the start-ups' approaches to innovation.

Start-up dynamics are also central to the Abrahams article, which sets out findings on the patterns of innovation at three South African tech hubs, and among the start-ups hosted by the hubs. Abrahams puts particular focus on the degree to which the hubs and their hosted start-ups pursue scale through "entanglement" with exogenous and endogenous factors and external entities.

In the fifth article, ElHoussamy and Rizk provide an account of their research into how innovation unfolds at makerspaces in Egypt, Tunisia, and Morocco. They find a diversity of approaches and models emerging in the three countries, but with all the spaces characterised by vibrant approaches to knowledge-sharing, innovation, and scaling. The authors also identify elements of fragility in this relatively young movement, and suggest some features that are likely to be central to the spaces that achieve greatest sustainability.

The maker movement also features in the final article of this thematic issue, by Schonwetter and Van Wiele. Based on data collection in South Africa and Kenya, the authors probe the extent to which social entrepreneurs can make use of fab lab makerspaces and 3D printers to take social innovations forward. The research found that, among other things, social entrepreneurs in both countries do indeed make use of fab labs and 3D printers--but the social entrepreneurs studied tended to favour purchasing or building their own open source 3D printers over using printers made available by fab labs.

It is hoped that readers of this thematic issue will be able to gain a deepened understanding of the lived practical realities of African collaborative innovators, and of these innovators' socio-economic, technological and political contexts.

ARTICLES

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Artificial Intelligence (AI) Deployments in Africa: Benefits, Challenges and Policy Dimensions

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Abstract

The deployment of artificial intelligence (AI) technologies is proliferating on the African continent, but policy responses are still at their early stages. This article provides an overview of the main elements of AI deployment in Africa, AI's core benefits and challenges in African settings, and AI's core policy dimensions for the continent. It is argued that for AI to build, rather than undermine, socio-economic inclusion in African settings, policymakers need to be cognisant of the following key dimensions: gender equity, cultural and linguistic diversity, and labour market shifts.

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Keywords
artificial intelligence (AI), Africa, automated decision-making (ADM), natural language processing (NLP), inclusion, gender, linguistic diversity, labour, policy, policymaking

Acknowledgements
This study was carried out under the auspices of the Open African Innovation Research (Open AIR) network, which is a partnership between the University of Cape Town, the University of Johannesburg, The American University in Cairo, Kenya's Strathmore University, the Nigerian Institute of Advanced Legal Studies, and the University of Ottawa. We acknowledge the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, and the International Development Research Centre (IDRC). The views expressed in this work are those of the authors and do not necessarily represent those of the research funders. This article includes elements of a paper presented by the authors to the 2020 We Robot virtual conference hosted by the Centre for Law, Technology and Society (CLTS) at the University of Ottawa (CLTS, 2020).

DOI: https://doi.org/10.23962/10539/30361

Recommended citation
Gwagwa, A., Kraemer-Mbula, E., Rizk, N., Rutenberg, I., & De Beer, J. (2020). Artificial intelligence (AI) deployments in Africa: Benefits, challenges and policy dimensions. *The African Journal of Information and Communication (AJIC), 26*, 1-28. https://doi.org/10.23962/10539/30361

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1. Introduction

There is a dearth of data on all aspects of artificial intelligence (AI) in Africa, and much of the available information is thus anecdotal (Oxford Insights & IDRC, 2019). Meanwhile, there is a need for African policy responses, at the national, regional, continental and international levels, aimed at ensuring that the continent's innovators, enterprises, communities, governments, and other actors are able to reap AI's benefits and mitigate its threats. Sound policy approaches will be needed to enable African nations to build ecosystems that are inclusive, socially beneficial, and adequately integrated with on-the-ground realities.

Smith and Neupane (2018) define AI as "an area of computer science devoted to developing systems that can be taught or learn to make decisions and predictions within specific contexts" (2018, p. 10). The European Commission defines it as "systems that display intelligent behaviour by analysing their environment and taking actions—with some degree of autonomy—to achieve specific goals" (EC, 2018). The Organisation for Economic Co-operation and Development (OECD) defines AI as "a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy" (OECD, 2019b, p. 7). The Institute of Electrical and Electronics Engineers (IEEE) favours the term "autonomous and intelligent systems (A/IS)" over AI (IEEE, n.d.).

Among the core elements of AI are algorithmically controlled automated decision-making (ADM) systems, or decision-support systems, which are socio-technological frameworks that comprise decision-making models and the algorithms that translate the models into computable code (Penner, 2019). ADM systems are increasingly used as part of decision-making processes in the public and private sectors. Public authorities use them to improve efficiency, implement complex processes, and support evidence-based policymaking, in areas such as public sector procurement (which is a major source of business for many companies). They make material decisions regarding financial, health, and even liberty outcomes. Accordingly, they can have far-reaching impacts involving the weakest members of society, with potentially significant negative consequences for individuals, organisations, and society as a whole (Penner, 2019).

While AI technologies and applications have the potential to address many of humanity's most pressing problems—through, for example, fostering a world that is less sick, less hungry, more productive, better educated, and better prepared to thwart the effects of climate change—this promise comes with risks of entrenched and amplified social inequality (Hagerty & Rubinov, 2019). AI grounded in non-representative or biased data can entrench existing social and economic inequities, with AI systems reproducing the representation gaps and biases of the data sets on which they are trained (see Powles & Nissenbaum, 2018). AI can be used by already-dominant technology firms to further entrench their economic and social power, or by governments to violate the privacy and other human rights of citizens. AI's negative consequences can be compounded by a lack of transparency and accountability as such systems are scaled up (see Gwagwa, n.d.; Koene et al., 2019).

AI's potential risks are particularly acute in the developing world, where, in the words of Hamann (2018), "the new technologies […] may build upon and exacerbate existing inequalities—both within developing countries as well as between developing and more developed regions". As Smith and Neupane (2018) warn, in respect of developing nations, "if we continue blindly forward, we should expect to see increased

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inequality alongside economic disruption, social unrest, and in some cases, political instability, with the technologically disadvantaged and underrepresented faring the worst" (2018, p. 12).

In contemporary African settings, both the benefits and risks of AI are readily apparent. Brandusescu et al. (2017) provide examples of innovative AI use in Kenya, Nigeria, and South Africa to address needs in health, agriculture, fintech, public transportation, and language translation. Smith and Neupane (2018) provide examples from these same three countries, as well as Uganda and Ethiopia, of beneficial AI use in point-of-care diagnostics, government service delivery, wildlife conservation, crop monitoring, water management, enterprise development, and financial services. UN Global Pulse has published findings from its testing of AI natural language processing (NLP) tools to identify Somali social media postings with a bearing on peacebuilding and Ugandan radio content that portends social conflict (UN Global Pulse, 2018). In Accra, Google's AI Laboratory is experimenting with compressed algorithms that can run on the computing power of mobile phones (Adeoye, 2019). IBM's mobile open source Hello Tractor platform is providing AI-based on-demand tractor access to Nigerian farmers (Assefa, 2018).

At the same time, AI's challenges and risks in African contexts are also potentially of great magnitude. In the wake of Nigerian online marketplace Jumia's public listing, during which most of its equity was transferred to foreign owners, there was a sentiment that such arrangements throttle Africa's homegrown tech industries (Madowo, 2020). A 2018 study of startups in East Africa found that 90% of funding had gone to the startups' foreign founders (Pilling, 2019). Foreign AI companies have been accused of using false African identities as marketing tools to raise capital and then eventually cashing out (Pilling, 2019). In the absence of significant AI R&D in Africa, the applications of AI deployed in Africa tend to originate from outside the continent and thus lack contextual relevance, particularly in respect of cultural and infrastructural factors (Oxford Insights & IDRC, 2019). And AI capabilities are in some cases being used by African governments to control citizens—for example, in Ethiopia (Gwagwa, 2018) and Zimbabwe (Chimhangwa, 2020). Instances of foreign-controlled and/or foreign-designed AI tools in African settings are increasingly being seen in neo-colonial terms, i.e., as elements of "algorithmic colonization" (see Birhane, 2019), "data colonialism" (see Couldry & Mejias, 2019), and "digital colonialism" (see Coleman, 2019).

If African nations are to build inclusive AI ecosystems, enlightened policymaking is essential. Yet the African AI policy discourse is still only embryonic. With this article, we seek to highlight some of the core AI opportunities, challenges, and policy dimensions requiring the attention of African policymakers.

2. Methodology and analytical framework

We reviewed literature on AI's manifestations and policy dimensions in both developed-world and developing-world settings. The literature included journal articles, books, chapters in edited volumes, electronic sources, conference papers, and reports by industry bodies and inter-governmental organisations. We organised the review findings in terms of an analytical framework drawing on two taxonomies: Calo's 2017 taxonomy for interrogating AI policy challenges (Calo, 2017); and Smith and Neupane's taxonomy of AI's potential risks in developing-world settings (Smith & Neupane, 2018). Our analysis of the literature was also broadly informed by findings from the on-the-ground situational analyses, in the form of case studies, which we and our research colleagues have conducted since 2015 under the auspices of the Open African Innovation Research (Open AIR) network (Open AIR, n.d.).

Calo's 2017 taxonomy of "key challenges" posed by "the contemporary policy environment around artificial intelligence" consists of the following five dimensions:

- "justice and equity;
- use of force;
- safety and certification;
- privacy and power; and
- taxation and displacement of labor" (2017, p. 403).

Calo's taxonomy has a developed-world focus. Accordingly, so as to ensure a proper consideration of developing-world dimensions, we also considered Smith and Neupane's proposed "proactive research agenda for the ethical and equitable application of AI in the Global South" (Smith & Neupane, 2018). Smith and Neupane identify the following "potential risks" posed by AI in developing countries:

- "fairness, bias and accountability";
- "surveillance and loss of privacy";
- "job and tax revenue loss through automation"; and
- "undermining democracy and political self-determination" (2018, pp. 11–12).

We found three areas of overlap between Calo's policy-challenges taxonomy and Smith and Neupane's potential-risks framework, as represented in the three rows of Figure 1.

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Figure 1: Overlaps between Calo (2017) and Smith and Neupane (2018)

Calo (2017): Key policy challenges		Smith and Neupane (2018): Potential risks
justice and equity	⟷	fairness, bias, and accountability
privacy and power	⟷	surveillance and loss of privacy
taxation and displacement of labour	⟷	job and tax revenue loss through automation

Among the three areas of thematic commonality between the Calo taxonomy and the Smith and Neupane framework, we determined that the two themes most central to understanding the implications of AI in Africa, which we discuss in the next two sections of this article, are *equity* and *labour*. (Privacy and surveillance issues are also, in our view, important issues, but it is less clear that they require distinctly African policy approaches, whereas matters of equity and labour seem to certainly require attempts at Africa-appropriate responses.)

3. AI and equity in African settings

Among equity's numerous dimensions, the two we focused on, for the purposes of this study, are *gender equity* and *cultural and linguistic diversity*, each of which is now discussed.

AI and gender equity

A core equity dimension is gender, and there is evidence to suggest that African nations are experiencing a transformative "feminization" of technology entrepreneurship (Monehin, 2017). Vibrant startup ecosystems that support women are emerging in Kenya, Nigeria, and South Africa, with North Africa catching up. One example is Morocco's WaystoCap, an ambitious female-led tech startup based in Casablanca that provides a cross-border commerce platform (Toesland, 2018). According to the 2017 Mastercard Index of Women's Entrepreneurship (MIWE), Sub-Saharan Africa had the world's highest rate of female entrepreneurs (27%), and 34.8% of businesses in Uganda, and 34.6% in Botswana, were owned by women. The study describes this level of ownership as "significantly higher than in the United States, the United Kingdom and Germany, to mention a few" (Monehin, 2017). In Egypt, women are adopting AI technologies to engage in ride-sharing platform services as drivers. This is unprecedented in the country's male-dominated taxi driving culture, and it empowers the women, not only by improving their ability to provide for their livelihoods, but also by breaking down social taboos and using digital technologies to ensure their safety (Rizk et al., 2018).

Another example of digitisation's potential benefits for African women emerges from African women engaging with code. When the African Girls Can Code Initiative (AGCCI) was launched in August 2018, 80 girls from 34 African countries signed up, within the first 10 days, to attend Coding Camp in Addis Ababa, Ethiopia (UN Women, 2018). SingularityNET, the startup that had the robot Sophia as one of its first use cases, is at the forefront of hiring and promoting African female engineers (Dishman, 2018). Code4CapeTown in South Africa invests in women coders and programmers, including running a coding programme for high school girls (Dishman, 2018).

At the same time, gender issues fall at the heart of inclusion paradoxes in respect of digital transformation and, as a subset of digital dynamics, AI dimensions (see, for example, UNESCO, 2020a). Women are typically disadvantaged by data and algorithm biases, which reflect and amplify inequities already in existence on the ground. AI algorithms are typically developed in the Global North, and trained on datasets representing realities that are significantly different from realities in African contexts—and thus may exclude certain communities, e.g., women, from particular services. Such "allocative harms" (Whittaker et al., 2018) can extend to decisions related to eligibility for bank loans or credit (Access Partnership, 2017). Also relevant are problems of facial recognition algorithms that can unduly exclude people of colour.

The potential of new technologies to magnify existing inequities becomes more challenging in contexts where inequality is multi-layered (Rizk, 2020). This tends to be the case in many African settings, where gender inequality is but one facet of complex and multidimensional inequalities that extend beyond income and that are rooted in various disparities—including disparities based on race, ethnicity, and social background. Such inequalities of opportunity are often aggravated by new technologies.

Multidimensional inequality is an entrenched reality for women in many African settings. For example, a 2018 Brookings Institution study found that 44% of women in Kenya were poor in terms of at least one dimension, and that women who lived in rural areas tended to be multi-dimensionally poor (Patel, 2018). In 2017, the employment gender gap reached nearly 80% in Algeria and 69% in Egypt (WEF, 2017). The digital divide is also gendered. Africa is the only continent whose digital gender gap has widened since 2013. Of the 60% of African women who own a mobile phone, only 18% have internet access, with over 200 million left unconnected (Majama, 2019).

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In this context, women in Africa are likely to be marginalised by AI on more than one level. First, there is the inaccuracy of the data, AI's primary input. Inaccuracies are produced by the "data blur" (Rizk, 2020) as aggregation clouds out the detail present in disaggregated data, especially on gender-sensitive issues like health and employment. Data inaccuracy can also be an outcome of "data blindness" produced by top-down data collection methodologies which miss activities and communities that fall outside the radar of a formal lens (Rizk, 2020), e.g., informal workers, many of whom are women. In Sub-Saharan Africa, informal employment constitutes 92% of total female employment and 83% of total female non-agricultural employment (Bonnet et al., 2019).

Such invisibilities in data feed into biases in policymaking and other decision-making constructs based on AI algorithms fed by deficient data. An example is algorithm-based decision-making in the financial sector, where women constitute 60% of the 400 million people in Africa who lack access to digital financial services across the continent. In Sub-Saharan Africa, roughly 35 million women are excluded from financial services (World Bank, 2018), and in Egypt, 91.7% of women did not have bank accounts in 2014 (World Bank, 2016b).

The lack of ownership of a bank account can be traced to other female invisibilities. In Uganda, women's inability to provide formal documents, such as identity papers and utility bills, prevents them from opening bank accounts as they are unable to fulfil the know-your-customer (KYC) requirements (Musiitwa, 2018). The fact that these cohorts of women are absent from the official data apparatus, and thus are consequently absent from the algorithm, contributes to their exclusion from these financial services and indeed other social support instruments, especially when related to subsidies, housing, and social safety nets.

AI and cultural and linguistic diversity

As forcefully outlined by Kulesz (2018), AI can be expected to have profound impacts on the diversity of widely available cultural expressions in both the developed and developing worlds and, in the absence of strong policy interventions, the impacts have the potential to be starkly negative, particularly for the world's poor countries who are not home to the dominant AI and digital content firms.

Kulesz (2018) sets out a worst-case scenario in which, in the "medium and long term", the dominant AI players (mostly American and Chinese companies) are able to "intervene simultaneously in all nodes of the creative chain and generate works based on user behaviour, in order to maximize consumption", resulting in the dominant firms creating "a 'perfect bubble' around users, which would lead to an unprecedented level of concentration in the creation, production and distribution of cultural goods and services" (2018, pp. 7–8). In this kind of future, Kulesz (2018) warns, "cultural expressions would have economic value, but they would convey neither identity nor meaning" (2018, p. 8), and the reality for cultural expression in the Global South could be as follows:

> The technological concentration and the "perfect bubble" [...] would see the artists and producers of the South gradually lose their autonomy and capability. If that were to happen, the future designers of African clothing would not be Cameroonian or Nigerian creators, but rather machine learning experts living in Silicon Valley or Tianjin. The North/South digital divide would then become an irreversible creative divide. (Kulesz , 2018, p. 10)

With respect to linguistic diversity, which is integral to cultural diversity, it is estimated that 17% of the world's languages, many of them in Africa, are "low resource languages" in the digital realm (Marivate et al., 2020), i.e., there are insufficient examples of use of the languages available online for the purposes of training NLP applications. These languages are marginalised by technology deployments, including AI deployments, developed in the Global North.

A key NLP project focused on African language preservation is the Masakhane community, which has more than 140 contributors from 17 African countries (Masakhane, n.d.). Masakhane outlines its mission in the following terms:

> Even in the forums which aim to widen NLP participation, Africa is barely represented—despite the fact that Africa has over 2000 languages. The 4th [i]ndustrial revolution in Africa cannot take place in English. It is imperative that NLP models be developed for the African continent […] In particular, for Africa to take part [in] the global conversation, we should be developing machine translation systems to translate the internet and [its] content into our languages and vice versa. (Masakhane, n.d.)

By February 2020, Masakhane members had developed and published 35 translation results for over 29 African languages online in an open access GitHub repository.[1] Training NLP systems in low resource African languages is highly complex because, as Orife et al. (2020) explain:

> African languages are of high linguistic complexity and variety, with diverse morphologies and phonologies, including lexical and grammatical tonal patterns, and many are practiced within multilingual societies with frequent code switching […]. Because of this complexity, cross-lingual generalization from success in languages like English [is] not guaranteed. (Orife et al., 2020, p. 1)

1 https://github.com/masakhane-io/masakhane-mt.

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We now turn to a discussion of another area of thematic commonality identified above between the Calo (2017) taxonomy and the Smith and Neupane (2018) framework: labour.

4. AI and labour in African settings

A pioneering contribution to the debates on the impact of machine learning on employment is the 2013 paper by Frey and Osborne, which predicted that 47% of people working in the US at the time were at high risk (70% chance or greater) of having their jobs automated within a decade or so (Frey & Osborne, 2013). The World Bank's *World Development Report 2016: Digital Dividends*, through applying the Frey and Osborne (2013) methodology to developing countries—including African nations Nigeria, Ethiopia, and South Africa—also made alarming predictions, warning that "[t]he share of occupations that could experience significant automation is actually higher in developing countries than in more advanced ones, where many of these jobs have already disappeared" (World Bank, 2016a, p. 22).

Important caveats to this analysis are provided by studies that have focused on the automation of "tasks" rather than entire occupations. In this respect, Autor et al. (2003) make a distinction between routine and non-routine tasks. Historically, the increasing use of automation technologies, such as information and communication technologies (ICTs), led to job polarisation. Automation has driven the reduction of jobs requiring middle-level skills, such as clerks, craft workers and machine operators, compensated for by increases, in the shares of the labour force, of managers, professionals, and technicians—and also, paradoxically, increases in the shares of the lower-skilled categories composed of sales and service staff and the elementary trades. While previous industrial revolutions worked through "de-skilling" work into easier tasks to be accomplished by middle- to low-skilled workers, AI is "up-skilling" work by hollowing out the middle ground between high-skill jobs and low-paying jobs (Lee, 2018).

These patterns of job polarisation were evident in many low- and middle-income countries over the period 1995 to 2012 (see World Bank, 2016a, p. 22). For instance, in the period 1995 to 2012, South Africa experienced a sharp drop in the employment share of the middling groups; however, this was accompanied by a lesser decline in the share of low-skilled categories (World Bank, 2016a).

Within firms, the increased use of big data, sensors, and machine learning can generate drastic changes in the way work is organised, potentially furthering employers' ability to control employee behaviour, for instance, through increased monitoring and surveillance activities. This strengthens employers' ability to discourage union activity, deepened by employees' increasing employment insecurity as the employers' ability to outsource work to other countries with lower labour costs, such as to call centres in India, expands (Bajaj, 2011). These dynamics are significant in nations,

such as those on the African continent, with large populations of unemployed or underemployed youth in urban areas, and the dynamics are often exacerbated by insufficient protections for those who become unemployed due to job displacement (Cyr, 2019).

To better anticipate the impact of AI on jobs in Africa, it is important to consider the distribution of the labour force. Approximately 54% of all workers in Sub-Saharan Africa are in the agricultural sector, and in some specific countries this figure surpasses 70% (Fuglie et al., 2019). In the agricultural sector, AI has two primary uses that are, or are expected to be, of significant impact and value (Walch, 2019). First, as with other sectors, AI has significant advantages in analysing data, and it is thus useful for predicting the weather, optimising planting and harvesting schedules, determining appropriate fertiliser needs, and the like. This use of AI has the potential to increase yields and overall land productivity or efficiency, and it is unlikely to negatively affect the African labour force in the agricultural sector. Indeed, by improving the ability to predict floods and drought, optimise land usage, and increase yields, AI may increase the need for workers in the agricultural sector. This use of AI is, therefore, not necessarily competitive with human labour, and could actually be complementary to it.

Second, AI-powered agricultural bots (robots) are known to, or are expected to, exceed human abilities for harvesting crops and picking weeds. Although this use of AI is, at least in part, competitive with human labour, the reality of African agricultural practices reduces the overall impact that AI is likely to have. Small farms, defined here as farms of two hectares or less, account for 40% (by area) of farmland in Sub-Saharan Africa, a substantially larger percentage of land than the percentage held by small farms in rich countries (Lowder et al., 2016). Furthermore, daily wages for farm labourers in Sub-Saharan Africa are substantially below those in highly developed countries. With a large percentage of relatively very small farms, and with an abundance of relatively inexpensive labour, there is less economic incentive in Sub-Saharan Africa than in developed-world settings to invest in agricultural bots. The negative impact of AI on farm labour could, therefore, be substantially less in Sub-Saharan Africa, compared with developed countries.

Another core attribute of Sub-Saharan African labour forces is the large number of people working in informal jobs. The International Labour Office has found that more than 85% of employment in Africa is informal (ILO, 2018). New forms of servitisation, facilitated by digital technologies, may open opportunities for developing countries, including in Africa. Uber and Airbnb provide examples of informal entrepreneurs finding niches in services facilitated by digital technologies and AI. And other examples are also emerging in manufacturing—involving 3D printing, digital platforms, and apps—where there could be room for informal actors to not only survive but also to thrive.

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5. Policy dimensions

As demonstrated in the preceding sections of this article, it is clear that AI offers myriad potential benefits and potential challenges for African nations, regions, and the continent as a whole. Less clear, however, are the policy responses needed and the level or levels at which the policymaking needs to occur—e.g., the African national, regional, and continental levels, and the global level. In this section we look at some of the current sites of AI policymaking at each of these four levels.

At African national levels

According to Onuoha's African AI policy survey for the 2019 *Global Information Society Watch*, only 17 of the 55 African Union (AU) Member States had enacted "comprehensive data protection and privacy legislation": Angola, Benin, Burkina Faso, Cape Verde, Côte D'Ivoire, Gabon, Ghana, Lesotho, Madagascar, Mali, Mauritius, Morocco, Senegal, Seychelles, South Africa, Tunisia, and Western Sahara (Onuoha, 2019, p. 60).

Meanwhile, the top five African countries in the 2020 global *Government Artificial Intelligence Readiness Index* are Mauritius (45th in the world), South Africa (59th), Seychelles (68th), Kenya (71st), and Rwanda (87th) (Oxford Insights & IDRC, 2020; Sey, 2020). That same report cites recent government progress towards AI readiness in Tunisia and Egypt (Sey, 2020).

The African country credited with having the first fully formalised national AI strategy is Mauritius (Sey, 2020), which launched its Mauritius Artificial Intelligence Strategy, along with the Digital Government Transformation Strategy 2018–2022 and the Digital Mauritius 2030 Strategic Plan, in December 2018 (GIS, 2018; Government of Mauritius, 2018). The government has also announced that it will establish a Mauritius Artificial Intelligence Council (MAIC) (Sey, 2020). Another leading country on the continent in respect of AI is Nigeria, which in November 2020 launched its publicly-run Centre for Artificial Intelligence and Robotics in Nigeria (CFAIR) in Abuja (*FinIntell*, 2020).

Several other countries have established task forces mandated to develop a national AI strategy. Kenya established its Distributed Ledgers Technology and Artificial Intelligence Task Force in February 2018 (*Kenyan Wall Street*, 2018). In its final report published in July 2019, the task force focuses on the potential and realised impacts of AI on key development areas such as health care, food security, manufacturing, housing, and education. The report provides general arguments for and against targeted regulation of AI by governments, and also provides general policy recommendations (Mpala, 2019). However, the report is far from a policy document, and the government has since said little about any policymaking regarding AI.

Tunisia's Secretary of State for Research launched the country's AI task force in April 2018, with the process to be driven by a task force established by Tunisia's Agence Nationale de la Promotion de la Recherche Scientifique (ANPR), with support from the UNESCO Chair on Science, Technology and Innovation Policy (Future of Life Institute, n.d.; Mehrez, 2019). South Africa established the Presidential Commission on the Fourth Industrial Revolution in April 2019 (DTPS, 2019). Also in April 2019, Uganda launched its Expert National Task Force on Fourth Industrial Revolution Technologies (Masereka, 2019; Uganda Media Centre, 2019). Egypt's National Artificial Intelligence Council, tasked with developing the country's AI strategy, convened its first meeting in February 2020 (MCIT, 2020). In June 2020, Rwanda announced it was working towards the development of a National Emerging Technology Strategy and Action Plan (Lasry, 2020). Several of the above-listed entities have mandates to find ways to build national AI expertise—and, by extension, policy capacity.

University-driven national AI capacity-building programmes are present in numerous countries, including Egypt, South Africa, Cameroon, Morocco, Senegal, Lesotho, and Ethiopia (see Effoduh, 2020). South Africa's Centre for Artificial Intelligence Research (CAIR), established in 2011, links nine research groups from six universities—the University of Cape Town, the University of KwaZulu-Natal, North-West University, the University of Pretoria, Stellenbosch University and the University of the Western Cape. It is funded by the Department of Science and Innovation (DSI) and coordinated by the Council for Scientific and Industrial Research (CSIR) (CAIR, n.d.). One of the CAIR member institutions, the University of Pretoria, is also involved in a national AI policy engagement exercise. The university's Data Science for Social Impact research group participates in the the Policy Action Network (PAN), convened by South Africa's Human Sciences Research Council), which in 2020 published the AI and Data Series of brief guides to AI's interfaces with equity, crime prevention, education, cities and towns, migration management, and health (Data Science for Social Impact, n.d.; PAN, 2020). South Africa also hosts a Centre for the Fourth Industrial Revolution, established at the CSIR in 2017 as part of a global network of such centres supported by the World Economic Forum (WEF) (C4IR-SA, n.d.).

At African continental and regional levels

The key African continental instrument with relevance to AI is the 2014 AU Convention on Cyber Security and Personal Data Protection (AU, 2014). However, as of the middle of 2020, only eight AU Member States had signed, ratified, and deposited the convention (AU, 2020). In October 2019 in Sharm-El-Sheik, Egypt, AU ministers in charge of communications, ICTs, and postal services—convened as the AU

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Specialised Technical Committee on Communication and Information Communication Technologies (STC-CICT)—called on Member States to:

> [e]stablish a working group on Artificial Intelligence (AI) based on existing initiatives and in collaboration with African Institutions to study:
> a. The creation of a common African stance on AI
> b. The development of an Africa wide capacity building framework
> c. Establishment of an AI think tank to assess and recommend projects to collaborate on in line of Agenda 2063 and SDGs. (AU STC-CICT, 2019)

The AU's Cybersecurity Expert Group (AUCSEG), at its inaugural meeting in Addis Ababa in December 2019, stated in its press release that "[a]s Africans, we need to articulate our own Philosophy, Ethics, Policy, Strategies and accountability frameworks for Cyberspace, Cybersecurity and Cognitive or Artificial Intelligence (AI)" (AUCSEG, 2019).

At regional level, the Economic Community of West African States (ECOWAS) has adopted the 2010 Supplementary Act on Personal Data Protection within ECOWAS, which is binding on the community's Member States. Other African regional economic bodies have also worked to produce non-binding instruments with relevance to AI—e.g., the East African Community's (EAC's) draft EAC Legal Framework for Cyber Laws, and the Southern African Development Community's (SADC's) Model Law on Data Protection in 2012 (Onuoha, 2019).

In respect of fostering African AI policymaking capacity, one key emerging continental initiative is the Artificial Intelligence for Development in Africa (AI4D Africa) programme funded by the International Development Research Centre (IDRC) and the Swedish International Development Cooperation Agency (Sida) (AI4D Africa, n.d.). In September 2020, AI4D Africa published a call for proposals for two AI policy research "think-and-do tanks"—one in Anglophone Africa, the other in Francophone Africa—to produce AI policy research that will "inform and facilitate the development of public policies and regulations that promote the inclusive benefits of AI, while mitigating the potential costs and risks" (AI4D Africa, 2020).

There is wide recognition on the continent that building robust African AI policymaking capacity also requires the development of a critical mass of AI skills. Accordingly, the AI4D Africa initiative has pledged to support not only the aforementioned policy research bodies, but also African AI networks, labs, and scholarships. At a 2019 workshop convened in Nairobi as part of the establishment of AI4D Africa, a core idea discussed by participants was how to mobilise collaboration between a network of African companies, universities, research centres, and public institutions to advance the AI4D Africa agenda (AI4D, 2019). The head of Google Ghana has

pledged support for this idea by advocating for better AI education across the continent, and by encouraging African governments to see AI as a key priority and to support efforts to use AI for the good of humanity (Russon, 2019). One flagship initiative in the area of AI capacity development is the African Master's in Machine Intelligence (AMMI), which is being delivered by a pan-African consortium of centres of excellence collaborating under the banner of the African Institute for Mathematical Sciences (AIMS) (AMMI, n.d.; AIMS, n.d.).

Other AI initiatives with relevance for African policymakers include the international Knowledge for All Foundation (K4A), which is mapping Africa's emerging AI ecosystem as part of its "Global South map of emerging areas" in AI, with a focus on "talents, players, knowledge and co-creation hot spots" (K4A, n.d.). Meanwhile, UN Global Pulse, spearheaded by the Office of the UN Secretary-General and with its African hub in Uganda (called Pulse Lab Kampala), is an "initiative on big data and artificial intelligence for development, humanitarian action, and peace" (Tatevossian, 2015; UN Global Pulse, n.d.). And the Global Network of Internet and Society Research Centers gave strong consideration to African voices at its 2017 Global Symposium on Artificial Intelligence and Inclusion in Rio (NoC, 2017).

There are also several active African machine-learning innovation and research communities. Deep Learning Indaba has held well-attended annual continental summits since 2017 (Deep Learning Indaba, n.d.). Data Science Africa has, since 2015, held continental events in Kenya, Uganda, Tanzania, Nigeria, Ghana, and Ethiopia (Data Science Africa, n.d.). Data Science Nigeria is also active (DSN, n.d.). AI research has also been undertaken by the Regional Academic Network on IT Policy (RANITP), sponsored by Microsoft and hosted by the Cape Town-based Research ICT Africa (RIA) network (RIA, n.d.) RANITP comprises researchers in South Africa, Nigeria, Uganda, Kenya, and Zimbabwe (RANITP, n.d.).

At global level

There are myriad international statements and declarations on AI, produced by civil society, private-sector, and public-sector actors. One of the most influential statements is the 2019 OECD Recommendation of the Council on Artificial Intelligence (OECD, 2019b), which was crafted with guidance from a multistakeholder expert group (OECD, 2019c). These OECD principles reflect many of the goals contained in The Public Voice's Universal Guidelines for Artificial Intelligence (UGAI) (The Public Voice, 2018). A key regulatory instrument is the EU General Data Protection Regulation (GDPR), which came into force in 2018 and which requires entities conducting transactions in EU Member States to observe high thresholds of protection for EU citizens' personal data and privacy (EU, n.d.). Though not specifically an AI instrument, the GDPR is of great significance to AI matters because many core practical and ethical AI matters include data protection elements.

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One characteristic of certain AI policy discussions at high-level forums in the Global North has been the marginalisation or exclusion of Global Southern inputs. One example was the Global Forum on AI for Humanity, hosted by the Government of France in late 2019. Notably absent from this "global" forum were Global Southern voices, with no representatives based at institutions in Africa, Latin America, or Asia (apart from Japan) (Geist, 2019).

The International Telecommunication Union (ITU) and 36 other UN agencies and initiatives are engaging with AI matters, collaborating under the ITU's AI for Good Global Summit processes (ITU, 2019). One initiative falling under this umbrella that has a strong African focus is the aforementioned UN Global Pulse initiative, which is active in East Africa via its Pulse Lab Kampala data innovation hub established in 2015 (Tatevossian, 2015). With respect to the three domains of African AI benefits and challenges highlighted in this article—gender, linguistic diversity, and labour—perhaps the most relevant, and Africa-inclusive, global policy processes currently underway are those being carried out by UNESCO.

UNESCO convened a Forum on Artificial Intelligence in Africa in Morocco in December 2018. In its Outcome Statement, the forum called for, inter alia, "the African Union, in partnership with the RECs [regional economic communities], to develop a continental strategy for AI, which includes digital data management, and that is based on a multi-stakeholders approach and underpinned by [the AU] Agenda 2063" (UNESCO, 2018). Subsequently, in November 2019, at UNESCO's 40th General Conference, Member States mandated the UNESCO Director-General "to prepare an international standard-setting instrument on the ethics of artificial intelligence (AI) in the form of a recommendation" (UNESCO, 2019). In fulfilment of that mandate, UNESCO assembled an Ad Hoc Expert Group (AHEG) to prepare a draft text of recommendation, which was published in September 2020 as the *First Draft of the Recommendation on the Ethics of Artificial Intelligence* (UNESCO, 2020b). Among the myriad inputs considered by the AHEG were the inputs of the aforementioned 2018 Forum on Artificial Intelligence in Africa in Morocco and, in August 2020, a virtual UNESCO Regional Consultation for the Arab States Region hosted by Egypt's Ministry of Communications and Information Technology (MCIT) (Phillips, 2020).

This UNESCO process has clear policy relevance for the AI dimensions discussed in this article because the process is strongly focused on AI's ethical and sustainable development dimensions. The UNESCO AHEG *First Draft* document of September 2020 proposes Member State actions under the following 10 "Areas of Policy Action":

- ethical impact assessment;
- ethical governance and stewardship;
- data policy;
- development and international cooperation;
- environment and ecosystems;
- gender;
- culture;
- education and research;
- economy and labour; and
- health and social well-being (UNESCO, 2020b).

Among these 10 policy action areas outlined in the UNESCO AHEG *First Draft* document, the "gender", "culture", and "economy and labour" sections provide policy action ideas that directly address several of the African AI benefits and challenges discussed in this article. In the gender policy action area, the UN document states, inter alia, that

> Member States should ensure that gender stereotyping, and discriminatory biases are not translated into the AI systems. […]
>
> Member States should encourage female entrepreneurship, participation and engagement in all stages of an AI system life cycle by offering and promoting economic, regulatory incentives, among other incentives and support schemes, […]. (UNESCO, 2020b, paras. 92, 93)

In its section on the culture policy action area, the document strongly targets cultural heritage and endangered languages, stating that

> Member States are encouraged to incorporate Al Systems where appropriate in the preservation, enrichment, understanding, promotion and accessibility of tangible, documentary and intangible cultural heritage, including endangered languages as well as indigenous languages and knowledge, […]. (UNESCO, 2020b, para. 96)

Also, in the section on culture, the document focuses on the intersection between NLP and matters of linguistic diversity:

> Member States are encouraged to examine and address the cultural impact of AI systems, especially Natural Language Processing applications such as automated translation and voice assistants on the nuances of human language and expression. Such assessments should provide input for the design and implementation of strategies that maximize the benefits from these systems by bridging cultural gaps and increasing human understanding, as well as negative implications such as the reduction of use, which could lead to the disappearance of endangered languages, local dialects, and tonal and cultural variations associated with human language and expression. (UNESCO, 2020b, para. 96)

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In its section on the economy and labour policy action area, the document points to the need for strong pro-competition measures, stating that, inter alia,

> Member States should devise mechanisms to prevent the monopolization of AI systems throughout their life cycle and the resulting inequalities, whether these are data, research, technology, market or other monopolies. Member States should assess relevant markets, and regulate and intervene if such monopolies exist, taking into account that, due to a lack of infrastructure, human capacity and regulations, LMICs, in particular LDCs, LLDCs and SIDS are more exposed and vulnerable to exploitation by large technology companies. (UNESCO, 2020b, para. 118)

Inputs on this UNESCO AHEG *First Draft of the Recommendation on the Ethics of Artificial Intelligence* are due by 31 December 2020, and a final draft recommendation is scheduled to be submitted to UNESCO's 41st General Conference in late 2021.[2] The final *Recommendation on the Ethics of Artificial Intelligence* that is eventually approved by UNESCO Member States is likely to be a valuable standard-setting tool for African policymakers to consult and reference as they take forward their efforts to craft policies that maximise AI's benefits and address its challenges.

6. Conclusion

From certain perspectives, it can be argued that there is a high level of diversity of AI deployment on the African continent. As revealed in this article, one aspect of diversity is in the types of problems that are being addressed by AI. From financial inclusion to combatting cultural and linguistic marginalisation, AI innovations are aimed at many different aspects of African society, economy, and government. Another form of diversity is in the people implementing AI solutions, and in this regard, the relatively high level of participation by women in African entrepreneurship is encouraging. Diversity of location is also noteworthy—while AI is clearly developing in countries that are well known as technology hubs (e.g., Kenya, Nigeria, and South Africa), there are also significant AI-focused activities in countries that are less frequently recognised for cutting-edge digital adoption (e.g., Uganda and Ethiopia). In contrast, government policy is an area where there is less diversity, as the vast majority of African countries lack a dedicated AI policy instrument.

AI has the potential to be as impactful in Africa as it is in other regions of the world, but as explained herein, the unique context will influence the depth and breadth of that impact. The labour force in Africa is very different from the labour forces in, for example, Europe and the United States, and, accordingly, the impact of AI on labour will likely also be quite different. This is similarly true for the financial sector and various aspects of inclusion. In many ways, the stakeholders responsible for the evolution and adoption of AI in Africa can be guided by the experiences of other nations and continents. At the same time, however, African AI stakeholders will ultimately chart a course that is substantially dictated by the unique characteristics of the continent. Future research should focus on the evolution of AI in Africa, from the development of the technologies through to the levels of acceptance by the people interacting with AI, and through to the ultimate impact of the technologies on society.

2 At the time of finalising this article, the dates of UNESCO's 41st General Conference had not been set.

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Indigenous Peoples, Data Sovereignty, and Self-Determination: Current Realities and Imperatives

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Abstract
This study explores the current state and dynamics of the global Indigenous data sovereignty movement—the movement pressing for Indigenous peoples to have full control over the collection and governance of data relating to their lived realities. The article outlines the movement's place within the broader push for Indigenous self-determination; examines its links to big data, open data, intellectual property rights, and access and benefit-sharing; details a pioneering assertion of data sovereignty by Canada's First Nations; outlines relevant UN and international civil society processes; and examines the nascent movement in Africa. The study identifies a fundamental tension between the objectives of Indigenous data sovereignty and those of the open data movement, which does not directly cater for Indigenous peoples' full control over their data. The study also identifies the need for African Indigenous peoples to become more fully integrated into the global Indigenous data sovereignty movement.

Keywords
Indigenous peoples, data, data sovereignty, self-determination, decolonisation, research, data collection, big data, open data, open science, access and benefit sharing (ABS), intellectual property (IP), UN, UNDRIP, CARE principles, FAIR principles, international, CANZUS, Africa

Acknowledgements
The author thanks University of Ottawa JD student Kelsea Gillespie for research assistance, and the multiple anonymous peer reviewers for their inputs. The author also thanks the internal reviewers at the Centre for International Governance Innovation (CIGI). This article was written as part of the author's participation in the Open African Innovation Research (Open AIR) network. Open AIR is a partnership between the University of Cape Town, the University of Johannesburg, Strathmore University in Nairobi, the Nigerian Institute of Advanced Legal Studies, The American University in Cairo, and the University of Ottawa. The author acknowledges the support currently provided to Open AIR by the Social Sciences and Humanities Research Council (SSHRC) of Canada and the International Development Research Centre (IDRC). This article draws on elements from Oguamanam (2018; 2019).

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DOI: https://doi.org/10.23962/10539/30360

Recommended citation
Oguamanam, C. (2020). Indigenous peoples, data sovereignty, and self-determination: Current realities and imperatives. *The African Journal of Information and Communication (AJIC), 26*, 1-20. https://doi.org/10.23962/10539/30360



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1. Introduction

International policy endeavours in support of the world's Indigenous peoples are framed around advancing active Indigenous participation in development pursuits within culturally respectful frameworks. The overarching objectives of these endeavours are geared towards Indigenous self-determination and mechanisms for measuring progress towards this self-determination (see Oguamanam, 2004). Colonial and post-colonial settler states and unitary states have tended, in service to their vested interests, to turn questions of Indigenous self-determination into sites of interminable interpretational somersaulting and foot-dragging (see Dalton, 2005).

In recent years, however, there has been a shift towards more encouraging state efforts to make space for the emergence of self-determined Indigenous development in diverse spheres pursuant to decolonisation and anti-racist agendas. This article focuses on a key element of this trend: the global Indigenous data sovereignty movement, which is pressing for all Indigenous peoples to have full control over the collection and governance of data relating to their communities. The next section sets out Indigenous data sovereignty's conceptual and practical elements, including its interfaces with big data and open data, and its links to matters of intellectual property and access and benefit sharing. The article then moves on to examine a pioneering realisation of data sovereignty, in respect of health information, by Canada's First Nations, followed by an outline of international responses and processes, including the strong role being played by Indigenous peoples in the CANZUS states (Canada, Australia, New Zealand, United States), and conjecture on Africa's place in the global Indigenous data sovereignty movement.

2. Conceptual and practical context

Indigenous data sovereignty

Data sovereignty denotes the right of states, in relation to other states or entities, "to govern the collection and ownership [of data], including access and use of data that is domiciled within their jurisdiction" (Oguamanam, 2018, p. 207). Data sovereignty, as an idea, is the assumption of responsibility to ensure that information is managed in ways "consistent with the laws, practices, and customs of the nation-state in which it is located" (Snipp, 2016, p. 39). Taking into consideration the sophistication of current technological interventions in data generation and storage, as well as the complex chains of data migration and data valourisation, it can now be persuasively argued that data sovereignty extends to the interest of states in the sanctity, integrity, and security of data—and of the cultural and other contextual sensitivity associated with data. In the words of Schultz and Rainie (2014, p. 1), "[d]ata is intimately linked to the sovereignty and self-determination of all nations".

Under colonial, neo-colonial, and unitary national frameworks, Indigenous peoples have had a troubled relationship with how data concerning them is generated, accessed, shared, applied, and owned. The data has typically been owned by the state in which Indigenous peoples are embedded, or by other non-Indigenous actors, particularly researchers and corporations. Indigenous peoples and their political entities have only comparatively recently begun staking their claims in the data space, as part of their quest for greater self-determination and, in the settler CANZUS states, as part of the broader decolonisation project (see, for example, Open North & BCFNDGI, 2017).

Indigenous peoples lament that they have been "researched to death", resulting in an extensive trail of abuses and victimisation in research contexts (see American Indian Law Centre, 1999; Blair, 2015; Goodman et al., 2018; Porro et al., 2015). Research is a systemic exercise in gathering and using information to arrive at specific conclusions for the advancement of knowledge and the making of policy. The default until relatively recently was that Indigenous peoples were passive objects and subjects of research funded by non-Indigenous entities and often conducted by academic researchers who may have had complicit relationships with corporations and other institutional actors in the data-generating space. Indigenous peoples did not set the research agendas, as those were predetermined without consultation or without their free, prior, and informed consent (FPIC). One particularly stark example of Indigenous peoples being framed as passive research subjects was the Human Genome Diversity Project, in which the research initially, before protests emerged from Indigenous and other activists, intended to extract human genetic material from Indigenous communities without their informed consent (see Amani & Coombe, 2005). Sterling (2011), Santos (2008), and Brower (1997) have also shed light on the abuse of Indigenous peoples in human genetic research.

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The undergirding development paradigm and framing of issues in research and data generation relating to Indigenous peoples have typically been culturally insensitive and delivered in top-down, prescriptive modalities. Knowledge arising from research has been valourised as a capitalist proprietary enterprise because "[t]here is no law or concept in Western society that recognizes inherent community rights and interests in data and information" (FNIGC, 2016, p. 141). Until recently, rarely did the importance of the interface between personal and collective or community agency resonate in non-Indigenous research paradigms. Furthermore, given the small size of many Indigenous communities, their demographic statistics were seldom reflected in national surveys (Schultz & Rainie, 2014).

Indigenous peoples are unequivocal that prevailing architectures for research and data generation in their territories have generally been ill-suited to their development aspirations and contradict their objectives of self-determination and self-governance.[1] While there have been significant efforts to treat research involving Indigenous peoples as a sui generis category (see Government of Canada, 2018), and to adjust institutional review and ethical clearance procedures to this end, matters of collecting, processing, and publishing data on or from Indigenous people are still often negotiated from non-Indigenous perspectives, without tackling questions of cultural sensitivity, sovereignty, and self-determination (Harding et al., 2012).

The Indigenous data sovereignty movement seeks to rectify the relationship between Indigenous peoples and Indigenous data. As Rainie et al. (2019) write,

> [Indigenous data sovereignty] refers to the right of Indigenous peoples to govern the collection, ownership, and application of data about Indigenous communities, peoples, lands, and resources. Indigenous data is […] data in a wide variety of formats inclusive of digital data and data as knowledge and information. It encompasses data, information, and knowledge about Indigenous individuals, collectives, entities, lifeways, cultures, lands, and resources. (Rainie et al. 2019, p. 301)

In the words of the Global Indigenous Data Alliance (GIDA, n.d.),

> While the term Indigenous Data Sovereignty is relatively new, Indigenous Peoples have always been data collectors and knowledge holders. The rise of national Indigenous Data Sovereignty networks reflects a growing global concern about the need to protect against the misuse of Indigenous data and to ensure Indigenous Peoples are the primary beneficiaries of their data. (GIDA, n.d.)

1 For a comprehensive literature review of Indigenous peoples' troubled experiences with the conduct of research, see Ermine et al. (2004).

Misuse of Indigenous data strikes at the core of the ability of Indigenous peoples to exercise their rights to self-determination. Authentic data can drive policy formulation, decision-making, mapping of development aspirations, problem-solving, and other calculations critical to Indigenous empowerment for development in a range of fields. These fields include education, language, finance, health, medicine, agriculture, environmental stewardship, community membership, lands, resources, artworks, rituals, ceremonies, cultural expressions, creativity, and innovation.

Big data and open data

Big data is massive-volume, high-velocity and high-variety information assets (Corrales et al., 2017; Lefèvre, 2018) on a scale beyond the capacity of conventional or isolated data processing applications, and convertible into diverse and far-reaching uses by powerfully endowed entities. Those entities, which include governments and large private-sector actors, are capable of using a wide variety of high-tech advancements to exploit big data. Meanwhile, open data approaches to big data are part of the "openness or open access movement and its continuing metamorphosis as a malleable approach toward enhancing the flow of information, reducing the costs of its access and optimizing its public impact in contrast to a closed proprietary approach" (Oguamanam, 2018).

Big data and open data have "a nuanced relationship" (Oguamanam, 2018, p. 200), in that they "are constructive and modified forms of proprietary [i.e., exclusive and commercial] use of data in self-interested ways that strategically [encourage] target forms of sharing via licencing or related schemes to optimize value" (Oguamanam, 2018, pp. 199–200). They are phenomena that each—and sometimes in combination—have the potential to be beneficial to Indigenous data sovereignty. For example, open data, with or without big data, can allow Indigenous peoples to engage in shared or collaborative uses of data across geographically dispersed nations and communities. Yet at the same time, big and open data phenomena reflect the complex interests and divergent stakeholders that operate in the data space, and those interests tend to be aligned neither with Indigenous peoples nor with the raison d'être of Indigenous data sovereignty. Clearly, "[t]he global data revolution and associated new technologies can be a double-edged sword for indigenous peoples if the values and principles of indigenous data sovereignty are not respected" (Open North & BCFNDGI, 2017, p. 7). What is often not mentioned is that, for reasons of sacralisation and other cultural considerations, not all forms of information or knowledge relating to Indigenous peoples are open to reduction into data or exposure to the public domain in the conventional sense.

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A core instrument in the open data movement is the 2015 International Open Data Charter (ODC), which begins with the statement that "[o]pen data is digital data that is made available with the technical and legal characteristics necessary for it to be freely used, reused, and redistributed by anyone, anytime, anywhere" (Open Data Charter, 2015). While there is much that is laudable in this statement and the others in the ODC, the instrument does not, in its current form, take cognisance of the requirements of Indigenous data sovereignty. As Rainie et al. (2019) write, the ODC's call for data's free use, reuse, and redistribution "by anyone, anytime, anywhere" is "in direct tension with the rights of Indigenous peoples to govern their data, including the right to decide what is shared or withheld, likely resulting from the ODC being developed without the involvement of Indigenous peoples" (Rainie et al., 2019, p. 301).

It is necessary to ensure that big data and open data approaches are understood and applied by nation states and other stakeholders in ways that, in the words of Open North and BCFNDGI (2017, p. 6), do not "further marginalize/reinforce structural oppression toward Indigenous Nations." According to Lauriault (2017), as quoted in Oguamanam and Jain (2017), the "open data community needs to critically reflect on its worldview and how it differs from that of Indigenous People". There is evidence to suggest that this point is not lost on certain big data and open data players. For example, Open North, a global big data entity, is actively involved with Canadian Indigenous people in efforts to foster Indigenous data sovereignty in ways that critically account for its relationship with open data and its underlying parameters (Open North & BCFNDGI, 2017).

IP and ABS

The question of how Indigenous data sovereignty protocols (e.g., the OCAP framework that is discussed below) deal with non-Indigenous use of Indigenous data is crucially important. And among the most egregious abuses of Indigenous knowledge by non-Indigenous actors are those perpetrated via the application of intellectual property (IP) rights—for example, via private-sector patenting, without FPIC, of pharmaceuticals, nutraceuticals and agricultural or food products developed with the use of Indigenous knowledge and/or genetic resources sourced from Indigenous lands.

Central to IP questions, and to Indigenous data sovereignty, are matters of access and benefit sharing (ABS) in respect of genetic resources on Indigenous lands, and the associated Indigenous knowledge (Robinson, 2010; 2014). The evolution of ABS has resulted in the reinforcement of valuable consent principles such as the aforementioned FPIC—through which, when IP rights are sought, there must be documentation of the source and origin of the genetic resources being acquired for research and, where applicable, a resulting invention or innovation (Robinson et al., 2017). ABS is a traction point for underscoring how biotechnology and Indigenous

ecological (or biocultural) knowledge constitute one of the core intersection points in the data sovereignty domain. In order for Indigenous peoples to be able to effectively participate in ABS, it is imperative that they have control over the data representations of their genetic resources and associated Indigenous knowledge.

One way in which Indigenous data can be harnessed in a manner that mitigates the potential for IP and ABS abuses is compilation of Indigenous knowledge into online databases that make clear the provenance of the knowledge. A pioneering initiative of this kind is India's Traditional Knowledge Digital Library (TKDL), established in 2001 by the Indian Government's Council of Scientific and Industrial Research (CSIR). The TKDL project has "structured and classified the Indian Traditional Medicine System […], thus enhancing the quality of search and examination of prior art with respect to patent applications […] in the area of traditional knowledge" (TKDL, n.d.). The Indigenous knowledge documented in the TKDL is made available to patent offices around the world, so as to both "protect Indian traditional medicinal knowledge" and "prevent its misappropriation [through unjust patenting]" (TKDL, n.d.). The presence of the TKDL has already resulted in more than 200 patent applications being rejected, withdrawn, or revised (TKDL, n.d.).

3. A pioneering national response: Canada's First Nations and the OCAP principles

In 1994, the Government of Canada, through Health Canada and its then-named Medical Services Branch, launched three nationwide longitudinal health surveys. The initiative excluded most members of Canada's First Nations. (The First Nations, with the Inuit and Métis, constitute the country's Indigenous peoples.) In an effort to address this gap, in 1995 the Medical Services Branch extended an invitation to regional First Nations representatives to participate in a supplementary survey. This invitation came at a time when, as explained by the First Nations Information Governance Centre (FNIGC), "the issue of First Nations jurisdiction over all matters including ownership of information was at the forefront of First Nations political thinking" (FNIGC, 2016, p. 146). Emblematic of the prominence of the issue at the time is the 1996 Report of the country's Royal Commission on Aboriginal Peoples (RCAP), which pointed to the fact that information-gathering on Indigenous people is typically conducted without considering the peoples' concerns and priorities (RCAP, 1996).

In response to the aforementioned government invitation to participate in a supplementary health survey, in 1997 the First Nations constituted a committee (the precursor to today's FNIGC) that conducted and delivered the inaugural First Nations Regional Health Survey (RHS) (FNIGC, 2016). The data collected through

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this exercise was, according to the FNIGC, "invaluable, helping to generate program resources in several key public and community health areas" (FNIGC, 2016, p. 147). In addition,

> First Nations were acutely aware of the opportunity to utilize the RHS as a vehicle to move the benchmark ahead in favour of First Nations' data jurisdiction and ensure the continued forward momentum of sovereignty over data information, knowledge and stories. It was from the works of the RHS that the concepts inherent to data jurisdiction were articulated. (FNIGC, 2016, p. 147)

The RHS is now undertaken every four years in Canada, and Canadian Indigenous peoples' participation is backed by the FNIGC-developed (and trademarked) ownership, control, access, and possession (OCAP) governance principles (FNIGC, n.d.). OCAP "represents principles and values that are intertwined and reflective of First Nations' views of jurisdiction and collective rights" (FNIGC, 2016, p. 149), and is institutionally administered by the FNIGC. According to the FNIGC, the RHS represents

> the first national survey to be fully owned, controlled and stewarded by First Nations. Nothing like it had ever been successfully completed anywhere in the world. Concepts such as full ownership of data and intellectual property by First Nations, First Nations stewardship of data and government access through a limited licence to use were to become essential elements of the original RHS and form the backbone of OCAP® principles as they exist today. (FNIGC, 2016, p. 146)

The First Nations' experience in Canada with the RHS is an "illustration of how sovereignty can be realized in relation to data, information and knowledge as part of a broader goal of self-determination" (Kukutai & Taylor, 2016, p. 9). Since its first implementation in 1997, the RHS has served as one of the beacons in the global Indigenous movement towards data sovereignty.

4. International responses and processes

UNPFII and UNDRIP

A key milestone during the first UN International Decade of the World's Indigenous People (1995–2004) was the establishment in 2000 of the UN Permanent Forum on Indigenous Issues (UNPFII),[2] a high-level advisory body to the UN Economic and

2 Establishment of a Permanent Forum on Indigenous Issues, ECOSOC Res 2000/22, UNECOS-OCOR, 45th Sess, UN Doc E/RES/2000/22 (2000).

Social Council (ECOSOC). Through ECOSOC, the UNPFII's opinions and recommendations are channelled to specific UN programmes, funds, and agencies for implementation and translation into policy. The UNPFII's work and mandates focus on six thematic areas, namely: economic and social development, culture, the environment, education, health, and human rights. In 2001, a year after the UNPFII was established, the UN Commission on Human Rights appointed a Special Rapporteur on the rights of Indigenous peoples.[3]

Six years later, in 2007, the UN adopted its Declaration on the Rights of Indigenous Peoples (UNDRIP) (UN, 2007a). In the same year, the UN Human Rights Council established the Expert Mechanism on the Rights of Indigenous Peoples (EMRIP) (UN, 2007b), which was tasked, pursuant to UNDRIP, with providing expertise and advice to the Human Rights Council.[4] The UNPFII, the Special Rapporteur, and EMRIP are, thus, the three main bodies in the UN system with special mandates that directly focus on Indigenous issues, with UNDRIP serving as the framing instrument.

An enduring objective of the Indigenous data sovereignty movement is advancing the rights enunciated in UNDRIP, including its unequivocal stance on the right of Indigenous peoples to self-determination. Specifically, Article 3 of UNDRIP provides that "Indigenous Peoples have the right to self-determination. By virtue of that right they freely determine their political status and freely pursue their economic, social and cultural development". And Article 31 of UNDRIP takes an omnibus and summative approach to the protection of Indigenous rights, declaring that:

> Indigenous Peoples have the right to maintain, control, protect, and develop their cultural heritage, traditional knowledge, and traditional cultural expressions, as well as the manifestations of their sciences, technologies, seeds, medicines, knowledge of properties of flora and fauna, sports and traditional games, visual and performing arts. They also have the right to maintain, control, protect and develop their intellectual property over such cultural heritage, traditional knowledge and traditional cultural expressions.

The UNPFII has devoted a significant portion of its work to the promotion of data sovereignty as part of its support for the right of self-determination unequivocally affirmed in UNDRIP. Among other things, the UNPFII pursues Indigenous data sovereignty as a means of ensuring accurate demography and enumeration in Indigenous communities and, in turn, better aggregation of Indigenous information

3 The first Special Rapporteur on the rights of Indigenous peoples was Mexico's Rodolfo Stavenhagen, appointed in 2001.
4 The UNDRIP resolution was passed in September 2007 and the EMRIP resolution was passed in December 2007.

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towards the measurement and evaluation of progress or lack thereof regarding UNDRIP and UN programmes that engage Indigenous peoples. The UNPFII's work in the area of data derives from its mandate 2(c), in terms of which it is required to "prepare and disseminate information on Indigenous issues".[5] At its first session in 2004, the UNPFII convened an Expert Workshop on Data Collection and Data Aggregation for Indigenous Peoples (UNPFII, 2004). As explained by Gilbert and Lennox (2019), this workshop established the following core principles:

> […] all data collection should follow the principles of FPIC [free, prior and informed consent]; the principle of self-identification should be paramount in determining subjects/categories of data collection; participation of indigenous peoples in the collection process is essential; and moreover, 'data collection must respond to the priorities and aims of the indigenous communities themselves'. (Gilbert & Lennox, 2019, p. 112)

In 2006, the UNPFII convened another data-focused workshop, which recommended, inter alia, that the UN "identify and adopt appropriate indicators of indigenous identity, lands, ways of living, and indigenous rights to, and perspectives on, development and well-being" (UNPFII, 2006). In the years since these 2004 and 2006 workshops on data collection and aggregation, the UNPFII has consistently placed Indigenous data issues at the core of UN development planning and implementation across numerous programmes, funds, and agencies (see Gilbert & Lennox, 2019). In turn, a wide range of other key international actors, including the World Bank, the International Finance Corporation, corporations, donors, and development agencies have come to recognise Indigenous-sanctioned data as being crucial to legitimate and informed insights into matters of Indigenous peoples' self-determination and development.

UN World Conference on Indigenous Peoples, IPMG

The outcome document of the 2014 high-level plenary meeting of the UN General Assembly, also known as the World Conference on Indigenous Peoples, provides in paragraph 10 that:

> [w]e commit ourselves to working with indigenous peoples to disaggregate data, as appropriate, or conduct surveys and to utilizing holistic indicators of indigenous peoples' well-being to address the situation and needs of indigenous peoples and individuals, in particular older persons, women, youth, children and persons with disabilities. (UN General Assembly, 2014)

5 Establishment of a Permanent Forum on Indigenous Issues, ECOSOC Res 2000/22, UNECOSOCOR, 45th Sess, UN Doc E/RES/2000/22 (2000).

Data on Indigenous peoples is integral to the UN's 2015 resolution, Transforming Our World: The 2030 Agenda on Sustainable Development (UN, 2015) and the 17 accompanying Sustainable Development Goals (SDGs), as adopted in 2015, with the UNPFII succeeding in ensuring that Indigenous-related data is "a key strand" of the SDGs (Gilbert & Lennox, 2019, p. 10), and that the resolution states "the need for the participation of Indigenous peoples at the country level and […] for disaggregated data on Indigenous status on Indigenous peoples' terms" (Rainie et al., 2019, p. 306).

The key entity for Indigenous peoples within the SDG process is the Indigenous Peoples Major Group for Sustainable Development (IPMG), which is a strong champion for the use of Indigenous data in the SDG implementation, monitoring, and evaluation processes. The IPMG is one of the eligible participating major groups in the SDG process (see Gilbert & Lennox, 2019; IPMG, n.d.). The group was proactive via a position paper it prepared for the proposed SDGs in which it advocated a monitoring and evaluation framework for gauging the impact of SDGs on Indigenous peoples and issues, especially the right to self-determination (IPMG, 2015).

UN CBD and Nagoya Protocol

Another UN instrument with great relevance to Indigenous data sovereignty is the 1992 Convention on Biological Diversity (CBD) (UN, 1992). Generally, the CBD and its 2010 Nagoya Protocol on Access and Benefit Sharing brought access to genetic resources, and to associated Indigenous or traditional knowledge, within a framework of fair and equitable sharing of benefits arising from the resources' utilisation. The Nagoya Protocol has a broad definition of "utilization of genetic resources", primarily focused on the context of research and development (R&D) in biotechnology (UN, 2010, Art. 2(c)). The CBD's definition of biotechnology refers to "any technological application that uses biological applications, living organisms and derivatives thereof, to make or modify products or processes for specific use" (UN, 1992, Art. 2). Derivatives are defined under the Nagoya Protocol as "naturally occurring biochemical compounds resulting from the genetic expression or metabolism of biological or genetic resources, even if [they do] not contain functional units of heredity" (UN, 2010, Art. 2(e)).

Both the CBD and its Nagoya Protocol are, on the face of it, oriented towards physical dealings with—i.e., use and transfer of—genetic resources. Within this orientation, matters of the provenance or origin of genetic resources (and associated Indigenous knowledge, where applicable) and of ensuring FPIC are relatively straightforward (Oguamanam, 2018, p. 198). However, there are today myriad applications of digital information and communication technologies (ICTs) in R&D relating to genetic resources, including resources in which associated Indigenous knowledge is also implicated. This transformation in R&D relating to genetic resources is animated

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through disciplinary convergences across, inter alia, bioinformatics, synthetic biology, digital sequencing, and artificial intelligence (AI) or machine learning. These ICT applications provide increasingly wide amplitude for generating, processing, and reducing genetic resources and associated Indigenous knowledge into digital, virtual datasets that proactively de-link the resources from, inter alia, their provenance in Indigenous and local communities. Such de-linking has ramifications for determining when information or datasets relating to genetic resources interface with Indigenous knowledge and, as such, should have the status of a derivative in relation to any resulting innovation. This determination of derivative status can be central to, inter alia, patenting and other forms of IP protection in relation to genetic resources. At the same time, digital transformations in the biotechnology sphere can have positive ramifications for open science.

Altogether, the aforementioned ICT deployments present both opportunities and challenges for Indigenous data sovereignty. There is, accordingly, a clear imperative for vigilance on the part of Indigenous peoples in respect of how the CBD and its Nagoya Protocol on ABS respond to, or could be interpreted in the light of, the new technological realities in which genetic resources are reduced to malleable and incorporeal datasets.

GIDA and IDSIG

Indigenous data sovereignty as an Indigenous-driven international initiative is currently led by the Global Indigenous Data Alliance (GIDA) and the International Indigenous Data Sovereignty Interest Group (IDSIG), both of which cooperate with the Research Data Alliance (RDA). IDSIG is an initiative of a tripartite network of national Indigenous organisations: Te Mana Raraunga (the Maori Data Sovereignty Network) in Aotearoa/New Zealand, the US Indigenous Data Sovereignty Network, and the Maiam nayri Wingara Aboriginal and Torres Strait Islander Data Sovereignty Group in Australia (Kukutai & Taylor, 2016; Oguamanam, 2018). In 2017, IDSIG issued the International Indigenous Data Sovereignty IG Charter Statement, which includes the following statements:

> Like other nation states, Indigenous nations need data about their citizens and communities to make informed decisions. However, the information that Indigenous nations have access to is often unreliable, inaccurate, and irrelevant. Federal, state, and local governments have primarily collected these data for their own use. Indigenous nations' reliance on external data that do not reflect the community's needs, priorities, and self-conceptions is a threat to self-determination. The demand for Indigenous data is increasing as Indigenous nations and communities engage in economic, social and cultural development on an unprecedented level. Given the billions of dollars in research funding spent each year and the increasing momentum of the international big data and open data movements, Indigenous nations and communities are uniquely positioned to claim a seat at the table to ensure Indigenous Peoples are directly involved in efforts to promote data equity in Indigenous communities. (IDSIG, 2017)

A 2018 global workshop on "Indigenous Data Sovereignty Principles for the Governance of Indigenous Data", convened by the RDA and International Data Week in Gaborone, Botswana, released what have come to be known as the CARE Principles for Indigenous Data Governance (GIDA, 2019). The CARE principles—collective benefit, authority to control, responsibility, and ethics—are now the guiding principles of the global Indigenous data sovereignty movement being taken forward by GIDA, IDSIG, and the RDA. The principles can be viewed as an effort to, inter alia, temper tendencies among big data, open data, and open science practitioners towards giving short shrift to Indigenous data sovereignty. GIDA sums up the sentiment in the following observation:

> The current movement toward open data and open science does not fully engage with Indigenous Peoples rights and interests. Existing principles with the open data movement (e.g. FAIR: findable, accessible, interoperable, reusable) primarily focus on characteristics of data that will facilitate increased data sharing among entities while ignoring power differentials and historical contexts. The emphasis on greater data sharing alone creates a tension for Indigenous Peoples who are also asserting greater control over the application and use of Indigenous data and Indigenous Knowledge for collective benefit. (GIDA, n.d.)

The FAIR principles cited by GIDA in this quoted passage are extolled by the open data movement, and are also consistent with big data and open science paradigms. Indigenous data sovereignty proponents are sceptical about the validity of CARE as a stand-alone set of principles, and hence they insist that there is a need for open data stakeholders, and indeed open science and big data stakeholders, to adhere to both the FAIR and CARE principles as a means of accommodating and accounting for Indigenous data sovereignty.

The CARE framework is oriented towards the collective benefit of Indigenous peoples achieved through the use of data for inclusive innovation and self-determined development. It also supports the authority of Indigenous peoples and institutions to control data relating to their territories, resources, land, knowledge, and language, and to ensure culturally sensitive data governance models, including adherence to FPIC. CARE emphasises both data for governance and governance of data, i.e., both the use of data for advancing Indigenous governance and, at the same time, the use of data in ways that follow data governance protocols appropriate to Indigenous data. CARE also strongly supports ethical considerations across the life cycle of Indigenous data, including reducing real and perceived harms, optimising benefits, and promoting human rights, including the rights espoused in UNDRIP.

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Indigenous Navigator

Established in 2014, the Indigenous Navigator is "a framework and set of tools for and by indigenous peoples to systematically monitor the level of recognition and implementation of their rights" (Indigenous Navigator, n.d.). The tools can be used to monitor progress towards the Indigenous empowerment and development objectives set out in, inter alia, the SDGs, UNDRIP, and the World Conference on Indigenous Peoples (see Gilbert & Lennox, 2019). The Indigenous Navigator facilitates the collection of high-quality grassroots and community data that are then fed into the project's online portal.

The Indigenous Navigator's pilot phase was in 2014, and this involved the use of the Navigator to generate quality data relating to progress on Indigenous issues in six countries: Peru, Kenya, Cameroon, Suriname, Thailand, and Nepal. The second phase, launched in 2017, involved 11 countries, including all the countries in the first phase, with the exception of Thailand, and adding Bangladesh, Cambodia, the Philippines, Bolivia, Colombia, and Tanzania.

5. African responses and processes

From the foregoing analysis, it is clear that Indigenous data sovereignty has to date been driven to a great extent by activities in CANZUS countries. In Africa, engagement with the global movement has yet to reach critical mass. Among the potential reasons for this slower evolution of the movement in Africa, compared to the CANZUS states, is the very different and ambiguous history of the instrumentalisation of the concept of indigeneity on the continent.

In African countries, indigeneity can be said to have two meanings (see Crawhall, 2011). According to one meaning, all black Africans are Indigenous to Africa. But according to the second meaning, the large and politically powerful ethnic groupings in many sub-Saharan African countries are relatively recent arrivals in the territories they inhabit, having migrated from West Africa and, upon arrival, encountered the Indigenous peoples already living there (Crawhall, 2011). While there has been, and still is, a reluctance by some African governments to champion the rights of Indigenous minorities in their nation states, there was evidence of growing acceptance of Indigenous self-determination among the African diplomats who participated in the development of UNDRIP, a declaration which the vast majority of African UN Member States adopted (Crawhall, 2011; UN, 2007). As Crawhall (2011) explains, central to African states' growing acceptance of Indigenous peoples' rights during the UNDRIP talks was the advocacy work of the Indigenous Peoples of Africa Coordinating Committee (IPACC), a civil society body composed of representatives of Indigenous peoples in numerous African nations. This augurs well for the future of efforts towards Indigenous data sovereignty on the continent.

Also contributing to the potential for a strong African data sovereignty movement is the robust engagement on the continent with matters of data governance, especially in the context of IP and development narratives, and in specific areas such as agricultural data (see Dagne, 2020). As in many other regions of the world, there is a growing exploration on the continent of elements of "open development" (see Smith & Seward, 2020) by development funders, development projects, researchers, scholars, and policymakers. The open development framework valourises open collaborative innovation (see Open AIR, n.d.), open data, open science, open access publishing, open government data, open health data, and open educational resources (OER) (Smith & Seward, 2020). These and similar ideas are finding traction in, and in relation to, African Indigenous and local communities who are largely represented in informal economic sectors.

At the same time, particularly in the context of AI deployments on the continent, there is growing concern about power imbalances between African and foreign participants, leading to complaints of "data colonialism" (see Couldry & Mejias, 2019). Thus, the opportunities and challenges presented by big data and open data, and their ramifications for the self-determined development of Indigenous peoples, are as real, in Africa, as elsewhere.

In the specific context of Indigenous data sovereignty, it is significant that, as noted earlier, the CARE principles were drafted in Botswana, with active African representation and participation in the drafting. In addition, it is notable that three African countries, namely Kenya, Cameroon, and Tanzania, were participants in the early stages of the operationalisation of the global Indigenous Navigator data platform.

6. Conclusions

For self-determined Indigenous development to be of any consequence, it must be rooted in data sovereignty. Put differently, the sine qua non for self-determined development is the unfettered ability of Indigenous peoples to set their own research agenda, frame or design their own research questions, and select their own research partners. Also necessary is the capability of Indigenous peoples to analyse and interpret research results, and to negotiate their applications or outputs as consequential and transformative exercises of self-determined development.

Without question, Indigenous data sovereignty as a theory and practice is a work in progress, with paradigmatic pulls and tensions surrounding it. One core source of paradigmatic pull and tension is the paradoxical role of ICTs. As with virtually all socio-economic realms, ICTs have redefined and emboldened Indigenous interest in data sovereignty. ICTs enhance the ease of sourcing and transferring information, potentially resulting in the intensification of asymmetrical power relations, reminiscent of how colonial states and their agents dealt with Indigenous data. At

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the same time, ICTs have emboldened Indigenous peoples by serving as authentic tools of decolonisation and self-determination—tools that are essential to furthering the advancement of Indigenous data sovereignty. Without introspection or protocols on how ICTs can better serve Indigenous peoples in their quest for data sovereignty, there is the potential for an uncritical embrace that leads to the slippery reductionist slope of technological determinism. Such a tendency would undermine the necessary emphasis on cultural and other contextual variables that are served and preserved by Indigenous data sovereignty vis-á-vis the rapid traction and interest now associated with open data, big data, open science, and related concepts.

A sign of the growing maturity of the Indigenous data sovereignty movement is its increasing emphasis on the need for high-quality data in order for Indigenous peoples to be able to evaluate progress and ensure accountability across development and human rights spectra. This quest for quality is evidenced in, inter alia, the Indigenous Navigator project discussed above. Another sign of the maturing of the Indigenous data sovereignty space is the increasing, albeit late, presence of African players. However, African Indigenous peoples have yet to fully integrate themselves into the global movement, and there is an urgent need for this integration to occur.

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Drivers and Modalities of Collaborative Innovation among Nairobi's Mobile Tech Start-Ups

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Abstract
This article sets out findings from research into the collaborative modalities present in the innovation practices of mobile tech start-ups in the Kenyan capital, Nairobi. Drawing on findings from qualitative data collection from respondents at 25 start-ups in the Nairobi mobile tech ecosystem, the study explores the start-ups' participation in tech hubs, their internal collaborative activities, their external collaborations, their approaches to managing the knowledge and innovations they generate, and their approaches to the scaling of their enterprises. The study finds that three key drivers of the start-ups' collaborative innovation practices are openness, networking, and informality.

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Keywords
mobile tech start-ups, tech hubs, innovation, collaboration, human resource development, knowledge governance, scaling, partnerships, networking, openness, informality, Nairobi, Kenya

Acknowledgements
The research for this article was conducted by the Centre for Intellectual Property and Information Technology Law (CIPIT) at Strathmore University in Nairobi, under the auspices of the Open African Innovation Research (Open AIR) network. Open AIR is a partnership between Strathmore University, the University of Cape Town, the University of Johannesburg, the Nigerian Institute of Advanced Legal Studies, The American University in Cairo, and the University of Ottawa. The authors acknowledge the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, and the International Development Research Centre (IDRC). The views expressed in this work are those of the authors and do not necessarily represent those of the research funders. The authors wish to extend special thanks to Miriam Wanjiku Karanja for extensive reviewing and editing. This article draws on elements of a working paper (Nzomo et al., 2020).

DOI: https://doi.org/10.23962/10539/30359

Recommended citation
Nzomo, V., Mwangi, J., Matu-Mureithi, L., Muchiri, C. W., & Rutenberg, I. (2020). Drivers and modalities of collaborative innovation among Nairobi's mobile tech start-ups. *The African Journal of Information and Communication (AJIC), 26*, 1-24. https://doi.org/10.23962/10539/30359

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1. Introduction

Kenya has been hailed as Africa's "epicentre of innovation" (Moime, 2016), with its digital innovation activities in and around the capital, Nairobi, coming to be known as the "Silicon Savannah". Kenya's tech innovation start-up sector is, to a great extent, focused on innovations for use on mobile handsets. Since the launch of the M-PESA mobile money application (app) in 2007 by Kenyan mobile operator Safaricom, the country has seen the growth of a large and vibrant mobile app development ecosystem. Many start-ups leverage the M-PESA platform to create solutions in online financial services (fintech) and related sectors (Mwangi, 2017). At the same time,

Kenya's mobile tech start-ups are also engaged in developing mobile tech solutions in a wide range of other key sectors, including agriculture (see Karuga, 2013) and healthcare (see Lawrence-Brown & Nieminen, 2016).

Among the many factors seen as responsible for the rapid development and uptake of mobile technology innovation in Kenya, and across the African continent, is the proliferation of technology hubs (hereafter "tech hubs") (see Adesida et al., 2016; De Beer et al., 2017; Kaigwa, 2010; *The Economist*, 2012). These spaces provide business support in the form of mentorship, office facilities, networking opportunities, and seed funding. Through a tech hub, a mobile tech start-up is potentially able to receive support for its efforts to move from the idea stage to the minimum viable prototype stage, and then to take a product or service to market. In Kenya, perhaps the best-known tech hub is iHub, which has been singled out by numerous commentators as making a core contribution to the Kenyan mobile start-up scene (see, for example, *The Economist*, 2012).

Elements seen as central to innovation practices in many African settings are openness and collaboration (see, for example, De Beer et al., 2014; Pembroke, 2015; Smith & Reilly, 2013; Smith & Seward, 2020). Open and collaborative approaches to innovation, supported by flexible, non-exclusive approaches to knowledge governance, have been found to be central to the success, and efforts to scale, exhibited by many knowledge-based enterprises on the continent (see De Beer et al., 2014; Open AIR, 2020). With respect to start-ups, as Pembroke (2015) points out, there are so many challenges that none can succeed by going it alone, and, through collaboration, entrepreneurs can counter some of the inherent challenges of entrepreneurship (Pembroke, 2015).

The goal of this study was to explore the approaches to, and dimensions of, collaboration as being practised by Nairobi's mobile tech start-ups. We were also interested in the start-ups' approaches to knowledge governance and to scaling, as dimensions linked to their approaches to collaboration. Accordingly, we conducted a qualitative survey of the experiences and perceptions of representatives of 25 mobile tech start-ups engaged in the following sectors: fintech, bitcoin, community development, healthcare, hospitality, security, geospatial services, marketing, advertising, transportation, education, agriculture, real estate, software development, automation, IoT (internet of things), and outsourcing.

As is presented in this article, the data produced compelling findings on the drivers and modalities of the start-up innovators' collaborations, knowledge governance, and scaling. We were also able to identify, in the data, three cross-cutting dimensions that seem to be core animators of the start-ups' innovation practices: openness, networking, and informality.

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2. Context

Kenyan start-ups

Start-ups in Kenya are, for the most part, micro and small enterprises (MSEs). In terms of the country's Micro and Small Enterprises Act of 2012 (hereafter "MSE Act"), *micro* enterprises have an annual turnover of less than KES500,000 (approximately USD4,600 in late 2020) and fewer than 10 employees, with small enterprises having an annual turnover of between KES500,000 and KES5 million (i.e., between USD4,600 and USD46,000) and between 10 and 50 employees (Republic of Kenya, 2012). In qualitative terms, we agree with Robehmed's (2013) conception of start-ups as entities "working to solve a problem where the solution is not obvious and success is not guaranteed".

Kenya's Vision 2030 development strategy recognises the need to strengthen start-ups and MSEs (GoK, 2007). The MSE Act, in line with Vision 2030, positions start-ups, particularly tech start-ups, as drivers of innovation. Start-up culture is characterised by "[a] workplace environment that values creative problem solving, open communication and a flat hierarchy" (Rouse, 2014). Such an environment aims, among other things, to provide an opportunity for the people working at the start-up to grow organically with it, even if employees ultimately decide to exit the company and, in many cases, launch their own start-ups. Start-up culture also typically involves flexible approaches to knowledge governance—i.e., innovative modes of knowledge-sharing and knowledge appropriation, often with an emphasis on informal modes. It has been found that the use of formalised intellectual property (IP) tools to appropriate knowledge among Kenya's knowledge-based businesses is minimal (Masinde, 2016; Rutenberg, 2013; WIPO, 2016).

In the period 2018 to 2019, funding of Kenyan tech start-ups was put at USD122 million (Disrupt Africa, 2019). Among the elements central to the growth of mobile tech innovation in Kenya are the aforementioned M-PESA mobile money platform and, in turn, the country's mobile money and fintech market (Mengistu & Imende, 2013; Pasquier, 2014; *The Economist*, 2012). Since the launch of M-PESA in 2007, and the subsequent opening of its application programming interface (API) to developers in 2015 (Mutegi, 2015), the Kenyan fintech sector has been transformed by numerous start-ups developing new M-PESA-linked products and services (see Adongo, 2015). In March 2020, Kenya, with a population of approximately 47.5 million, had 55.2 million active mobile subscriptions (a penetration of 116.1% of the population, with many users having more than one mobile SIM card); 29.1 million active mobile money subscriptions (61% penetration); and 202,102 active mobile money agents (CAK, 2020).

The emergence of Safaricom and its associated services, including M-PESA, was made possible by the deregulation of Kenya's telecommunications industry, starting in 1999. Several socio-economic factors have also contributed to the explosive uptake

of M-PESA and other mobile money transfer systems, including: the low number of Kenyans with bank accounts (and, in turn, credit cards); the high number of urban Kenyans who support relatives in rural areas; and security problems posed by transferring funds by hand or through intermediaries, e.g., via bus transport (Mengistu & Imende, 2013). Government support for Kenya's connections to international undersea fibre optic data cable projects, through strategic partnerships with the private sector, has also contributed by making broadband internet widely available and affordable (Mengistu & Imende, 2013).

Tech hubs and collaborative innovation

In mid-2019, according to one calculation, there were 681 active tech hubs across the continent (Giuliani & Adaji, 2019). Africa's tech hubs can be understood in terms of three prevailing hub "archetypes" (see De Beer et al., 2017):

- *cluster hub:* A small geographical region, e.g., a neighbourhood or urban corridor, containing a number of individual hub entities that frequently interact. Nairobi's Ngong Road is an example of a cluster hub, as it is home to iHub, Nailab, m:Lab East Africa, and Nairobi Garage.
- *company hub:* An individual hub entity serving a particular community of innovators, "interacting with the outside world in a manner similar to a company" (De Beer et al., 2017, p. 250) and operating either as part of a cluster hub or in a more stand-alone fashion.
- *country hub*: "a more macro view of a hub, where an entire country or region advertises itself as a progressive hub, and government policies guide the actions of the country or region" (De Beer et al., 2017, p. 250).

African tech hubs' culture of openness has generated support from many development partners, who believe that open collaboration holds the key to the success of start-ups on the continent, and who further believe that tech hubs can enable sustainable tech entrepreneurship. Tech hubs have been credited with fostering collaboration-enabling environments where start-ups can meet new people, find resources and investors, and test their business models (Pembroke, 2015). Since its establishment, Nairobi's iHub has sought to build an innovation community committed to sharing and collaboration, and these objectives were also central to the establishment of m:Lab in the same building as iHub (Gathege & Moraa, 2013). iHub seeks to create an environment for open innovation and collaboration between developers, academia, industry, venture capitalists, and investors (Gathege & Moraa, 2013). Its key vehicles for collaborative innovation are hackathons and competitions, during which ideas are openly shared. M-Farm and Rupu are among the start-ups that materialised after such iHub events. It has been argued that, as part of their internal collaboration processes, start-ups seeking to develop their human resources need to leverage the skills of current employees by ensuring that they serve as trainers (Bahrami, 2016).

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For tech-based start-ups, a key form of collaboration is the interaction between individuals inside the organisation, where everyone works together to achieve a clear and shared aim in a specific context (Lopez Hernandez et al., 2018). The impact of collaboration on innovation is to some extent dependent on the nature of the partners involved in the process (Faems et al., 2005). In instances where collaboration is between a start-up and an established company, the value derived by each firm will be dependent on each actor's strengths (Steiber & Sverker, 2020). Organisations can harness collaboration in various ways, including internally through configuring their infrastructures in a manner that enables the sharing of ideas, and externally through their choices of location. Jiménez and Zheng (2018) argue that tech hubs' collaborative processes can contribute to human-centred development dimensions that are broader than employment and product development benefits.

Organisations can adopt closed or open models in their collaborative efforts. Closed innovation models are characterised by enterprises' efforts to, among other things, isolate their innovations and to keep them secret (De Beer, 2017, p. 17). Open collaboration models perform robustly not only in software innovation domains but also in many other types of ventures (Levine & Prietula, 2014). There is now a growing adoption of open collaborative models of innovation that can, for example, break down barriers to knowledge flows between enterprises (De Beer, 2017, p. 17). In Kenya, as mentioned above, the leading mobile telephone service provider, Safaricom, opened the application programming interface (API) for its M-PESA mobile money services in 2015. This opening was aimed at nurturing open innovation in Kenya (Safaricom, n.d.).

3. Research design

Methodology

The study used desk research to generate secondary data, and a survey questionnaire to produce primary data. In the desk research, basic information was gathered on all the start-ups that could be traced to Nairobi tech hubs, with contact information stored for the purposes of sourcing respondents for the administration of a semi-structured survey questionnaire, as outlined below. The desk research also yielded important background information on the start-up ecosystem in Kenya, including relevant reports, studies, and news articles. Based on the findings from the desk research, 25 start-ups in Nairobi were selected. Key resource persons at the start-ups were identified and contacted, and their inputs received through a semi-structured survey questionnaire administered via one of four means: an in-person interview, a phone interview, an online video interview, or respondent completion of the questionnaire in writing online. All interviews were audio-recorded and transcribed.

Questionnaire

The questionnaire (see Appendix) focused its questioning on the following elements of the 25 start-ups' mobile tech innovation practices:

- establishment, registration, duration of operations, human resources;
- sector(s), main products, types of problems addressed by innovations;
- organisation of workspaces, collaborations within the start-up, generation of business ideas;
- collaborations with external partners and stakeholders;
- sharing and protection of business knowledge and innovations; and
- approaches to the scaling of their enterprises.

Respondents

Table 1 below shows the sectors in which the 25 survey respondents' start-ups operated, the date on which the surveys were completed, and the survey mode used for each respondent.

Table 1: Respondents' sectors, survey dates, and survey modes

Respondent number	Start-up's sector(s)	Survey date	Survey mode
1	community development	9 March 2017	phone interview
2[1]	bitcoin, fintech	4 April 2017	online video interview
3	software development	20 February 2017	in-person interview
4	software development	22 February 2017	in-person interview
5	health	3 March 2017	in-person interview
6	digital marketing	31 March 2017	in-person interview
7	healthcare	8 June 2017	phone interview
8	outsourcing solutions	3 March 2017	in-person interview
9	software development	26 May 2017	phone interview
10	restaurants, leisure	17 April 2017	online questionnaire
11	IT solutions, security	2 May 2017	online questionnaire
12	IT solutions, geospatial services	9 May 2017	online questionnaire
13	IT solutions, advertising	15 May 2017	online questionnaire
14	IT solutions, machine automation	18 May 2017	online questionnaire
15	IoT (internet of things)	23 May 2017	online questionnaire
16	healthcare	24 May 2017	online questionnaire
17	transport and route mapping	26 May 2017	online questionnaire

1 This second response to the survey was provided cooperatively by two individuals from a single start-up, with each responding to the questions relevant to their area of expertise.

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18	IoT (internet of things)	29 May 2017	online questionnaire
19	education	29 May 2017	online questionnaire
20	agriculture	30 May 2017	online questionnaire
21	real estate	6 June 2017	online questionnaire
22	fintech	9 June 2017	online questionnaire
23	healthcare	2 August 2017	in-person interview
24	healthcare	2 August 2017	in-person interview
25	fintech	3 August 2017	in-person interview

Table 2 shows the gender breakdown of the 25 respondents, and their roles in their respective start-ups.

Table 2: Respondents' gender, role/position

Characteristics	No. of respondents	% of respondents
Respondent's gender		
Male	19	76%
Female	5	20%
Did not say	1	4%
Respondent's role/position in start-up		
Founder/CEO	13	52%
Technical staff member	7	28%
Director	2	8%
Other	3	12%

Table 3 shows the core characteristics of the 25 start-ups that the respondents represented.

Table 3: Core characteristics of the 25 start-ups

Characteristics	No. of start-ups	% of start-ups
Number of employees in start-up		
1–3	3	12%
4–6	8	32%
7–9	5	20%
10–12	2	8%
13–15	3	12%
16 and above	4	16%
Legal status of start-up		
Sole proprietorship business	3	12%
Not-for-profit entity	1	4%
Limited liability partnership	2	8%
Limited liability company	19	76%
Location of start-up in Nairobi[2]		
Ngong Road	3	12%
Kilimani	4	16%
Westlands	4	16%
Juja	2	8%
Thika Road (Kenyatta University)	3	12%
Madaraka Area (Strathmore University)	6	24%
No physical space (online-based)	1	4%
City Centre	1	4%
Upperhill	1	4%
Months/years since start-up's establishment		
< 6 months	1	4%
6 months–1 year	3	12%
18 months–2 years	3	12%
24 months–3 years	4	16%

2 Respondent 9's start-up has offices in both Nairobi and Eldoret.

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36 months–4 years	6	24%
48 months–5 years	4	16%
60 months–6 years	1	4%
72 months–7 years	3	12%
Company hub that start-up was based at or involved with at time of research		
Metta	1	4%
iHub	5	20%
iBiz Africa	6	24%
Chandaria BIIC	3	12%
KeMU Hub	1	4%
C4D Lab	2	8%
m:Lab East Africa	1	4%
Nairobi Garage	1	4%
SPRING accelerator	1	4%
Nailab	3	8%
Independent start-up (not involved with any company hub)		
Respondent 13	1	4%

4. Findings and analysis

We now present findings, drawn from the questionnaire responses, in terms of five themes:

- participation in tech hubs;
- internal collaboration;
- external collaboration;
- knowledge governance; and
- scaling.

Participation in tech hubs

Of the 25 start-ups surveyed, 10 were, at the time of the research, co-located with other start-ups in *company* hubs (according to the De Beer et al. (2017) company hub definition provided above); 14 had their offices in close proximity to other start-ups in a *cluster* hub (according to the De Beer et al. (2017) framing); and one was not interacting significantly with any hub.

In company hubs

For the 10 start-ups in company hubs, the hubs were said to provide benefit through numerous opportunities for networking and developing business ideas, in addition to affordable and serviced offices. The resident start-ups rely on the open and interactive spaces within the hubs in order to meet new tech entrepreneurs and investors, access mentorship opportunities, remain aware of tech trends, and explore business and networking opportunities with other start-ups. According to respondent 5, whose start-up was working out of the iBiz Africa company hub:

> iBiz Africa offers a platform where start-ups can share information, and the fact that [our] developers get to grow by sharing their challenges and technical problems with other developers at iBiz [is an added advantage]. This process [of interacting with other developers] helps our developers solve problems much faster.

A similar sentiment was provided by respondent 20, whose start-up has had substantial interactions with various tech hubs:

> Involvement in accelerators and tech hubs has been a huge factor in our success. We met our first angel and institutional investors at [an] accelerator, and have expanded the business through networks built at various accelerators and tech hubs.

According to respondent 6, the networking opportunities offered by company hubs are so crucial to business development that some start-ups seek to switch hubs once opportunities at one hub have been exhausted:

> We have been at iBiz for the past two years, and feel that we have exploited all the networking opportunities, including getting business from other start-ups working at iBiz, and have saturated that window of opportunity. Moving to a workspace with a similar set-up, such as Nairobi Garage, would afford us more networking opportunities and a chance to interact with other start-ups at the hub, including competitors that are in the same space, so as to understand the dynamics at play.

In cluster hubs

Among the 14 start-ups with offices in geographical clusters of start-ups, the two located in Westlands, a Nairobi suburb, cited the advantages of the area's many IT companies and IT start-ups, hence allowing easy interaction and exploration of ideas.

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Also extolling the virtues of participation in a cluster hub was respondent 4, from a start-up located in the Ngong Road cluster hub:

> The area around Ngong Road and Kilimani is a cluster for tech hubs and tech start-ups. […] [We] had offices along Kilimani Road, Adams Arcade, and then moved to our current location on Ngong Road. [We] moved office as [we] scaled […]. The clustering of tech companies [increases] the ease of sharing experiences, networking, learning from shared experiences, and growing as a start-up/company.

Internal collaboration

Use of open-plan offices

All the interviewees extolled the virtues, for all or most of their internal activities, of open-plan office set-ups in which teams—in particular, developer teams—are able to work openly and collaboratively. In the words of respondent 20: "[we] have an open work [space where] all teams are mixed and work collaboratively". According to respondent 8, from a start-up based at the iBiz Africa company hub, an open-plan office "provides the opportunity to network and collaborate with other start-ups that operate from iBiz". Two of the start-ups had opted for closed offices for their senior management combined with open-plan areas for their tech developers, allowing developers to easily share ideas and collaboratively solve technical problems. Respondent 18's start-up had its offices in a townhouse where its founders lived and which had an open-plan office set-up. Respondent 21's start-up had previously been hosted in an incubator hub with shared offices. As the start-up grew in size, it needed more space, and it opted to move to a private space where, among other things, it was better able to establish its own company culture. In the new space, it had adopted "[an] open office setup, [but also] with separate quiet/thinking rooms" (respondent 21).

Use of online platforms

The start-ups carrying out substantial amounts of fieldwork also make extensive use of virtual open working environments. They tend to have physical meetings as a team only when absolutely necessary. Mostly they communicate and collaborate via online tools such as Slack, Scrum Agile, Jira, Trello, Basecamp, WhatsApp, and email. These tools have the necessary flexibilities, allowing for a mixture of in-office and remote collaborative working between the start-ups' founders, staff members (both part-time and full time), interns, and collaborators hired for specific tasks.

Collaborative development of human capital

On-the-job training, sometimes supplemented by the use of free online training resources, is the start-ups' preferred mode of human resource development. In addition to being a cost-effective form of human capital development for start-ups operating

under tight financial constraints while seeking to grow and scale, on-the-job training was said to have numerous additional benefits. In the words of respondent 13:

> [We] prefer on-the-job training and collaboration through learning. It offers a fulfilling experience for us. It also serves as an important avenue to spread the company culture while offering our interns a chance to grow from the ground up.

At respondent 23's start-up, one of the founders has developed a practical-oriented internal training programme targeted towards the specific needs of the start-up's trainees. Respondent 14's start-up uses YouTube Tutorials for any "heavy training" that members need. Respondent 18's start-up also uses YouTube as an online training resource, as well as free online courses offered on massive open online course (MOOC) platforms such as Coursera and edX. Training can also play an important role in product development at the start-ups—serving, in the words of respondent 13, "as an avenue to innovate around existing products while coming up with new ideas and processes". According to respondent 15,

> […] training programmes […] make the members of the start-up more resourceful, as well as better equipped to handle specific tasks that in turn would enable the members of the start-up to access their skills and knowledge in providing innovative client-based solutions. The training has also proved to be very useful to the members of the start-up in the competitive tech industry.

According to respondent 17, the knowledge acquired by Kenyan university students during their degrees is "[…] very theoretical and not practical enough". In the words of respondent 24, "[f]ormal education does not prove useful when running a start-up". According to respondent 7:

> The training offered [at respondent 7's start-up] is more hands-on, i.e., more practical. Despite the interns/students being in their final year of study [at university], they lack the hands-on skills required in the marketplace, which is very worrying. The students possess a lot of theoretical knowledge as opposed to practical skills.

Training can also have a strong personal empowerment dimension for employees. In the words of respondent 21, "training not only helps them get better at their individual roles, but also empowers their decision-making capabilities in their own personal lives".

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Collaborative development of business ideas

The respondents generally saw their start-ups' business idea-generation processes as being collaborative, and typically following one of three approaches: a spontaneous approach, a human-centred design approach, or a "lean canvas" approach (Maurya, 2012). Six respondents indicated that their start-ups are, to a great extent, spontaneous, i.e., do not adopt any specific formal process, in their origination of business ideas. In the words of respondent 12: "[when] any idea comes up, we SWOT it [conduct a strengths, weaknesses, opportunities and threats analysis], do market research, [then] work on it". According to respondent 2:

> When an idea is pitched, a few of the team members will see if the idea is viable, and when the idea is deemed viable, they will map out the implementation of the idea into different phases. There is a communal system of sharing business ideas.

Ten respondents saw their start-ups' processes for developing business ideas as being primarily based on the observation of the needs and problems faced by potential customers, i.e., a human-centred design process. In the words of respondent 20, from a start-up targeting the agricultural sector: "[t]ypically, business ideas are ideated to solve a problem; either one we are facing or one our customers are facing. We ideate collaboratively, implement, test and refine the solution." According to respondent 18: "We do customer research by building simple websites, marketing them and seeing how much interest they pull from potential customers." Respondent 4 explained the process in this way:

> Ideas […] come from customers and the solutions created are bespoke solutions to cater for the clients' needs. The process to create these bespoke solutions involves requirement-gathering, analysis of the client's legacy system, and the development of a proposed solution to solve the customer's pain point.

Four of the surveyed start-ups use elements often associated with the lean canvas technique to develop business ideas. The lean canvas technique involves team members collectively brainstorming ideas, capturing the ideas on a one-page canvas or flipchart, and then writing down a model for the implementation of the ideas (Maurya, 2012). In the words of respondent 21, whose start-up was in the real estate sector: "[w]e use the lean canvas to brainstorm, and the validation board to experiment/go to market". According to respondent 2, whose start-up is in the bitcoin and fintech sector:

> [w]hen an idea is pitched, a few of the team members at [the start-up] will see if the idea is viable, and when the idea is deemed to be viable, they will map out the implementation of the idea into different phases. There is a communal system of sharing business ideas.

External collaboration

All the surveyed start-ups collaborate externally with other (non-rival) start-ups and individuals through various means, including joint ventures, strategic partnerships, consultancies, and contractual arrangements. For respondent 20's start-up, external collaborations are with a mix of both long-term partners and partners with whom the start-up engages on an as-needed basis:

> We have an extensive partnership ecosystem of organisations including data suppliers, farmer organisations, development organisations, and financial institutions. We also engage with external consultants on an ad hoc basis.

According to respondent 20, "[c]ollaboration allows us to remain a lean team, while accessing the resources and expertise we need to succeed". In the words of respondent 21 in the online questionnaire: "[we] get resources we wouldn't be able to afford [if it] weren't … for collaboration". And in the words of respondent 16: "[c]ollaboration reduces risks, shares resources, [and] improves expertise".

Respondent 14's start-up has found that external collaboration enables it to learn new things from its partners, especially in respect of the innovation process. According to respondent 17, external collaborations benefit the start-up "through sharing of different ideas [and] approaches to growth". In the words of respondent 19, the main benefit of collaboration is that "[t]here are partners who come to complement our weakness with their strengths". Respondent 22 spoke of using collaborations with external partners to create new revenue streams and product lines. Respondent 15's start-up collaborates with public relations companies that can boost the start-up's public image and engage in community service work that the start-up would not be able to successfully perform.

For respondent 13's start-up, external partners provide access to additional African markets beyond Kenya:

> The companies we have collaborated with have a wide reach across the African continent. They will play an important role in allowing us to scale faster, a process that would have taken a long while if we were to pursue these avenues ourselves.

At the same time, external collaborations are not without their challenges. While respondent 13's start-up has benefited from external collaborations, the respondent voiced a concern that, because the number of decision-makers increases, collaborations can slow down product development. Respondent 16 expressed the view that some collaborations can serve to limit a start-up's involvement with other potential partners. Respondent 23's start-up has experienced challenges in working with some

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non-governmental organisations (NGOs) and with Kenyan County governments, due to collaborations being halted as a result of lack of consistent funding or the termination of funding.

Knowledge governance

It was found that some of the start-ups have experienced what they regard as misappropriation of their ideas—by other start-ups, or individuals with whom they have collaborated. Respondent 20 gave the example of having discussions with potential start-up team members "who were thinking about similar products [and] who then went on to start a company with similar aspects to our work".

Among the 25 start-ups surveyed, only six were found to have used non-disclosure agreements (NDAs) to protect their knowledge, and a majority (13) had not yet engaged in any form of formalised knowledge protection or appropriation, such as via the intellectual property (IP) tools of trademarks, patents, utility models, or claims of copyright. Seven respondents said that their start-ups have copyright registrations (even though registration is not necessary in Kenya in order for copyright to exist in a work), two spoke of pending patents applications, five said that their start-ups have trademarks, and one spoke of the start-up having a trade secret. According to respondent 5, the value of IP to the start-up's business is to protect against copycats (both start-ups and established companies) using their ideas. In the words of respondent 4:

> We put a lot of resources from the business's finances to develop products that are aimed for the mass market, so intellectual property protection provides a way for us to protect our long-term interests and avoid anyone else ripping-off our products for their own benefits. IP adds to the value of the whole company, like having patented solutions could increase the value of the company when it comes to valuation.

However, respondent 7's start-up has found the registration process for trademarks and patents with the Kenya Industrial Property Institute (KIPI) to be slow, and thus a poor use of time and resources. The start-up approached the IP office of a local university to assist with a patent application process, but found the university's process too involved. The general perception among most of the start-ups is that Kenya's patent and trademark registration processes are overly long, complicated, and expensive. Respondents 23 and 25 were of the view that their start-ups' resources are better spent on product development and on scaling the business than on the "secondary" priority of IP protection—although they acknowledged the importance of their start-ups finding ways to protect their IP.

Respondent 8 explained that in the fast-moving world of mobile app development, IP protections will not dissuade competitors from creating similar products and entering the market in which you trade: "So, we haven't really thought of patenting anything because, you know, information technology is based on growth: make something better and sell it." Respondents 3, 7 and 25 stated that for their start-ups, the first-mover advantage is more important for growth than patent protection. As respondent 25 explained: "As far as we know, there's no clear way to protect your knowledge or know-how. So how we [do it] is, we execute faster, before somebody else." Respondent 7 stated that in the world of technology, time is of the essence, so rather than "waste time" with patent protection, the aim of the respondent's start-up was to "develop things and move first/fast into the market". Table 4 provides a picture of what the 25 respondents said were the modes of knowledge appropriation, and efforts at competitive advantage, used by their start-ups.

Table 4: Start-ups' modes of knowledge appropriation/protection and pursuit of competitive advantage

Modes of knowledge appropriation/protection used by start-up	No. of start-ups	% of start-ups
None	13	38%
Copyrights	7	21%
Trademarks	5	15%
Trade secrets	1	3%
Patents (pending applications)	2	6%
Non-disclosure agreements (NDAs)	6	18%
Means used to compete with rival firms		
Superior quality and affordability	8	32%
First-mover advantage	5	20%
Branding and marketing	4	16%
Product innovation	8	32%
Collaborations	0	0%

Scaling[3]

The start-ups were found to be seeking to scale through, among other things, enlarging their product ranges (e.g., by developing and commercialising new products), opening more outlets, entering new markets, and increasing their number of employees. For example, respondent 23's start-up at first offered its services for free, and later began charging a subscription fee. The start-up now launches new products for sale to its subscribers in order to increase the capacity of the company to scale.

3 For an in-depth treatment of approaches to innovation-scaling by start-ups and other knowledge-based enterprises in African settings, see Open AIR (2020), *Scaling Innovation: How Open Collaborative Models Help Scale African Knowledge-Based Enterprises*.

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Respondent 22's start-up found collaboration to be of great value in the pursuit of scaling, as it creates new revenue streams and product lines. And, as we saw above in section 6 on "external collaboration", respondent 13's start-up is seeking to scale "across the African continent" through external partnerships.

Respondent 9's start-up has changed its collaboration structure in order to pursue scaling. Initially the team at the start-up worked jointly and collaboratively on a single project. In order to scale, the team split into four teams of two each, to head four different projects simultaneously—including projects outside Nairobi, e.g., in the town of Eldoret, in western Kenya, where the start-up has established a second office.

Some start-ups have changed their business models in order to scale. At respondent 25's start-up, the first business model, based on the start-up's development of a retail discount card platform, consisted of partnering with service providers to increase the service providers' sales. The next business model involved a shift to a mobile point-of-sale solution for the same service providers, which, according to respondent 25, is more amenable to scaling. In the words of respondent 25, "[…] we decided to pivot into a mobile point-of-sale [product], in the form of a mobile app that enables businesses to capture sales and purchases, record their expenses, and manage their stock".

5. Conclusions

The findings and analysis provided above suggest a number of cross-cutting drivers of the start-ups' collaborative innovation practices. Three key drivers are:

- openness;
- networking; and
- informality.

Openness is at the heart of Nairobi's mobile tech ecosystem, as exemplified by the start-ups' organisational set-ups, physical spaces, processes for developing business ideas, and modes of human capital development. Also, many of the approaches to knowledge governance adopted by the start-ups are grounded in an ethos of interaction and open collaboration, both internally and with external partners. We also consider the culture of openness by the start-ups as integral to their approaches to the scaling of their enterprises, as it allows them to optimise their business models while not losing sight of their specific product and service offerings. Further, openness facilitates networking and funding opportunities for the start-ups and enables additional skills development for team members. It is important to state that in respect to knowledge governance, some of the start-ups combine elements of both openness and protection, i.e., they consider certain aspects of their business knowledge to be open to all others, while other aspects are either kept confidential or closely guarded (with, in some cases, IP protections in place or being sought).

The role of *networking* in the practices of start-ups is another prominent feature in the findings. Tech hubs are primary sources of networks for most of the start-ups, with the hubs connecting the start-ups with each other, with investors, and with other strategic partners. Collaborative external partnerships, forged through networking, are key drivers of the start-ups' innovation and enterprise development practices.

In respect of the third cross-cutting factor, *informality*, the mobile technology space in Kenya has, since the advent of M-PESA, witnessed an upsurge in mobile tech innovations driven largely by self-employed or freelance or part-time developers engaged in start-ups located within or around tech hubs. At the same time, it must be noted that some of these developers have engaged in the limited formalisation of certain aspects of their enterprises, e.g., through company registration, full-time employment for team members, written contracts with clients and consultants, NDAs for third parties, and use of the IP system. Thus, there is evidence of the start-ups bridging between, and harnessing, both informal and formal modalities within a general pursuit of open, networked collaboration. This bridging of informal and informal elements is also present in the start-ups' human capital development modalities, with almost all the start-ups in the study emphasising the need to supplement formal education for their team members with practical, and largely informal, on-the-job skills training.

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Appendix: Questionnaire

1. Name of start-up?
2. Name of interviewee? Position at start-up?
3. Date of establishment of the start-up?
4. How long has your start-up been in operation?
5. Location of the start-up and why?
6. Has your start-up had offices in another location/other locations? If so, what were the reasons behind your start-up having offices at these other locations and what was the reason for your re-location to your current offices/office space?
7. How is your office space organised for teams at work?

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8. Type of registration of the start-up? (business, company, LLP etc.)
9. Details of founders of the start-up? (e.g., name, designation, level of education, expertise, age, gender)
10. Has the structure of your start-up changed since the company was founded? (e.g., change in management, have some of the founders left the company? etc.)
11. Total number of staff at the start-up?
12. What problem(s) does your "mobile tech" start-up aim to solve and how?
13. What is your start-up's leading product/service?
14. Do you consider yourself to be in the mobile tech space and why?
15. Has your start-up had any interaction/involvement with any tech hub(s), e.g., incubator, accelerator, co-working space? Why?
16. How has any interaction/involvement with any tech hub(s), e.g., incubator, accelerator, co-working space, affected your start-up? Why?
17. Typically, how are business ideas developed and tested at your start-up?
18. Typically, how are intangible business assets (know-how, ideas, and processes) protected at your start-up?
19. Typically, how is business knowledge shared at your start-up among the core staff members and other staff members/consultants that work in conjunction with your start-up?
20. Typically, how is customer business knowledge shared at your start-up?
21. Does your start-up have any contracts in place with its core team and other staff, etc.?
22. Does your start-up have any contracts in place with customers?
23. Does your start-up have any contracts in place with business partners?
24. How do you collaborate with other companies or external individuals in your operations?
25. Does your start-up have competitors? If so, how does it maintain a competitive edge?
26. Does your start-up have copycats? If so, explain with examples of how you deal with copycats.
27. How does your start-up generate revenue?
28. How does your start-up plan to scale up its business?
29. How does your start-up plan to make its business sustainable?
30. What types of funding has your start-up received? If so, what percentage of total expenditure is accounted for by external funding?
31. What means do you use to protect your innovation(s)?
32. Do you employ any intellectual property protection in your start-up? Why? Why not? Which types? How?
33. What is your perception of the value of intellectual property protection to your business?
34. Do you utilise third party software in your operations? If yes, which software and why?
35. What contribution, if any, does mobile tech innovation have to the society in Kenya?
36. What is missing/lacking in the mobile tech space to ensure growth?

Innovation Entanglement at Three South African Tech Hubs

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Abstract
This study explores innovation modalities at three South African tech hubs: Bandwidth Barn Khayelitsha and Workshop 17 in Cape Town, and the Tshimologong Digital Innovation Precinct in Johannesburg. The study finds that tech start-ups' ability to scale is generally enhanced by their participation in the hubs. Furthermore, it is found that scaling by start-ups, and by the tech hubs hosting them, is enhanced when they actively drive the terms of their "entanglement" with exogenous and endogenous factors and external entities—a conceptual framework first developed in an earlier study of university research linkages (Abrahams, 2016). This present study finds that innovation entanglement by the hubs and their start-ups allows them to work through the adversity and states of complexity prevalent in their innovation ecosystems.

Keywords
tech hubs, digital innovation, tech enablement, collaboration, knowledge creation, knowledge governance, complexity, innovation entanglement, South Africa

Acknowledgements
The research for this article was carried out as part of the Wits LINK Centre's participation in the Open African Innovation Research (Open AIR) network, in partnership with the University of Cape Town, the University of Johannesburg, Strathmore University in Nairobi, the Nigerian Institute of Advanced Legal Studies, and The American University in Cairo. The author acknowledges the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, the International Development Research Centre (IDRC), and the UK Department for International Development (DFID). The views expressed in this work are those of the author and do not necessarily represent those of the research funders. The author also extends thanks for the contributions of all the research respondents, and for the contribution made by Wits LINK Centre Master's student Yolisa Kedama, who compiled information on all South African tech hubs in operation at the time of the research. The LINK Centre is amongst the founding institutions at one of the three hubs studied, the Tshimologong Digital Innovation Precinct.

DOI: https://doi.org/10.23962/10539/30358

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Recommended citation
Abrahams, L. (2020). Innovation entanglement at three South African tech hubs. *The African Journal of Information and Communication (AJIC), 26*, 1-29.
https://doi.org/10.23962/10539/30358



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1. Introduction: The need to explore "entanglement" in tech hub innovation ecosystems

Tech hubs can be seen as interacting ecosystems—or communities of researchers, software developers, digital makers, tech start-ups, small and micro enterprises (SMEs), and corporate clients and investors in innovation—brought together "to create the best conditions for long-term business success for all involved" (Zwegers & Sassen, 2015). Tech hubs generally include learning, incubator, and accelerator facilities. They focus on a wide range of industries and sectors moving into digitalisation, hosting young entrepreneurs designing digital applications and content for agriculture (a local South African example is pest management in macadamia nut orchards), education (a local example is online learning for applications in dynamic software for secondary school mathematics teachers), energy, fashion, health, retail, and other sectors. Tech hubs are an interesting phenomenon on the African continent, particularly in Kenya, Nigeria, and South Africa which have many, as the hubs operate with limited resources and stand in stark contrast to the large global platform firms and content providers (e.g., Amazon, Facebook, Netflix) (Van der Aalst et al., 2019) and to the global-scale cloud service providers and systems integrators and aggregators (e.g., Microsoft Azure, Google, Oracle Cloud) (Holst, 2020).

The common feature across tech hubs is that they are collaborative working spaces and competence building-centres, using digital technology to incubate tech and business start-ups and/or to accelerate existing businesses. While broadband internet penetration is still relatively low on the African continent, the rapid growth in Wi-Fi hotspots, smart phones, and laptop devices has advanced internet penetration and access, creating demand for digital applications (apps), software platforms, 3D-printing, data analytics, and digital solutions, ranging from digital health to smart homes and smart city solutions. Tech hubs have become spaces where young aspiring tech start-ups can access fast Wi-Fi, office space, and meeting space; receive training, coaching, and mentorship; engage in networking and building partnerships; and get assistance with start-up funding, venture capital funding, and other inputs. Most tech hubs in South Africa, as on the African continent in general, provide arenas for learning and practising software development and related skills, as well as the

business and management skills required for tech start-ups to participate in the digital innovation ecosystem, and to advance their capacities, their creativity and their income. These tech start-ups are learning and actively producing in response to a demand for niche solutions and/or platform-based solutions.

Research problem statement

Extensive digitisation in the context of creating inclusive future cities (Banai, 2020), convergence innovation beyond digital automation (Lee & Trimi, forthcoming 2021), and the COVID-19 digital surge illustrating socio-economic benefit and cyber-risk (De et al., 2020) should all focus our attention on tech hubs as particular institutional spaces for digital innovation. These developments indicate that it is relevant, in the pandemic period and beyond, to consider the evolutionary nature of tech hubs, as this could be a period of heightened integration with clients, cities, and communities to meet increasing demand, or a period of high risk of economic marginalisation. With respect to the complexity of addressing either of these challenges (meeting demand or potential marginalisation), tech hubs will need greater capacities and influencing factors than just their innovative or entrepreneurial capabilities. Clustering is one of the ways in which high-tech start-ups gain ground: Adler et al. (2019) analyse the macro-geographic spread of high-tech clusters across city-regions, as well as the micro-geographic organisation and the spatial division of labour at a neighbourhood level. Other important mechanisms include business model evolution and contextual ambidexterity (Balboni et al., 2019). However, there are yet other means that tech hubs use to evolve, where the key actors and institutions slowly succeed, despite the challenges of limited resources.

This study's research problem, investigated in the context of South Africa, engages with elements of "entanglement" by *actors* (tech start-ups created by innovator-entrepreneurs) and *institutions* (tech hubs that host start-ups) with influencing factors (*resources, values* and *value*) and entities in an innovation ecosystem. In South African innovation ecosystems characterised by limited resources and emerging values systems, entanglement can serve as a means to enhance the actors' and institutions' strategic positioning and hence their value-creation capability, both of which are necessary for progressing to scale. This study's exploration of innovation entanglement builds on previous research (Abrahams, 2016) that focused on research-oriented entanglement by South African universities.

In order to advance the strategic positioning and resilience of tech hubs in Africa, it is necessary to understand the approaches to scaling that are present in the strategies and activities of these tech hubs. This research problem was chosen because of its relevance to the frequent focus on scaling in existing tech innovation literature (Atiase et al., 2020; ElHoussamy et al., 2020; Kelly & Firestone, 2016; Littlewood & Kiyumbu, 2018; Nzomo et al., 2020; Open AIR, 2020), its relevance to the sustainability of tech hub communities and the start-up enterprises that make up these

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communities, and its relevance to the integration of tech hubs into broader digital innovation ecosystems. Three South African tech hubs, along with their resident start-ups, were selected for study.

2. Context: Tech hubs operating under adverse conditions

Tech hubs in Africa

Critical reviews of digital tech hubs in Africa (see Comins & Kraemer-Mbula, 2016; De Beer et al., 2017; Desta, 2018; ElHoussamy et al., 2020; Friederici, 2019; Jiménez & Zheng, 2017) are essential to promoting sustainability and long-term success, as they promote deep insight into real-world institutions and innovation challenges. In 2019, the GSMA Ecosystem Accelerator programme reported that there were 618 tech hubs active in Africa, a 40% increase since 2018 (Giuliani & Ajadi, 2019). Unlike that report's definition of tech hubs as including those that "only offer co-working facilities instead of specifically tech-focused support programmes or funding", this study considers tech hubs to include those that actively engage in the creation of digital applications and services, or actively engage in any form of additive manufacturing, or use digital tools and infrastructures for digitally supported entrepreneurship. The application and use of digital technologies in each of these forms can support small business start-ups, and cater for demand from medium to large businesses, public sector clients, and non-governmental clients.

The four African countries found by GSMA Ecosystem Accelerator to have the most hubs were Nigeria (85 hubs), South Africa (80), Egypt (56), and Kenya (48) (Giuliani & Ajadi, 2019). For the purposes of this study, it is argued that tech hubs in Africa generally operate under adverse conditions, as their innovator-entrepreneur and start-up communities compete with large national and global firms for innovation resources (both financial and non-financial), operating in small corners of the markets for digital applications and services. This presents a major barrier to scaling up, as relevant to the tech start-ups, the tech-enabled businesses, and the tech hub itself.

South African tech hubs

The scope for this study of South African tech hubs was limited, selecting from among the hubs, incubators, and co-working spaces where digital innovation is the focus, or where digital technologies are used as an enabler of productive activity. At the time of the research, roughly 50 entities across four of South Africa's nine provinces met these criteria, the provinces being Gauteng, the Western Cape, KwaZulu-Natal and the Eastern Cape. An AfriLabs and Briter Bridges 2019 report documents 78 active tech hubs in South Africa (Giuliani et al., 2019, p. 6), with that report's definition of tech hubs including co-working spaces, incubators, accelerators, and hybrid innovation hubs.

Both our data collection and the Giuliani et al. (2019) data confirm that the two largest concentrations of tech hubs in South Africa are in the Western Cape and Gauteng, which are home, respectively, to South Africa's second-largest and largest cities, Cape Town and Johannesburg. Accordingly, the three hubs identified for study (see "Constructivist research design" section below) were two hubs in greater Cape Town and one in Johannesburg.

The concept of entanglement

Briefly expressed, the initial concept of research entanglement refers to the positionings that *actors* and *institutions* adopt, within university research sub-systems characterised by adversity and increased complexity, in relation to ecosystem factors (*resources*, *values*, and *value*) and external entities within the same ecosystem. The actors and institutions tend to position themselves in a heightened state of interaction with the often-competing ecosystem factors (grounded in resources, values, and value) and with external entities, in order to gain advantage and overcome adversity within that ecosystem (Abrahams, 2016). The competing factors and external entities can either shape the evolution and hardiness of the actors and institutions, or see them fade from existence (Abrahams, 2016). In the present study, the innovation entanglement with competing ecosystem factors and with external entities was explored in respect of the positionings of tech start-ups (the *actors*) and the tech hubs (the *institution*s) hosting the start-ups.

3. Constructivist research design

This study used a constructivist research methodology, so as to allow for exploration of the application of the entanglement conceptual framework established via the grounded theory methodology in the earlier study (Abrahams, 2016). This study sought to obtain insights into entanglement modalities present in South African tech hub innovation ecosystems.

Data collection

Data collection was conducted at three tech hubs, selected due to the apparent differences in their features, in their locations within their cities, and in their phases of evolution: Bandwidth Barn Khayelitsha (Cape Town), Workshop 17 (Cape Town), and Tshimologong Digital Innovation Precinct (Johannesburg). The data collection process comprised: observation of business overview presentations from innovator-entrepreneurs at each of the hubs and meetings with hub community management, in order to inform the design of the interview protocol; desktop review of background data on tech hubs in South Africa; semi-structured interviews with 17 respondents at the three hubs; and a focus group at Bandwidth Barn Khayelitsha. The interview respondents—seven at Bandwidth Barn Khayelitsha, five at Workshop 17, and five at the Tshimologong Digital Innovation Precinct—were a mix of (1) hub community

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managers and (2) key informants resident in the hubs as innovator-entrepreneurs, establishing tech start-ups engaged in incubating or accelerating start-ups. The focus group at Bandwidth Barn Khayelitsha comprised six women engaged in micro-businesses. Ethical clearance for the research was obtained from the Human Research Ethics Committee Non-medical, University of the Witwatersrand, with Protocol Number H16/11/01.

Data analysis

The data analysis was qualitative, consisting of identifying the core recurrent themes in the transcripts of the 17 interviews and of the focus group discussion. In this article's reporting of the findings from the data, the respondent codes used are as follows:

- respondents BBK1 to BBK7 = the seven Bandwidth Barn Khayelitsha respondents;
- respondents W17.1 to W17.5 = the five Workshop 17 respondents;
- respondents T1 to T5 = the five Tshimologong Digital Innovation Precinct respondents; and
- BFG respondents = the Bandwidth Barn Khayelitsha focus group respondents.

The three hubs studied

As stated above, the three hubs selected for study—Bandwidth Barn Khayelitsha and Workshop 17 in Cape Town, and the Wits Tshimologong Digital Innovation Precinct in Johannesburg—were selected because of their apparent differences in terms of features, locations, and stages of evolution. At the same time, however, the hubs do have several commonalities. All three have attractive, high-ceilinged, multi-use, flexible-use spaces for co-working and events, including shared tables, discussion nooks, working areas with couches and tables, whiteboards, and cubby holes for storage; a staffed front desk; a coffee shop; a strong youth focus; and, very importantly, high speed Wi-Fi. All three cater, to varying degrees, for activities related to pre-incubation, to start-up incubation, and to business acceleration. For all three, these types of activities include regular events to engage the resident tech community in specially designed innovation learning, in broader digital knowledge content, and in engagements with potential business clients and small-scale investors.

Bandwidth Barn Khayelitsha

Bandwidth Barn Khayelitsha is a tech hub for entrepreneurs in all fields. It is located at Lookout Hill, a tourism centre overlooking Khayelitsha, with a view of the mountains and the sea, in a community with formal residential areas but with a preponderance of informal settlements. Khayelitsha, though part of greater Cape Town, is located far from the city's main productive and services sectors. The community experiences high levels of unemployment, food insecurity, infrastructure shortcomings, and extreme poverty. In this socio-economic context (Beyond our Borders, 2017), the Bandwidth Barn caters mainly for tech-enabled businesses and also for some tech

start-ups. This tech hub was, at the time of the research, offering free space to its resident businesses and start-ups, and it planned to later move to a rental model. All the businesses and non-profit organisations (NPOs) operating from the tech hub at that time were incorporating tech usage in their operations, e.g., for registration of a company when it reaches the appropriate stage of business development, for digital marketing, and for doing background research for a business (respondent BBK7; BFG respondent). The Bandwidth Barn is open from 09h00 to 17h00 on weekdays, with ad hoc events taking place outside of those hours as arranged, including some at weekends.

Workshop 17

Workshop 17 is specifically designed as an innovation space, with tech serving as an enabler of innovation and often also as a key feature of innovation. It is located in central Cape Town's Waterfront district, the city's top destination for local and international tourism, which has had more than 24 million visitors and has generated ZAR335billion (approx. USD20.6 billion[1]) in revenue since 1990 (V&A Waterfront, 2020). Workshop 17's main hours of operation are 07h00 to 19h00 on weekdays, with community members able to use the venue after hours and with many events and tech talks taking place over weekends. Firms located at Workshop 17 at the time of the research were engaged in, inter alia, conceptual marketing, crowd-sourcing of data for clients, building data models, building financial technologies (fintech), managing events and event security, coding, creative design for digital branding and marketing for small businesses, apps design, platform design, and 3D-printing. Workshop 17 now has five locations in South Africa, but had only one at the time of data collection.

Tshimologong Digital Innovation Precinct

The Tshimologong Digital Innovation Precinct is, formally, an entity of the University of the Witwatersrand located in the Johannesburg inner city area of Braamfontein. The Precinct's environment is characterised by inner city businesses, historical buildings and railway yards, cultural precincts, proximity to two universities (Wits University and the University of Johannesburg), and a view of the Witwatersrand gold mine dumps (Trangoš, 2015). Braamfontein has a resident tertiary student population of around 6,700 (Gregory & Rogerson, 2019), including students registered at Wits, the University of Johannesburg, and several technical and vocational training colleges located in and around Braamfontein. The tech hub operates within its own framework, but under the rules and procedures of the university. Tshimologong's operating hours are 07h00 to 22h00 weekdays, with ad hoc events and hackathons taking place after hours as arranged (including on weekends), including the Wits Fak'ugesi African digital creativity festival, which usually runs in September each year but went virtual during October to November 2020, as a result of the COVID-19 pandemic (Fak'ugesi, n.d.).

1 Calculated based on the ZAR: USD exchange rate on 25 October 2020.

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4. Findings on hubs' and start-ups' innovation modalities

The findings are presented here in the thematic categories that emerged most strongly from the interview and focus group data, as follows:

- hub provision of infrastructure and services;
- hub provision of networking opportunities;
- hub provision of opportunities for collaboration;
- hub and start-up approaches to knowledge governance; and
- hub and start-up approaches to local appropriateness.

Hub provision of infrastructure and services

One of the core themes present in the data is *hub provision of infrastructure and services*, i.e., provision of Wi-Fi service, office space, meeting rooms, events spaces, pre-incubation support, incubation support, and in-hub acceleration support. The tech hubs provide access to an extensive range of tangible and intangible *resources* not otherwise available to young digital entrepreneurs or to tech and business start-ups.

Respondent W17.4 at Workshop 17 proposed several core requirements essential to hub success, including: location (e.g., proximity to transport nodes, availability of parking, being in a district that is neither plateauing nor declining in economic attractiveness); the physical space (e.g., heating, ventilation, air-conditioning, lighting, high ceilings, outside spaces); and human elements (well-trained, highly educated employees passionate about creating tech hub success). Respondent BBK7 at Bandwidth Barn Khayelitsha said the four key elements needed by a tech hub are: (1) ensuring a flow of skills into and among the tech start-ups; (2) providing an incubator service; (3) connecting start-ups to industry partners and to enterprise development opportunities; and (4) having some industry partners operating from the hub. According to Tshimologong respondents T4 and T5, a successful tech hub requires a specific resource environment, including the availability of: software systems, engineering resources, facilities for hosting the app or the platform, testing and stress-testing facilities, and funding to hire developers. At Tshimologong, some of these resources are brought and provided by the community members themselves (respondents T4, T5).

Respondent BBK2 spoke of being "here for the space", due to a lack of privacy at home and the need for a suitable environment to meet with clients. Respondent BBK3, whose business is focused on financial literacy training through online video tutorials in multiple local languages, said: "I really need access to internet because I always have to be online, [and it must be] fast enough."

Another necessary element commented on by respondents is flexibility of pricing. Tech hubs generally charge membership fees on a tiered basis, with the fee dependent on the space resources and the services they need to use. Respondent W17.1 favoured per-use pricing, e.g., a charge per hot desk, per-use, on the grounds that

such pay-as-you-go models allow members to "spend less or spend more; that's what these environments give us […]. Add on what you need as opposed to [a] pay-per-resource-bundle."

Although both Tshimologong and Workshop 17 offer access to their shared workspaces and services at prices substantially lower than prices in the commercial market, some respondents at these hubs voiced concern that the prices are still unaffordable for many individuals and enterprises that come from low-income communities. By way of demonstration, the current tiered scheme for Tshimologong has five price levels, ranging from ZAR1,500 [USD92,70] per month for full access, including mentorship and tech and business development Master classes; ZAR800 [USD49,42] per month for light access, excluding mentorship; ZAR120 [USD7,41] per day for "no frills" drop-in users; R300 [USD18,53] per month for student users; and ZAR150 [USD9,26] per month for virtual users (Tshimologong, 2020). Workshop 17 membership fees range between the On the Road membership, starting at ZAR1,100 [USD67,96] per month (60 hours per month, with additional costs for add-ons), and the Rooted membership, starting at ZAR3,318 [USD204,99] per month (access to all five locations plus add-ons), with all memberships including private access to the Workshop 17 community and events (Workshop 17, 2020).

According to respondents, tech hubs need to offer both low overheads and attractive social environments, with the key words used being "young", "creative", "hip", and "non-traditional". Respondents from enterprises making use of Bandwidth Barn Khayelitsha and Workshop 17 spoke of the attractiveness of being able to host their clients in a "trusted" hub environment. A Bandwidth Barn focus group respondent praised the hub as "a professional-looking space to take clients", and in the words of one respondent (BBK1, 2017):

> […] people trust me more, because they believe I will give them a good service. They will say, "I can't give this guy business, because he doesn't have [an] office, he doesn't have a desk". [And] three years, five years from now, I would like to have a private room, not an open space.

One area where respondents pointed to a need for some improvement was in mentoring. Respondent T5 said there is a "lack of [the] right type of tech mentors that realise the difference between good tech and smoke and mirrors." According to one of the Bandwidth Barn Khayelitsha focus group respondents, it "would be more helpful if a mentor was appointed to do follow-up after training. Most times it's like you [are] on your own, you just swim on your own." There was a general view among users of the three hubs that, in addition to more regular mentoring, there is a need for more workshops on growing a business—and "not just the basic stuff", as one respondent put it, while acknowledging that this would have resource and cost implications.

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There was criticism, among respondents, of government support programmes being delivered through hubs. Respondent W17.2 argued that governmental enterprise development programmes tended to be poorly designed and bureaucratic, while another respondent argued that government support measures were unreliable. In the words of one of the Bandwidth Barn Khayelitsha focus group respondents:

> As start-ups in our townships, we are struggling to access funding, more especially from [the] government side. When they [government representatives] present at *imbizo*s [meetings], you feel you qualify, but when you get there, there are many [types of] red tape, and, by the time you comply, they tell you the budget is finished. Age is also counting. We can't get funding, because we are over the age. But also the youth can't get funding. [There are] lots of boundaries that you can't cross.

The tech hub management respondents spoke of a key dimension of their hubs being the fostering of synergies with potential future business partners. Hub manager respondents also reflected on the significant challenges associated with providing the necessary support to individuals and start-ups using the hub premises and services. In the words of respondent W17.4, knowledge creation for high-impact end-results requires a "high touch" approach to member engagement, i.e., "regular coffees and updates to know the customer" (respondent W17.4). According to one tech hub manager respondent, a hub is ideally able to apply the principle of "one size doesn't fit all", spending time with each start-up in order to understand the start-up's business, to offer advice, and to mentor. But the start-ups tend to need many hours of advice, particularly those coming from challenging socio-economic settings. Intensive individualised support for each start-up is typically not sustainable for a hub, given that a mentor resource may cost ZAR500 [USD30.89] per hour, or ZAR5,000 [USD308.91] per month—a cost higher than the hub's monthly membership fee.

According to a Tshimologong hub management respondent, many tech start-ups do not have the foundational knowledge or technical ability to use the full range of digital innovation tools (e.g., IoT tools, block chain tools) to create novel solutions, and they tend to get stuck at the ideas stage of knowledge creation (respondent T2). According to this respondent, while it may be tempting for hub management to seek to solve all problems, it is more realistic to strike a balance between, on the one hand, the hub providing support and solutions, and, on the other hand, the hub requiring tech start-ups to go out externally to find external avenues for support and solutions. But realism can be fraught: it tends to be very challenging for tech start-ups, on their own, to find external learning resources, generate the necessary contacts, and navigate the complex worlds of business and government. These challenges can easily lead to a mismatch of expectations between tech start-ups and hub management.

Respondent T1 said that at Tshimologong, process matters are continually being reviewed, reset, and advanced, based on evolving insights gained by hub management and by its start-ups. At the time of the research, Tshimologong's emerging process (stated in broad terms) was to review the business concept proposed by each tech start-up, consider the technical viability of the idea, assess whether the tech start-up's team had the capacity to deliver, and understand the potential speed to get to market. Parameters and criteria for assessment in the pre-incubation stage included the tech start-up being required to: (1) create a business model identifying the target audience, stakeholders and resource requirements; (2) conduct some level of product-oriented research; (3) make a pitch; and (4) demonstrate progress. The hub had found that following these steps allowed incubatees to optimally unlock the opportunities provided by working with the broader community management team, which was able to focus on supporting the logistical aspects of getting the product to market (respondent T1).

One specific programme being delivered by Tshimologong at the time of the research was a cohort programme, with 20 start-ups per cohort, in which the cohorts worked through a 13-week programme that included orientation elements such as creating a business model canvas (a popular approach in the incubator world). Not all participants in the cohort moved at the same pace, meaning that, in the words of respondent T2, the approach was "great for management, but not for participants". After completion of the 13 intensive weeks, limited mentoring continued on a once-weekly basis for a maximum period of one more year. According to respondent T5, the challenge for start-ups in the cohorts was "coming with a question and leaving with an actual development".

Tshimologong also had, at the time of the research, a dedicated acceleration programme, for those who already had a business that was earning revenue and needed tailored support measures, such as a consultant support on intellectual property (IP) management or on tax matters. According to respondent T3, a participant in the programme:

> The accelerator programme […] was presented to us [as], if we put in the work and we meet our milestones, then we get access to investors. So it's an incentive for me to do my best work. Hence we decided to […] concentrate on creating a product that people will be crazy about when we release it […]. Here the thoughts are correct, the moulding of businesses [is] done the right way.

At time of the research, additional parameters were being put in place at Tshimologong for the accelerator stage. Explicit, written guidelines for expectations at each level of development were being designed by the business unit responsible for monitoring and evaluating the progress of community members (respondent T1). The

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goal was for the Tshimologong enterprises who were receiving acceleration support to have their activities and progress measured in terms of formal guidelines and criteria, while at the same time still allowing them the flexibility required to engage in innovation.

Hub provision of networking opportunities

Another core theme in the data is that of *hub provision of networking opportunities*, with the networks in question being both within the hubs and beyond in the hubs' greater ecosystems, and with the networks being grounded in the sharing of knowledge, of innovation, and of business opportunities. External networking opportunities are all specifically relevant to the start-up acceleration phase. This points to the specific importance of intangible knowledge *resources* as a key component of a desirable tech hub ecosystem.

Respondents spoke of the benefits of interaction and mutual support among individuals and entities within the tech hub, i.e., among developers, entrepreneurs, start-ups, and small enterprises. According to respondent W17.3, the conversations made possible by the tech hub are not about the passive intake of information, but rather they are seeds for practical approaches to creativity and production: "It's not merely theory." Respondent T5 from one of the Tshimologong start-ups said that their start-up is completely self-sufficient, and thus their key interest in being part of the hub is networking within a sharing community:

> […] the people and the networks you make with other people like yourself […] [It] generates interest, gets like-minded people together. That's where real progress starts happening. By us being in close proximity, we can help each other out, due to our different expertise.

Respondent W17.1 spoke of the importance of hub provision of high-quality access to business and knowledge networks. Other respondents spoke of: the benefits experienced through business introductions enabled by the "high traffic" at the hub, the heightened opportunity for networking due to the presence of many diverse community members, and the hub providing a "centre of support in a faulty ecosystem" and "aggregation in the ecosystem" (BBK and W17 respondents). At the Tshimologong hub, key networking events are its hackathons, workshops, pitch sessions, and the annual Wits Fak'ugesi African digital creativity festival. In the words of Bandwidth Barn Khayelitsha respondent BBK5, who has attended the Wits Fak'ugesi festival at Tshimologong:

> Last year September I attended the Fak'ugesi Festival, Jo'burg for the first time […] the vibe, the culture, the activity […] we were playing games, people were sharing their stories, how they are creating their apps. I made friends. I met a lady doing an Instagram exhibition. We were building

> games, we were coding and I showed my own creative skills. I was with the Amaze team, programming. That's when I started to realise that I could create apps and websites, so such organisations are really helpful.

However, respondent T5 at Tshimologong said the hub needs to be do a better job of linking its hosted enterprises with outside stakeholders. The respondent gave the example of an event at the hub, to which external stakeholders were invited, which "did not feature any of the local people, or use any of the local people. […] 50 people in the precinct and not one of them is showcased."

At Workshop 17, knowledge generation and networking are driven to a great extent by its events calendar. The calendar includes networking events to enable start-ups to engage with each other, and events at which industry leaders, academia, corporates, and enterprises showcase their knowledge and seek to build understanding. Workshop 17 is also active in facilitating introductions for funding, and it keeps a funding register (respondent W17.2). According to respondent W17.3, networking, both formal and informal, is regarded by Workshop 17 participants as a mode of creation, and a necessity for creation—and, accordingly, hub community members invest time and energy in going to the hub's events, thus helping feed the community's networking, meet-up, and developer ethos.

According to respondent BBK2 at Bandwidth Barn Khayelitsha: "This space plays a role through events and providing the networking. Most […] young people are starting businesses and they fail. So this space is important to the long-term success of small business in Khayelitsha." Key to the Bandwidth Barn's provision of networking are its relationships with local partners. Its partners include local tour guides offering "the Khayelitsha experience", corporate partners Airbnb and Telkom, and government partner the Western Cape Department of Economic Development and Tourism.

Hub provision of opportunities for collaboration

A third core theme in the data is *hub provision of opportunities for collaboration*, with the collaboration being grounded in sharing (of information, knowledge, and experience), and in peer-to-peer learning and skills development modalities. At Bandwidth Barn Khayelitsha, the hosted start-ups, both non-profit and for-profit, "circulate business among ourselves" (BFG respondent), with some of the hub's enterprises providing, for example, advertising and facilitation services to other enterprises at the hub. This data points to the emergence and presence of the *values* of collaborative learning and knowledge sharing in pursuit of innovation outputs.

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According to respondent BBK2:

> You learn some other ideas from the other people, not your own way of doing things […] sometimes you meet other business owners here who do auditing and other guys are doing tax returns so they help you, they do the online tax filing […] [and learning] how to use your cellphone for your business, some things I didn't even know, [like how to] speak to a person via Skype.
>
> Success is very much linked to knowledge-sharing […] I can do more, I am getting more business than before […] more clients, more income, more networks. Online includes email, internet payments for staff, internet banking, phone people using Skype. Most young people use technology using their phones. We have pamphlets and posters at the malls and they call and email back, [and we conduct] online interviews using Skype. People email their CVs straight to you, people email requesting interviews […] Easy when you work with the bank. Today I was busy investing money with the bank online.

Another Bandwidth Barn respondent (BBK5) spoke of the values associated with enterprises "trading" design skills for income, in order to generate mutual benefit:

> I'm a painter and a designer. […] I wanted to trade the skills to make other businesses successful […] because I saw a gap where small businesses are existing in the market without an image and a corporate identity. In a digital world, every business is online but [some businesses] are not in that world, so I wanted to create digital marketing and branding for small businesses in Khayelitsha and in South Africa, from start-up business to existing businesses, and make that service available online through direct marketing and driving traffic to my website.
>
> This creative design and digital marketing, this is innovation. […] I want to teach people how to do creative design and teach entrepreneurs the importance of design for their business, for businesses who do not have a great awareness [of] tech-enabled branding, mainly start-ups, especially the design using digital software and interacting through digital spaces.

Tshimologong respondent T3 spoke of the importance of peer-to-peer knowledge creation:

> Knowledge creation amongst our peers is predominantly through observation and engaging the market, testing your assumptions. Ninety per cent of the time your assumptions are incorrect and that's at the heart of knowledge creation in the start-up context […] can't be too theoretical […] have to put it into practice […].

At Workshop 17, respondent W17.1 highlighted the power of everyday conversation, and told the story of

> […] two start-ups talking about different technologies and challenges in collaboration […] [saying things like] "Sounds like this is your challenge […] I've used this alternative tech […] would it be useful to you?" Six months later this tech was core in their delivery, so a casual conversation led to formalisation in their operation.

Another anecdote told was one in which hearing about a failure from peers at the hub led developers along a different route, saving them significant time and money. This respondent spoke of the ideal where the developers and entrepreneurs at the hub are all mentors to each other. Respondent W17.4 spoke of the importance of a collaborative environment in building the resilience that start-ups need in order "to work through the hard times":

> [There is] greater resilience in a tech hub than outside a tech hub, because the success of those around you drives you to be successful […]. Being resilient is often not [about] being by yourself and pushing by yourself […]. [You] can be cornered in your own organisation. But when you're surrounded by 93 companies and sharing success and failure, [this] aids resilience. Fail, share, have a coffee, get some perspective. [That] creates resilience.

It was also felt that collaboration was an important contributor to building relationships—relationships, between enterprises, that are built around trust, *value* creation, and mutual benefit through reaching a given outcome, or through building a particular product, "and sometimes [building] sales opportunities" (respondent W17.5). It was said that relationships built up over time create credibility in terms of ability to deliver and ability to perform. For start-ups, such relationships are not only important with their peers but also with hub community leaders and, often more importantly, hub middle management, with whom the start-ups interact frequently.

However, at the same time, respondents identified elements needing improvement in hubs' delivery of opportunities for collaboration. Respondents at both Bandwidth Barn Khayelitsha and Workshop 17 spoke of the need for their respective hubs to be based to a greater extent on creating opportunity to experiment, on being places where "things [are] happening on the floor"—with greater peer-to-peer exchange, greater levels of advising and understanding among start-ups, more collaborating through business referrals, and more pulling of other tenants into each other's teams (respondent BBK6; multiple W17 respondents). Respondent T5 at Tshimologong was concerned that there is "not sufficient acknowledgement" of the people and

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projects that are "instrumental in the production" that occurs at the hub: "The precinct talks about the community, but gives themselves kudos, [and] not the businesses concerned."

Addressing the dynamics of relations between hub users, respondent T3 stated that "a lot of the attempts to collaborate and create value [i.e., benefits or advantages] for our peers left many people feeling that they got the short end of the stick." Respondent T3 spoke of the importance of

> […] building the culture of creating things together and, if things didn't go well, building the culture of reconciling ourselves to that. [This is] the value of failing forward. But honesty is in short supply. On integrity, we fall short. At this stage of the evolution of the ecosystem, which is still in its infancy, [integrity] needs to be curated into the DNA of the ecosystem [so as to create] a more inclusive innovation space. […] Here it's about us, us, us – the value [i.e., benefit or advantage] of the community not the individual. […] For Africa, the community is more important than the individual. Yes, there will be things that go seriously wrong, so how do you come out of that and still collaborate rather than walk away?

Respondent T3 stated that collaboration can be undermined when enterprises perceive one another as competitors:

> […] developers working in Java and PHP should be collaborating, but don't, because they think they're going after the same client – but they're not. They could be creating an integrated or collaborative offering […] [saying to each other] "I can't do it alone, let's go and present together".

Hub and start-up approaches to knowledge governance

A fourth core theme found to be present in the data is *approaches to knowledge governance* by hubs and by their hosted enterprises. The concept of knowledge governance refers, in this context, to approaches to protecting and/or sharing innovations, including making use of intellectual property tools. Respondents T1 and W17.1 said IP ownership is a not a priority for them, as they want to focus their efforts on generating innovations. As one of these respondents said, "[we are] not necessarily interested in owning the IP, because we believe we can always come up with new IP". This cluster of data relates to the early stage of innovation output, to the intellectual property generation that the actors and institutions seek as a common purpose in the process of *value* creation. The nature of intellectual property rights, what can and

cannot, or should and should not be protected, and how and when to protect IP were not always clear to the respondents in the tech hubs studied. However, tech start-ups lean towards generating IP that is then freely available to share and leverage.

The prevailing logic among many of the respondents engaged in software development is that, in the software realm, it is important to continually build from scratch, partly because this creates the knowledge foundations that give the particular developer the advantage to continually build the next thing. At Workshop 17, respondent W17.5 stated that the open ethos in the digital innovation environment, where a great deal of development occurs on open platforms, dilutes the "need and desire" to keep IP closed:

> Many companies are desensitised to the core IP […]. They are willing to share with less emotion, because the tech industry is so quick in terms of innovation and how quickly things move. What's relevant today may not be relevant tomorrow. [The] rate of change is key to knowledge-sharing.

Respondent W17.5 explained that while the rapid rate of change "may be a barrier to entry for some", it can be overcome through "more familiarity in terms of [being] first to market and, in our instance certainly, relationships". For respondent W17.3, IP is not something that requires a focus on protection, as their firm is more concerned with the services it can provide and sell based on the IP it has generated.

However, at the same time, some respondents, such as respondent T3 at Tshimologong, spoke of the importance of IP ownership, with respondent T3 saying that one role of the Tshimologong hub is to provide advice for start-ups on IP rights and IP law. "If I write code, the IP is mine", respondent T3 stated, adding that several start-ups at the hub were hoping that Tshimologong would help them in protecting their IP, due to their fear that an investor might seek access to the IP as part of an investment. Respondent T3 spoke of the often limited awareness of the dynamics of IP protection, with the start-ups in question being unclear about how to manage this part of investor relationship-building:

> the start-up does not know how to package the knowledge in terms of IP. […] When you are talking to investors, [you] don't know what to keep and what to divulge, what to protect and how to leverage the IP, hence the usefulness of being at the university. That's one core thing that should be given to us at the end of the 12 weeks [of the accelerator training programme]: [knowledge about] how you create trademarks, [how] to open it up to the market so that people play around with it. We think about IP incorrectly as entrepreneurs, [with] fear, [which hinders] entrepreneurial success.

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Respondent T2, functioning in a community management role at Tshimologong, stated that the hub does not seek any share of IP rights that may emerge from innovations generated by start-ups at the hub.

> If there is any sniff of Wits [University] owning IP as a condition for using the space, they [tech start-ups] will not come here. So they pay a membership fee; we give everyone a vanilla-flavoured package of support; there's no Wits IP in the package and they own 100% IP and equity in their company. If they want to work with a Wits academic to support one of the start-ups, we would fall under the national IP Act, but that hasn't happened yet.

The Wits IP policy specifies that the university owns IP created by employees, and thus it does not cover any of the Tshimologong hub participants, such as the start-up participants, who are not Wits employees.

Hub and start-up approaches to local appropriateness

The last core theme present in the data is *approaches to local appropriateness*, i.e., approaches to serving the needs of local innovators and the needs of local citizens and consumers. This cluster of data relates to the forms of *value* that were generated in the tech hubs studied.

The hub where these matters were found to be most complex is Bandwidth Barn Khayelitsha, which faces acute socio-economic challenges linked to its spatial and economic isolation within greater Cape Town. Khayelitsha is about 35 kilometres from downtown Cape Town and is poorly connected, by transport and other economic infrastructure, to local *resources* and markets. The impoverished conditions experienced by most of the households in the township make local appropriateness a great challenge for Bandwidth Barn Khayelitsha innovators seeking to serve local needs. Many Khayelitsha residents do not own a smartphone or, if they do own a smartphone, they often lack the ability to pay for large amounts of internet data usage. Also, local clients for Bandwidth Barn developers' services tend not to have large budgets at their disposal.

Due to local factors such as these, respondent BBK6's development team at the Bandwidth Barn has found itself "forced" to provide only basic web development and social media support services, in order to cater to local client needs—rather than making use of the team's higher-level skills in mobile app development, robotics, and artificial intelligence. In the words of respondent BBK6:

> We want to get into that [higher-level development], but most of these things require a specific amount of funding. If clients cannot meet the cost requirements, then it can't be done. We have been doing some exploration, but it all came down to the fact that we need resources.

According to respondent BBK4 at the Bandwidth Barn, a tech hub needs to be a space for increasing the levels of digital participation in its broader community:

> A lot of the businesses operating here are tech-enabled, and other businesses operating here are starting to understand the shift to tech enablement, [as are the] local schools coming in […]. The tech hub is a key component in shifting towards a tech-enabled Khayelitsha.

According to BBK respondents, Khayelitsha's economic and social isolation needs to be decreased, through the efforts of the local community working together with government, private-sector, and non-profit partners, in order for the tech hub to reach its full potential. The hub and the broader Khayelitsha community need to transition from being entities that are "being looked at" to entities that are understood to be partners with economic potential (respondents BBK4, BBK7). One of the challenges in building the tech hub community in Khayelitsha is that "most people start a business because they want to earn money, not because they've done a market analysis. However, members of the [tech hub] community need to […] have a creative mindset […] to be able to compete" (respondent BBK7).

For all three tech hubs studied, although there are marked differences across the socioeconomic contexts in which they operate, the imperative that innovations emerging from the hub are locally appropriate is, at each hub, a highly challenging one to meet. In the words of respondent T2 at Tshimologong, "people fall in love with their technology, and may be developing something not wanted by the target market. So [there needs to be an emphasis on] understanding your customer/market, not just loving the tech." Success, according to respondent T2, is about building sustainable businesses, and "not just about ticking the boxes of ideas, the business model […]. Until [you are] operating in the world and creating revenue, you haven't achieved anything."

According to respondent T1 at Tshimologong, ideas for digital production and services need "to be disruptive in nature, or have high impact in one's community, […] social impact, [serving as] an enabler that simplifies people's lives." In the words of respondent T3 at Tshimologong:

> One of our primary activities is research, [which] should be [the] practice for all businesses: research your market, would-be buyers, their psychology […]. Any business should be a research-based business, underlying the development of digital products. For us, innovation is about: what are the real problems that people are not thinking about? […] We use design thinking. We are not trained researchers, but we use the available tools within this tech hub to do our work.

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5. Analysis: Innovation entanglement, scale, and sustainability

Two cross-cutting themes present in much of the data from the interviews and the focus group discussion are (1) the quest, by the hubs and start-ups, for scale; and (2) the hubs' and start-ups' quest for sustainability. It must be noted that the terms "scale" and "sustainability" are, of course, open to varying interpretations. Furthermore, as outlined in the recent *Scaling Innovation* research report by the Open African Innovation Research network (Open AIR, 2020), sustainability is often a central feature of successful scaling. In this study, the conceptions of scaling and sustainability posited by the interviewees and focus group respondents are particularly present in the statements they provided on matters of:

- overcoming adversity and responding favourably to complexity in tech hub innovation ecosystems; and
- building multi-dimensional innovation ecosystems.

The five components of the entanglement conceptual framework outlined at the beginning of this article—namely *actors*, *institutions*, *resources*, *values*, and *value*—are represented in the data in respect of how start-ups (actors) and tech hubs (institutions) leverage infrastructure and tech-support services (resources), as well as collaborative learning and knowledge-sharing (values), to foster the creation of applications and platforms to meet demand (value). This enables the poorly resourced actors and institutions to manage the complexity of interacting in knowledge markets. This study thus contributes to an expanded exploration of the entanglement framework, notably the findings that tech start-up actors and tech hub institutions freely engage in entanglement dynamics; that key types of resources are both exogenous (tangible, specialised infrastructure and services for tech start-ups), and endogenous (intangible knowledge resources); that key values are collaborative learning and knowledge-sharing; and that output value is constituted by freely available IP, as well as locally appropriate software, content, and applications. This research expanded the initial framework of research entanglement, to create a means of understanding innovation entanglement in tech hubs.

Certain of the findings accord with the data on open innovation approaches in the relevant literature, but this article extends that knowledge through the theorisation of innovation entanglement behaviour. In particular, what is new to our understanding are the findings that (1) shaping or success factors present in highly resourced, highly structured innovation environments also emerge strongly in poorly resourced, embryonic tech hubs; and that (2) a key to sustainability and scalability, for both the start-ups and the tech hubs, is their mutual entanglement in the processes of accessing resources, building values systems, and creating value, irrespective of how fractured and non-linear these processes may be. With respect to mutual entanglement, the crucial point is that actors and institutions become involved in a heightened

state of interaction with the competing ecosystem factors and the external entities, in "messy" ways, moving along paths that show some significant resistance, as they seek the optimal solutions under adverse circumstances. In other words, the actors and institutions often seek paths of significant resistance, rather than paths of least resistance.

Overcoming adversity and responding favourably to complexity in tech hub innovation ecosystems

The start-up actors studied have emerged from environments characterised by lack of easy access to institutions, to resources, to the private sector, and to markets. They also lack formal access to universities and university research sub-systems, and to publicly funded research entities. The start-up actors have been compelled to move into a particular kind of institutional setting, a tech hub, at which they have to attempt to create and co-create in the face of adverse conditions—conditions which do not disappear just because the actors are now based at a tech hub. Even when operating out of a hub, the start-up actors still do not have easy access to significant amounts of finance, investment, skills, and knowledge. Despite their resource constraints, tech hubs and their resident start-ups persist in their contribution to digital innovation at the small, local scale, with potential for contributing at the regional scale.

The particular form of innovation support looked at in this study, where start-ups are fostered by tech hubs, lacks the relative financial certainty and stability, and relatively predictable path to achieving scale and sustainability, found in innovation-support endeavours taking place in large private-sector entities, in some university entities, and in government-supported research and development (R&D) entities—although of course it must be noted that digital innovation tends to be a medium- to high-risk endeavour in almost any conditions. Risk tends to be more effectively mitigated in business and government contexts—through engagement in multiple simultaneous initiatives and the ability to wait and see which ones pay off—while tech hubs, in the South African context at least, tend to lack (compared to the private and public sectors) the extensive human and financial resources necessary to create many parallel development initiatives.

The start-up entities accepted into a hub's incubation programmes, and/or making use of a hub's infrastructure and services, tend to be characterised by low and irregular income, and limited savings. Accordingly, some tech start-ups give up, while others manage to push through the adversity and stay on the path towards scaling and sustainability. Some tech start-ups grasp every opportunity to remain in whatever programme they are accepted into, while others drop out, or fail to take full advantage

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of a hub's services and opportunities. This raises the question as to the distinguishing features of those tech start-ups that are able to stay on the necessary path. According to respondent T5:

> What defines the real techies [as opposed] to the people just trying to make money, [is that the techies] will push through regardless of the circumstances. Most people in the space will keep pushing through, even if they don't get the support they need, even if they don't get the business models. That kind of mentality is going to grow those people […]. The fact that we believe in the tech that we use [means that this type of business] will be a viable business […]. [We are] spending a lot of resources at the early stage of the technology, getting limited output from the resource input, but we know that this will change […]. [It] has to be sustainable, but even when things are tight, we love what we [are] doing and we keep pushing on.

Volunteering and "hustling" by start-ups are noted as being important to making them, and the tech hubs that they are part of, successful. Hustling is understood as grasping every opportunity, and constantly looking for, and taking on, temporary projects, particularly ones that create short-term income generation opportunities for start-ups and their teams, one example being events management for local sports events. Respondent BBK1 summarised this approach as follows: "one space, two hustlers, and 500 people getting an income".

According to respondent W17.1 at Workshop 17, a key dimension of adversity is uncertainty, and hence, according to this respondent, incubated start-up enterprises may sometimes, in the face of this uncertainty, need or specifically choose to take on "too much", as this may create small growth opportunities in the short term, with sustainable business or employment opportunities only arising in the longer term. In a context such as South Africa, with its huge income disparities and its history of deliberate under-development of areas inhabited by black South Africans, another element of the adversity and complexity is the negative assumptions often made about small-scale black innovators. In the words of respondent BBK6 at the Bandwidth Barn:

> [innovative] ideas are expected to come from a certain organisation/race/company, in terms of size, so when a small, black company comes up with something disruptive, it's not really trusted. There's a question of legitimacy […].

Another element of adversity for the start-ups on the path to scaling and sustainability is the need to take an innovation to market, so as to monetise it. Creating the bridge into the corporate market, and speaking the corporate language, requires more than just business models. It requires learning how to actually be in business.

In the words of respondent W17.1, "[…] what we've learned from the market [is that] being a small company in a mature market is extremely tough". According to respondent W17.5, participation in the market also requires learning how to operate successfully in the face of global economic downturns (a statement that has been made highly prescient by the subsequent emergence of the COVID-19 pandemic).

With respect to the tech hubs, and the scaling of their offerings and building of their sustainability, the data analysis indicates that external funding can be a double-edged sword. While it can help a great deal, at the same time, it potentially leads to over-dependence on money that arrives (and may abruptly stop arriving), at the whim of a donor. According to respondent T2 at Tshimologong, resources acquired not through *donor–recipient relationships* but rather through *operational partnerships with industry*, in which mutual self-interest can be established and both parties feel they gain from the arrangement, have much greater potential stability. Ultimately, tech hubs need to foster a multiplicity of resource streams.

Accordingly, the activities of tech hubs and their start-ups must be aimed towards deep engagement in the broader digital innovation ecosystems beyond the hubs, in order to effectively overcome adversity and benefit from complexity. This deep engagement needs to be with potential future customers, where the strength of future relationships and networks is uncertain; with knowledge brokers and specialists; with IP lawyers and advisors; and with the consumer markets that will determine and influence local appropriateness and therefore the value of the applications and services. Such engagements tend to be highly demanding of time and available knowledge, and tend to greatly stretch tactical organisational capabilities—yet they are too attractive to avoid. The result is a high degree of entanglement, where an individual start-up may be engaging with many possible collaborators and future clients in parallel, in order to counterbalance the absence of even small-scale investment capital.

Building multi-dimensional innovation ecosystems

According to several respondents, when start-ups begin to mature and pursue scale and sustainability, they want, and need, to be fully embedded in a larger innovation ecosystem. A key feature of scaling is increased access to local, regional, or global marketplaces—particularly for the tech hubs that need to scale to push forward access to markets, while individual start-ups will have limited potential for such engagement. Extensive reach and insight into potential future markets and specialisations is an emerging area of focus for tech hubs, as they are more able than individual start-ups to negotiate this level of entanglement. One key feature of engaging with markets, according to respondents at all three hubs, is creation of innovation specialisations—through, for example, a focus on gaming and gamification at one hub, and a focus on fintech or edtech at another. The necessary complex matching processes require tech hub facilitators to have skill sets that can make such specialisations work.

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In the data from the tech hub interviews, it is clear that greater attention is needed to optimise the roles of all potential partners in knowledge generation processes: the roles of the start-ups, the hubs, and, for example, university academics and private-sector industry partners. Respondent T1 spoke of the great potential, at Tshimologong, for greater integration between the Wits University academic community and the digital tech community at the precinct; greater integration between the university's Engineering Faculty and the tech hub so as to enable the tech community to benefit from shared access to equipment; and greater knowledge-sharing between the hub's enterprises and academics working in the biosciences. Respondent T3 cited the significant potential for innovation that could be fostered if Tshimologong start-ups were to have access to university-based scientists such as entomologists (relevant to designing applications to manage pests in fruit or nut orchards), to academics in mining or health sciences (relevant to designing digital mining or digital health applications), and to academics working on IP law (relevant to the design of industry-start-up contracts). Regardless of whether or not a tech hub is based at a tertiary institution, access to and integration between the tech hub and a university or a technical and vocational college can be mutually beneficial to both entities, as each learns progressively from the other.

These findings, on tech start-ups' and tech hubs' pursuit of scaling and sustainability through leveraging prevalent competing ecosystem factors and building numerous complex relationships with external entities in an innovation ecosystem, link to findings from my earlier research (Abrahams, 2016). In that earlier study, I was able to identify the importance of entanglement between a heterogeneous group of non-university-based and university-based research-innovation actors. In the context of this current study, innovation entanglement helps elucidate the dynamics present in relations between hubs, hub start-ups, and external entities in their innovation ecosystems (e.g., universities, private-sector entities, government entities, donors, and non-profit organisations). There is evidence that the hubs and start-ups work through adversity and complexity, and increase their chances of succeeding, through entanglements with large entities, such as universities, private-sector actors, branches of government, or development donors, and through webs of entangled relationships between tech start-ups, between start-ups and hubs, and between hubs.

6. Applying the innovation entanglement framework to tech hubs

Based on the findings of both the earlier research (Abrahams, 2016) and this more recent study, I conclude that, for tech hubs, their start-ups, and the external entities with which they interact (whether universities, private-sector entities, branches of government, donors or non-profits)—when engaged in innovation as a form of communitarian behaviour and contending with competing factors grounded in resources, values, and value—the entanglement dynamic plays out in two main ways.

A first entanglement modality is one spearheaded by the large, formalised entities in the communitarian innovation ecosystem, entities that will tend to be oriented towards bureaucratic imperatives. The downside of this kind of entanglement for small-scale innovation actors and institutions (i.e., start-ups and tech hubs) is that large bureaucratic formations tend not to have a feel for the DNA of communitarian values as understood by smaller-scale actors and institutions. Large, formal entities, e.g., universities, governments, sizeable private-sector entities, and sizeable donors or non-profits, will tend to assert, or reassert, rigid rule-driven governance and management frameworks. A university, for example, will tend to be guided by highly organised, and highly rationalised, memes for organising R&D and innovation. It will generally have standardised functions for funding and reporting. It will generally require conformity to rigid frameworks for performance that are set by the university and must be followed, even where greater flexibility may be required in terms of what constitutes success, failure, or resilience. University-based R&D, even in the 21st century, tends to be a highly structured domain.

A second entanglement modality, which is more amenable to the inherent ethos of a tech hub and its start-ups, is one in which the ecosystem's "soft science" innovation elements are prevalent and strongly fostered. This would produce an entanglement ethos characterised by flexibility, rather than by the relative rigidity of the "hard science" innovation pursued by large, formalised entities. It is likely that the ideal for tech hubs and their start-ups is the co-existence of these two entanglement modalities, such that a tech hub and its start-ups can participate in, and benefit from, both types of innovation entanglement.

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Research respondents

At Bandwidth Barn Khayelitsha, Cape Town, interviewed in 2017

Respondent BBK1.
Respondent BBK2.
Respondent BBK3.
Respondent BBK4.
Respondent BBK5.
Respondent BBK6.
Respondent BBK7.

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At Workshop 17, Cape Town, interviewed in 2017
Respondent W17.1.
Respondent W17.2.
Respondent W17.3.
Respondent W17.4.
Respondent W17.5.

At Tshimologong Digital Innovation Precinct, Johannesburg, interviewed in 2017
Respondent T1.
Respondent T2.
Respondent T3.
Respondent T4.
Respondent T5.

Bandwidth Barn Khayelitsha focus group, Cape Town, conducted in 2017
BFG respondents.

Appendix A: Protocol for Semi-Structured Interviews

Broad designation and institution of key informant (for analysis purposes only):

Date of interview:

Please note that these are guiding questions. The researcher is interested in noting and understanding the histories, nature and characteristics of high-tech hubs and those factors that foster their success, in particular with respect to knowledge governance.

Metrics
(i) Please mention or refer us to some of the key metrics that reflect the status and level of advancement of this high-tech hub, including

- metrics for innovation input and output
- metrics of innovation value produced
- any other relevant metrics

Modes of knowledge creation and knowledge governance
(ii) What are the prevailing modes of knowledge creation at the tech hub and the related governance mechanisms?
(iii) In your view, what is it that academics, innovators and managers do that tends to lead to success in the innovation project, or to lead to failure in the innovation project?
(iv) In your view, what is it that academics, innovators and managers do that tends to lead to success in the long term innovation venture, or to lead to failure of the high-tech hub?

Understanding the complex context for innovation practices
(v) How do the complex challenges of innovation practice on a short-term (one year) and a long-term (3 to 5 year) basis affect your knowledge creation and knowledge governance behaviours?
(vi) How does government and institutional policy, law and regulation, in particular, IP law and open IP approaches affect your knowledge creation and knowledge governance behaviours?

(vii) How do tech transfer offices, advisors, financing and other support measures enable or present barriers to your innovation projects and to high-tech hub development?

High-tech hub evolution
(viii) Briefly explain this high-tech hub's evolution in terms of any of the following:

- innovation and knowledge production
- collaborative innovation
- appropriation of intellectual property (IP)
- the role and contributions of innovation actors, innovation-oriented institutions and innovation resources
- the nature and importance of innovation-oriented values
- the innovation value produced

Appendix B: Focus Group Guide

Broad designation and institution of key informants (for analysis purposes only):

Date of focus group event:

Note to focus group: Please note that these are guiding questions. The researcher is interested in noting and understanding the histories, nature and characteristics of high-tech hubs and those factors that foster their success, in particular with respect to knowledge governance. This particular set of questions is aimed at understanding your collective view of the collaborative innovation experience.

Metrics
(i) How would you measure the success of the innovation activities that you engage in here at the high-tech hub?

Modes of knowledge creation and knowledge governance
(ii) Please explain how you produce knowledge in this collaborative working environment. [For example, why is it better to engage in collaborative innovation than to work alone?]
(iii) How is the intellectual property you create owned and released or used for commercial or social or public benefit?
(iv) How do you earn income or other value from the intellectual property you create?

Understanding the complex context for innovation practices
(v) Please briefly explain some of the major challenges you face in this form of collaborative innovation.
(vi) How do you address or resolve these challenges?
(vii) What, in your view, are the strengths and weaknesses of how innovation is governed/managed in this high-tech hub? [For example, decision making, management, leadership, government policy or law or regulation, tech advisors, financing, any other]

High-tech hub evolution
(viii) What, in your view, are the overall strengths and weaknesses of the high-tech hub approach to innovation?

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Innovation Practices at Makerspaces in Egypt, Tunisia and Morocco

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Abstract
This article sets out findings from research exploring approaches to innovation at makerspaces in Egypt, Tunisia, and Morocco. Based on interviews with individuals involved in makerspaces in each country—seven spaces in Egypt, two in Tunisia, and one in Morocco—we provide findings on the origins and general characteristics of the spaces, as well as findings on five core themes that emerged from the interviews: knowledge-sharing; innovation and product development; openness, collaboration, and innovation ownership; attitudes towards intellectual property (IP); and scaling.

Keywords
maker movement, innovation, entrepreneurship, knowledge-sharing learning, skills development, innovation ownership, intellectual property (IP), scaling, Egypt, Tunisia, Morocco

Acknowledgements
The research for this article was carried out under the auspices of the Open African Innovation Research (Open AIR) network, which is a partnership between The American University in Cairo, the Nigerian Institute of Advanced Legal Studies, Strathmore University in Nairobi, the University of Cape Town, the University of Johannesburg, and the University of Ottawa. The authors acknowledge the support provided for this research by Open AIR, the Social Sciences and Humanities Research Council (SSHRC) of Canada, the International Development Research Centre (IDRC), and the UK Department for International Development (DFID). The views expressed in this work are those of the authors and do not necessarily represent those of the research funders. The authors also acknowledge the research assistance provided by the following researchers at the Access to Knowledge for Development Center (A2K4D) at The American University in Cairo: Sarah El Saeed, Mai El Khamisi, Mohamed Hosny, Farida Kamel, and Nancy Salem. The authors are also thankful to the interviewees for sharing their views on the issues addressed,

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and are grateful for the comments received, through the internal review processes of the Open AIR network, from Prof. Erika Kraemer-Mbula of the University of Johannesburg and Dr. Isaac Rutenberg of Strathmore University. This article draws on elements of a working paper (ElHoussamy & Rizk, 2018).

DOI: https://doi.org/10.23962/10539/30357

Recommended citation
ElHoussamy, N., & Rizk, N. (2020). Innovation practices at makerspaces in Egypt, Tunisia and Morocco. *The African Journal of Information and Communication (AJIC), 26*, 1-25. https://doi.org/10.23962/10539/30357

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1. Introduction

Amidst the socioeconomic and political flux present in North Africa since the Arab uprisings that swept across the region, starting in early 2011, a number of innovation spaces have emerged in Egypt, Tunisia, and Morocco in which makers, hackers, and entrepreneurs can meet and collaborate. While alternative modes of innovation and creation have historically been neglected by a majority of African policymakers due to the "unconventional nature of their enterprises", recent years have witnessed a sharp increase across the continent in civic participation in—and researcher and policymaker interest in—the maker movement (Ekekwe, 2015). The movement is especially significant in African contexts, because it empowers citizens to use their local expertise and skills and translate this know-how into solution-oriented innovation that targets problems that exist in their daily lives, such as problems of access to clean water, energy, health care, and food (Ekekwe, 2015).

The maker movement has been called a "new industrial revolution" (Anderson, 2012). Sharing is at the core of this revolution, in contrast to the predominance of industrial secret-keeping in the past. This sharing serves to fulfil the promise of the public good characteristics of knowledge, notably non-rivalry, where the value of knowledge increases rather than diminishes with use and sharing. Makerspaces, which provide tools to entrepreneurs and other individuals, also provide access to technologies. This presents youth and potential entrepreneurs with opportunities to access sophisticated technologies and means of production at low costs. One of the unique attributes of the maker movement is that the creative process of making is shared with others, allowing others to improve and build upon innovations. This is similar in concept to the free and open source software (FOSS) movement, whereby codes are freely available for individuals to build on and improve.

In our study, we aimed to gain insights into how the maker movement is unfolding in three North African countries: Egypt, Tunisia, and Morocco. In particular, we were interested in the modes of innovation, knowledge-sharing, knowledge management, product development, and scaling present in the 10 spaces we studied. This study aims to provide an initial North African contribution to the emerging body of empirical research on the maker movement in Africa (see Armstrong et al., 2018; De Beer et al., 2017; Kraemer-Mbula & Armstrong, 2017).

2. Study background and context

Makerspaces are physical spaces with fabrication tools where individuals can design, prototype, and create manufactured items for a variety of purposes. Makerspaces provide individuals with free or low-cost access to shared equipment, training in use of the equipment, and participation in a collaborative community. The collaborative community allows for peer-to-peer knowledge exchange and sharing, whereby a maker who is knowledgeable about one tool can aid other innovators, and vice versa: "One capable craftsman with a […] 3D printer can provide improved manufacturing services and specialized components for hundreds of artisans; similarly, a technically literate artisan with a computer […] can assist hundreds of […] mechanics." (Waldman-Brown et al., 2014, p. 13). According to Good (2013), the spaces transform collective knowledge into a physical or digital product. This final product keeps getting revised and improved upon and the evolving process of that product reflects the learning that takes place in a makerspace.

The maker movement phenomenon has been on the rise in developing countries, in line with efforts to address local problems in innovative ways at low cost. We can draw a parallel between makers and "lead users", a term coined by Von Hippel (1986) to describe those who identify needs for products before their market demand arises. Lead users generally start firms based on the solutions they develop, similar to makers who often create products to solve problems affecting them personally or affecting the communities in which they live.

Typical fabrication tools found in a makerspace are 3D printers, laser cutters, milling machines, CNC routers, engraving machines, soldering tools, and woodworking tools. Makerspaces benefit from open source appropriate technology (OSAT), which encourages innovation by using mostly open designs and blueprints. With particular importance in developing-world settings, OSAT allows for imported technologies to be adapted, altered to meet local developmental needs, and produced at low cost (see King et al., 2014). For example, the RepRap open design 3D printer, which is often found in makerspaces, is an open source desktop 3D printer capable of printing plastic objects. The printer is portable, and has the ability to affordably custom manufacture a wide arrange of items, based on free-of-charge open source design files (King et al., 2014).

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Van Holm (2017), situating makers within the practice of entrepreneurship, proposes that makerspaces "aid in the creation of new enterprises" and "offer an environment supportive of innovation" (Van Holm, 2017, p. 25). Significantly, however, Van Holm argues that driving entrepreneurship is in fact not the maker movement's greater strength. Rather, Van Holm argues, the movement's greatest power lies in its potential, through its "openness and flexibility", to engender community development, education, and sustainable development (Van Holm, 2017, p. 30).

Makerspaces provide an open collaborative space that is inviting to entrepreneurs who want to innovate, and also to those more focused on the "making" without having an overtly entrepreneurial mindset. Makerspaces provide an opportunity for innovation to occur in a setting of sharing and openness. For those with an entrepreneurial mindset, makerspaces offer collaborative opportunities and tools to develop ideas from inception phase to market launch. This emerging phenomenon of collaborative and digital fabrication within the African maker movement has the potential to transform dynamics in a variety of industries on the continent (see Ekekwe, 2015).

Makerspaces and their users exhibit attributes of what can be referred to as a "community of practice" (see Sheridan et al., 2014; Wenger et al., 2002). Communities of practice, according to Wenger et al. (2002, p. 4), "are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis". Within a makerspace, there tends to be a formal learning component along the lines of the traditional teacher-to-student model, and at the same time a strong, non-hierarchical, informal element that allows users to exchange skills, experiences, and ideas. This prioritisation of peer-to-peer knowledge-sharing is one of the key, transformational characteristics of the maker movement. In spite of the differences in the scale of makerspace projects, participants, and funding, all makerspaces share an ethos of using the creative process to share knowledge.

Several of the makerspaces we identified in North Africa, and included in our study, are fabrication laboratories (fab labs), which are makerspaces following specifications set out by the international Fab Foundation at the Massachusetts Institute of Technology (MIT) Center for Bits and Atoms. The Fab Foundation was established in 2009 to support the development of an international network of fab labs designed to

> provide access to the tools, the knowledge and the financial means to educate, innovate and invent using technology and digital fabrication to allow anyone to make (almost) anything, and thereby creating opportunities to improve lives and livelihoods around the world. (Fab Foundation, n.d.)

According to the Fab Foundation, a fab lab is a technical prototyping platform for innovation and invention, providing stimulus for local entrepreneurship. A fab lab is also a platform for learning and innovation: a place to play, to create, to learn, to mentor, and to invent (Fab Foundation, n.d.).

3. Research design

We undertook both desk research and exploratory fieldwork, with our main method of data collection during fieldwork consisting of semi-structured interviews based on an interview protocol (see Appendix). We deemed exploratory fieldwork to be the most appropriate method, given the limited data available on the maker movement in North Africa. The interview sample consisted of 16 individuals: 11 people from seven makerspaces in Egypt, two people from two makerspaces in Tunisia, four people from one makerspace in Morocco, and a person connected to Maker Faire Cairo. We used purposive sampling to select the makerspaces and interviewees included in the study, with the choices somewhat dependent on our established contacts in each country. All the interviewees agreed that their names could be used in our publications based on the research.

As per the interview protocol, we asked the interviewees about the following in respect of their respective makerspaces:

- the space's core characteristics (establishment, operational model, tools, links to other spaces and/or enterprises);
- creative processes, knowledge-sharing, innovation, learning, skills development, users;
- dynamics in terms of intellectual property (IP) and informality;
- scaling of innovations and products; and
- measuring innovation.

The interviews were audio-recorded and the transcripts analysed qualitatively, with the findings organised in terms of the main themes that emerged in the interviewees' statements. The 10 makerspaces included in the study are listed in Table 1.

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Table 1: The 10 makerspaces studied

Name	Location	URL
Fab Lab Egypt	Cairo	https://fablabegypt.com
Qafeer Makerspace	Cairo	https://www.facebook.com/qafeermakerspace/
Fab Lab in New Cairo (FLiNC)	Cairo	https://www.fablabs.io/labs/fablabnewcairo
FabLab AUC	Cairo	https://www.facebook.com/FabLabAUC/
Karakeeb Makerspace	Alexandria	https://www.facebook.com/karakeeb.co/
icealex	Alexandria	http://icealex.com
Alex Hackerspace	Alexandria	https://www.facebook.com/alexhackerspace/
FabLab ENIT	Tunis	https://www.facebook.com/FabLabENIT/
LEVEL1	Tunis	http://www.level1hub.com/
Fablab Casablanca	Casablanca	https://www.facebook.com/FABLAB.CASA/

4. Findings on the makerspaces' core characteristics

Fab Lab Egypt

Fab Lab Egypt was launched in 2012, operating out of a garage. It was the first official fab lab to open in the country (Fab Lab Egypt, n.d.), and its initial model was purely educational and focused on providing programmes and workshops. In 2016, it moved to a new and larger location to become a platform to empower makers, to host start-ups, and to draw in individuals not involved in the maker movement. It provides an open collaborative makerspace equipped with digital fabrication and prototyping machines and tools, and it offers business-to-business (B2B) services that provide a source of revenue for the operation of the lab. At the time of our research, the space was hosting three resident start-ups. Fab Lab Egypt has been self-funded since its inception.

The makerspace directed its B2B work towards its main vision of spreading the maker culture by partnering with mobile operator Orange Egypt to create mini-fab labs in Egyptian governorates. Fab Lab Egypt is the caretaker of several other makerspaces throughout Egypt and also collaborates widely. Their rationale for collaboration is that they aim to spread the maker culture in the country, rather than monopolise the maker market.

The creation of Fab Lab Egypt was followed, in 2013, by the opening of Qafeer Makerspace in the 6th of October City district, and, in 2015, by the opening of Fab Lab in New Cairo (FLiNC). These makerspaces were intended to target citizens in both the west and the east of Cairo (Fablabs.io, n.d.). When criticised by other emerging makerspaces in Egypt for having a "monopoly" on workshops offered to the community, Fab Lab Egypt suspended this service and began directing any workshop requests to other makerspaces in the country (El Safty interview). Fab Lab Egypt collaborates with other makerspaces in assisting new spaces to open up. Fab Lab Egypt also organises the annual Maker Faire Cairo, bringing together makers from different parts of Egypt to showcase their work and to collaborate. For the smaller spaces unable to afford a booth at the Maker Faire, Fab Lab Egypt waives the fees to enhance the visibility of these smaller makerspaces in the maker community. Fab Lab Egypt strongly believes that the closure of any makerspace has a negative impact on the maker movement in Egypt as a whole.

Qafeer Makerspace

Founded in Cairo in 2013 and affiliated with the Fab Foundation, Qafeer Makerspace closed in 2019 due to financial difficulties, but it was in operation at the time of our research and we interviewed its director. It functioned mainly as a community-run makerspace, using the meeting room of an existing co-working space, Qafeer Labs. The founders of Qafeer Labs established the makerspace through an online crowd-funding campaign on Zoomaal (n.d.) that managed to raise more than USD16,000. It was the first makerspace established in Cairo's 6th of October district, and it collaborated with other makerspaces so as to have access to tools that it lacked. Although it is open to anyone, it offered few formal training sessions on the use of its tools and thus relied on attracting relatively experienced makers (El Zoughby interview).

Fab Lab in New Cairo (FLiNC)

FLiNC was launched in late 2015—with the help of Fab Lab Egypt—by Giza Systems, a systems integrator in the Middle East and North Africa that assists businesses in asset-intensive industries to streamline their operations. FLiNC, located at the Giza Systems offices, is fully funded by the private sector, specifically Giza Systems and EMC2 Dell, as part of the corporate social responsibility (CSR) programmes of both entities. Being associated with a private company brought advantages in terms of finding financial resources to create the space (El Raffei interview). Accredited

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by the global Fab Foundation, FLiNC is registered as a non-governmental organisation (NGO), under the Giza Foundation umbrella, and although it is located on the premises of a private company, FLiNC aims to serve the maker community at large and to expand its maker base. It offers regular workshops to the maker community in Egypt, and collaborates with other spaces in competitions and events. For example, together with Fab Lab Egypt, FLiNC co-hosts FabLab on Wheels (FLoW), a mobile fab lab created to improve accessibility. FLoW is located inside a bus, which mostly tours governorates outside Cairo and Alexandria where virtually no makerspaces exist. FLoW volunteers help makers to use the tools provided in the space, and also discuss the viability of potential products that makers want to create (FabLab on Wheels, n.d.).

FabLab AUC

Located at The American University in Cairo (AUC) and affiliated to the Fab Foundation, FabLab AUC officially began operating in April 2017 for AUC students (AUC, 2017). Two engineering students at AUC launched FabLab AUC, and it is the only university-based makerspace in Egypt that is included in this research. AbdelRahman Shalaby, one of the co-founders of FabLab AUC, was first introduced to the concept of a makerspace when he interned at Fab Lab Egypt. He wanted to bring this concept to AUC students, so he partnered with another student, Mohamed Ragab, to create the space. FabLab AUC was built from scratch in an existing lab at AUC's New Cairo Campus. Shalaby and Ragab pitched the idea to the Mechanical Engineering Department, and received moral encouragement but no financial support. They then turned to different entities on campus to solicit the necessary funds to open the makerspace. It now receives financial support from various AUC entities, including the Mechanical Engineering Association (Shalaby and Ragab interview). FabLab AUC is a rapid prototyping working space, equipped (at the time of our research) with a 3D printer, a laser cutter, a four-axis CNC milling machine, and a variety of other mechanical and electronic tools. FabLab AUC is a non-profit entity, and while it charges a symbolic fee for the use of the space, all money is poured back into the lab and used to buy materials and to support projects.

Karakeeb Makerspace

Located in Alexandria, community-based Karakeeb Makerspace was established in 2013 in the city's Jesuit Cultural Center. It is a mini-makerspace that attempts to spread technology and knowledge of digital fabrication, as well as the culture of making, to people with non-engineering backgrounds. The space is completely volunteer-based and self-funded; it also relies on non-financial donations in the form of machines and tools. Karakeeb collaborates closely with Fab Lab Egypt and icealex, a second makerspace in Alexandria, and participates in Egypt's annual Maker Faire in Cairo. Karakeeb was founded as the result of a partnership between two Egyptian youths and a pastor. The pastor first provided Mina Effat and Rabab Hassan with a 2x2-metre room to set up the makerspace in the Jesuit Cultural Center. A few months later, a slightly bigger room, 2x5 metres, became available and Karakeeb's co-founders began to search for funds. They received the money for their first machine from a friend of the pastor, who asked his wedding guests to give gifts in the form of monetary contributions to Karakeeb (Effat and Hassan interview). Karakeeb aims to support start-ups and works with local NGOs to spread the maker culture, especially targeting underprivileged youth. The space maintains close ties with the Egyptian maker community through participation in events and workshops.

icealex

icealex (Innovation, Collaboration and Entrepreneurship Alexandria) is part of the international ICE hubs network based in Germany, which has branches in Ethiopia, Egypt, and Germany. The ICE hubs focus on helping developing countries create environmentally friendly and sustainable products. The makerspace was built in 2013 by three youths with the help of the maker community and crowd-funding. icealex encourages an open source collaborative culture. The space holds monthly workshops to transfer various technical skills to makers, in addition to an entrepreneurship programme to help interested makers develop their innovations and become more market-driven. There is a co-working area within the space, as a secondary activity to the makerspace. icealex sources income from corporate users to subsidise services for start-ups and students (Bastawy interview). icealex participates in the annual Cairo Maker Faire. In January 2017, its sister branch, icecairo, shut down due to the rising costs of products necessary for the operation of the makerspace and the increasing economic challenges in Egypt generally (icecairo, n.d.).

Alex Hackerspace

Also in Alexandria is Alex Hackerspace, a community-run makerspace established in 2015, using only self-funding. Founder Amr El Shaer came up with the idea for Alex Hackerspace in 2010, but it was not until 2015 that he co-founded it with his partner. In 2014, El Shaer was awarded a place in the US Department of State's International Visitor Leadership programme, a professional exchange programme that allowed him to tour the US for 22 days, examining different makerspace models. Upon his return, El Shaer quit his full-time job and focused on creating Alex Hackerspace (El Shaer interview). It provides a variety of tools for makers at a low cost, as well as consultancy services and courses on hands-on creation of different innovations and products. The space is completely self-financed by its founders, both in terms of machinery and operational costs. Alex Hackerspace caters both to makers with an engineering background, as well as to makers new to the idea of fabrication and hands-on innovation. They maintain close ties with the Egyptian maker community by co-hosting workshops and participating in events.

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FabLab ENIT

FabLab ENIT, in the Tunisian capital Tunis, was established in the National Engineering School of Tunis (ENIT) in 2013 by a professor, as a collaboration initiative with other professors from Europe to bring innovation modules to universities across North Africa. The goal of the makerspace is to give students and faculty equal access to different modes of production. FabLab ENIT does not charge any subscription fee for using the space. Users pay for the costs of the materials they use. The space is student-run and is accredited by the Fab Foundation. When first established, FabLab ENIT was funded by the European Union (EU) as part of an ongoing collaboration between ENIT and the EU, and later the space became fully funded by the university. The space collaborates with other makerspaces in Tunisia, as well as several fab labs throughout Europe (Ben Rejeb interview). The space relies on the university to give students the training needed to use the makerspace equipment, for engineering production, in contrast to most other spaces that give workshops and informal one-on-one sessions. Unlike Egypt's university-based FabLab AUC, Tunisia's FabLab ENIT collaborates with other makerspaces.

LEVEL1

LEVEL1, established in September 2017 in Tunis, is both a makerspace and a co-working space. It focuses on helping makers in the gaming and video industry, with specific emphasis on 3D gaming, virtual reality (VR), and augmented reality (AR)—areas the founders believed were not being sufficiently addressed by the maker movement in Tunisia. LEVEL1's main aims are to enhance the culture of making in the areas of gaming and video, and to help makers gain access to these industries. The space provides VR and AR workshops for adults and students, as well as workshops for children to help them create their own applications and games. LEVEL1 is completely self-financed by one of the founding partners, who uses revenue from his amusement park company to sustain the space and to purchase the necessary tools (Bouslama interview).

Fablab Casablanca

Fablab Casablanca in Morocco was launched in 2014 after two makers attended a Fab Foundation event in Munich, Germany, and were inspired to replicate the fab lab model in their hometown of Casablanca. Fablab Casablanca is accredited by the Fab Foundation and emphasises a self-manufacturing, do-it-yourself culture, using computer-controlled machinery. The space is open to anyone who wants to use the tools and equipment for educational, commercial, or personal interests. The machines include laser cutters, a 3D printer, and various electronic tools. It is completely self-funded by one of its founders, based on revenues from a private computer chip company. It has strong ties within the maker community and provides free weekly training sessions. It hosts an association for entrepreneurs that encourages makers to scale their creations into businesses (Abouch and Kouska interview).

Table 2: Makerspaces' core characteristics

Name	Year of establishment	The physical space (new v. upgraded)	Type of entity	Funding and income
Fab Lab Egypt	2012	Original location: Upgraded from personal garage New location: New space	Community-based	Provision of paid B2B services; user fees for space and machine use; membership fees
Qafeer Makerspace	2013 (closed in 2019)	Upgraded within existing co-working space	Community-based	Crowdfunding; user fees for space and machine use; membership fees
Fab Lab in New Cairo (FLiNC)	2015	Upgraded within an existing private company	Community-based	Private funding; user fees for space and machine use; membership fees
FabLab AUC	2017	Upgraded from empty lab space at AUC	University-based	University funding; user fees for machine use; no membership fees
Karakeeb Makerspace	2013	Upgraded space within cultural centre	Community- based	Crowdfunding and private funding; user fees for space and machine use; no membership fees
icealex	2013	New	Community-based	Crowd funding; user fees for space and machine use; membership fees
Alex Hackerspace	2015	New	Community-based	Private funding; user fees for space and machine use; no membership fees
FabLab ENIT	2013	Built from scratch on university campus	University-based	Private funding and university funding; user fees for space and machine use; no membership fees
LEVEL1	2017	New	Community-based	Private funding; user fees for space and machine use; no membership fees
Fablab Casablanca	2014	New	Community-based	Private funding; user fees for space and machine use; no membership fees

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5. Thematic findings

We now present key findings that emerged from the qualitative data analysis in terms of five thematic areas:

- knowledge-sharing;
- innovation and product development;
- openness, collaboration, and innovation ownership;
- attitudes towards intellectual property (IP); and
- scaling.

Knowledge-sharing

Both informal and formal modes of learning are prevalent in all the makerspaces we studied. Peer-to-peer collaboration between users of the spaces is key to the spaces' community-of-practice attributes (according to the aforementioned Wenger et al. (2002) community of practice concept).

Fab Lab Egypt offers customised internship programmes for delivery of business-to-business (B2B) services to client and school programmes in science, technology, engineering, and mathematics (STEM) skills. This lab also offers a Maker Diploma course, which introduces the basic principles of making and prototyping. A dentist who was awarded his Maker Diploma from Fab Lab Egypt now 3D prints his moulds, improving the accuracy of his procedures (El Safty interview). The lab also offers a six-week technical internship, called "Maker Chef", to educators and hackers specifically, and presents interns with an opportunity to join Fab Lab Egypt's tech team (Maker Chef, 2016).

FLiNC's main focus is on teaching engineering-learning strategies so as to transform new makers into proficient makers (El Raffei interview). Conceptual design was prioritised, as it related to how people can think of a design for something to be produced. In addition, FLiNC provides process management workshops that people can add to their resumes (El Raffei interview).

FabLab AUC stresses learning-by-doing and designing-for-manufacturing. The lab's users are mostly engineering students, and the space aims to bridge the gap between a design idea and actual implementation or manufacturing. The lab has a technical team to help entrepreneurs who do not have a background in design (Shalaby and Ragab interview).

Alex Hackerspace places emphasis on providing its makers with "unconventional learning" via hands-on exposure to tools that can be used to create new products (El Shaer interview). The space offers courses in woodworking, metal welding, 3D printing, laser cutting, the use of CNC routers and other electronics, and the creation of handicrafts. Makers work and learn in groups, in a collaborative environment. The skills gained through the training courses were often cited on learners' resumes to help them in finding employment.

At Karakeeb Makerspace, many modes of learning are pursued, including mentoring and peer-to-peer learning experiences. Karakeeb offers an introductory safety and electronics course for anyone who visits the space for more than three hours, and Karakeeb staff provide help in operating the machinery. The learning at Karakeeb is said to transpire organically as a result of collaboration. Collaboration is said to be highly prevalent in the space, with the co-founders stating that people from different disciplines work better together and can learn from each other (Effat and Hassan interview).

icealex has the advantage of being situated within a larger technology innovation space, thereby connecting makers to entrepreneurial and marketing skills. The space offers a three-month internship, whereby interns experience different staff roles and get a chance to build a variety of skills. icealex emphasises a do-it-yourself ethic, whereby makers explore and learn through trial and error. The space also encourages peer-to-peer mentoring. It hosts monthly workshops targeting different skill sets for makers, in addition to offering entrepreneurship programmes for makers and artisans. Mentoring and technical assistance sessions are also offered.

Alex Hackerspace has an initiative whereby it purchases access to massive open online courses (MOOCs) that makers would otherwise not be able to afford on their own, and offers them for free. The course content is divided between the makers who signed up, and then each maker is responsible for teaching their fellow makers the content of the section they have been assigned. This allows the makerspace to cost-effectively introduce makers to a variety of necessary skills (El Shaer interview).

At FabLab ENIT, an emphasis is placed on the makers, who are almost exclusively students at the university, learning new skills through seeing the innovation processes present in each other's projects. FabLab ENIT also holds regular training sessions on 3D printing, digital manufacturing, and design-to-concept creation. At FabLab ENIT, makers learn from within their community of practice at the space. The space gives the makers the opportunity to work with expensive machines. They can access the machines easily and at a low cost, and can use the knowledge and skill sets gained in their later employment after university. FabLab ENIT holds regular training sessions on concept creation, design, digital manufacturing, and 3D printing, in which new makers learn the necessary skills from teachers or mentors. These skills have helped makers to secure employment after graduation. Several makers have used these skills to obtain internships and job opportunities. Makers report that job interviewers are very interested in the innovations that they have created at the fab lab (Ben Rejeb interview).

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At LEVEL1, the space caters largely to university students, including Master's and PhD students, who are looking for access to tools to complete their graduation projects. Makers at LEVEL1 have access to the regular co-working space, and a select few opt for the "VIP" option, whereby they have access to consultancy services, in return for producing a creation that benefits the community. LEVEL1 provides workshops in AR and VR for adult makers. There are also workshops for children, called Kids Hacker Labs, to develop children's skills in coding, software development, and application-building (Bouslama interview). LEVEL1's Bouslama explained that the software skills needed to enter the gaming market that are obtained through use of the regular and co-working space, as well as via attendance at various workshops, helps young entrepreneurs find employment in the gaming market—a market driven by young entrepreneurs (Bouslama interview).

At Fablab Casablanca, makers are able to supplement their knowledge of technology, electronics, and 3D printing through attendance at free weekly training sessions conducted by volunteers. Session topics are based on user preferences. The lab offers workshop spaces, provides several courses and workshops on how to use specific machines, and provides workshops on concept design and basic making concepts for beginner makers. The space welcomes both new and experienced makers (Fablab Casablanca, n.d.). The directors of Fablab Casablanca stress that people work more in groups than individually, and learn an abundance of skills from each other (Abouch and Kouska interview).

At Qafeer Makerspace (which, as explained above, closed down in 2019, after our data collection), one-on-one assistance was the main learning tool offered, whereby the makerspace staff helped students while they worked on their projects. One of the co-founders served as the core support person for learning about product design, which was the main skill area covered by the space. Qafeer also offered courses, mostly design-related, which took up to 15 people, based on the demand for a certain topic. Due to time and resource constraints, Qafeer staff usually operated the 3D printer and other tools for the makers, most of whom were students. Therefore, although the makers were introduced to the tools available in the space and learned how they functioned, they seldom operated them on their own (El Zoughby interview).

Innovation and product development

Across the makerspaces studied, the most prevalent type of innovation found was social innovation, i.e., innovation based on seeking low-cost solutions to local problems and needs.

icealex supports makers in the use of human-centred design methodology to identify social innovations worthy of pursuit, i.e., to identify a challenge that is relevant to the community and then identify potentially viable solutions worthy of pursuit. icealex organises and hosts networking events and hackathons aimed at generating these

viable ideas. One of icealex's makers has created a portable laser cutter, Risha Laser Cutter, which, coupled with its supplementary mobile app, allows users to draw their designs directly on their phones and laser-cut them using the portable cutter. This innovation is aimed at supporting marginalised communities with no access to this technology (Risha, n.d.). Another innovation produced at icealex is a water purification filter, which uses palm tree branches and stones. The filter was developed by a young woman whose parent suffers from kidney problems resulting from drinking contaminated water. This locally relevant, low-cost alternative works almost as well as the expensive industrialised version (Bastawy interview).

At Karakeeb Makerspace, it has been found that innovation usually occurs when makers set out to create solutions either to a problem in their everyday lives, or to ones they have witnessed in their community. A few years ago, makers at Karakeeb created an emergency lamp, powered by old mobile phones, to address Egypt's power cuts. This is a low-cost solution to a societal problem, and also an entrepreneurial endeavour. In the environmental sphere, Karakeeb co-founders and makers collaborated to create a smart trash bin that rewards the user for correctly separating trash, by posting to social media and praising the user's environmental effort (Effat and Hassan interview). One Karakeeb maker has started an accessory and decoration business based on products she designs and produces at the space.

At Fab Lab Egypt, one maker has used 3D printing to create a low-cost prosthetic hand. At FabLab ENIT, a maker has 3D-printed a prosthetic hand that incorporates robotics (Ben Rejeb interview). The Alex Hackerspace stated that the emphasis of the space is on providing an environment for the development of low-cost innovative solutions.

At FLiNC, users mainly produce low-cost products such as picture puzzles and woodwork. At FabLab AUC, where the makers are university students, we found that fidget-spinners were being created that could be sold for less than half their market price (Shalaby and Ragab interview).

Openness, collaboration, and innovation ownership

While the makerspaces studied all promote an openness ethos grounded in collaboration and sharing, our interviews found that the makers themselves sometimes find themselves in situations where they wish to claim and protect ownership in their innovation outputs. Most of the interviewees cited tensions that sometimes arise, among makers, between open collaboration and competition.

At Alex Hackerspace, the makers, before working on any group project, have to sign an agreement outlining the division of roles and percentage of work on each task in the project, so that everyone knows which part is assigned to them and what their

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share will be in any benefits from the final outcomes. This signed agreement is then used to settle ownership disputes (El Shaer interview).

At icealex, mediation, facilitated by the space, is used to settle innovation-ownership disputes. In an effort to prevent disputes from arising in the first place, icealex hosts regular workshops on the elements of the open collaboration (Bastawy interview).

At Fab Lab Egypt, innovation-ownership disputes typically arise when a maker feels a product might have commercial potential. While makers appreciate learning from each other, at the same time, there is also a degree of fear of collaboration due to the existence of a competitive culture. The disputes are resolved through agreements that assign innovation-ownership to the maker, or to more than one maker, working on the innovation. In general, lab management facilitates the reaching of an agreement but remains neutral, with the disputes ultimately resolved by the makers themselves. The lab directly intervenes in a dispute between members of the community only (1) if the dispute is seen as affecting the reputation of the space or the maker community as a whole; or (2) where the dispute involves one of the lab's staff members. At the time of our research, Fab Lab Egypt did not have a formal code of conduct—an absence which, according to the space's general manager, was problematic, i.e., it was problematic to have a shared culture, but no written rules governing it (El Safty interview).

At FLiNC, at the time of our research, there had been some innovation-ownership disputes between makers, but the disputes had not yet been resolved because the makerspace did not yet have a formalised dispute settlement mechanism in place. The lab was considering developing such a mechanism, and the FLiNC interviewee was of the view that the space could also benefit from having a guide on how to establish formal IP rights in one's innovation (El Raffei interview).

At Karakeeb Makerspace, the trend is towards collaboration and away from competitiveness, which can perhaps be partially attributed to the fact that the space is based in a cultural centre. The space's co-founders have found that people from a variety of different disciplines can work well together. At the time of our research, there had not yet been any innovation-ownership disputes and, accordingly, the space had not yet been required to play any role in such matters (Effat and Hassan interview).

At FabLab AUC, at the time of our research, there had not been any innovation-ownership disputes. The outputs of the makerspace are prototypes and not products, thus reducing the chances of disputes and making an ownership-dispute resolution structure unnecessary (Shalaby and Ragab interview). At FabLab ENIT, there had also not yet been any innovation-ownership disputes at the time of our research, and the space did not have a structure to address such matters. The space encourages its

makers to work on an open collaborative basis, and so far makers had been willingly sharing their work and models (Ben Rejeb interview).

At Fablab Casablanca, the space does not view resolution of innovation-ownership disputes as part of its mandate, and all innovation creators are clearly given full ownership over their creations (Abouch and Kouska interview). LEVEL1 also leaves issues of innovation-ownership to the makers. The space had launched only very recently at the time of our research, and thus it remained to be seen whether significant issues of innovation ownership would arise (Bouslama interview).

At Qafeer Makerspace, innovation-ownership disputes were almost non-existent, apparently due to the small size of the group of makers and the nature of their outputs. The space was focused on introducing skills and augmenting university education, rather than generating inventions (El Zoughby interview).

Attitudes towards intellectual property (IP)

While innovation-ownership disputes arise in some of the makerspaces studied (as seen in the preceding section), due to users fearing that others may seek to copy their ideas and resulting products, these disputes and fears do not result in efforts to secure formalised IP protection, e.g., patents. The issues seem clearly to be matters of competition and secrecy, rather than formal IP protection. This lack of focus on formalised IP would appear to have several causes.

First, many of the users of the makerspaces studied tend to be individuals at a very early stage of joining the maker movement, who are still seeking knowledge about self-manufacturing tools. Second, the types of innovations taking place in the makerspaces generally do not warrant the consideration of formalised IP protection, i.e., the innovations produced are often incremental innovations that do not lend themselves to formalised IP protection. Third, IP issues are not well understood by most of the makers using the spaces studied. And fourth, efforts to secure formalised IP would run counter to the prevailing open collaborative ethos of the spaces.

As pointed out by Omar El Safty, general manager of Fab Lab Egypt, the physical setup of makerspaces, with their shared spaces and tools, forces makers to work together and collaborate. IP considerations, in the words of El Safty, are a "hassle in the maker community globally", leading to largely unnecessary debates regarding the benefits of open source approaches to innovation versus proprietary (i.e., IP-based) approaches. His experience is that makers usually do not like the idea of patents and other proprietary protection measures, and resort to protection only when a legal consultant advises them that this is the best option for their product. According to El Safty, out of the 15 start-ups that, at the time of our research, had businesses

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connected to their work at Fab Lab Egypt, only three had applied for patents for their innovations (El Safty interview).

Karakeeb Makerspace supports the open source ethos and tries to steer makers away from proprietary thinking (Effat and Hassan interview). icealex advocates for an open source culture, where everyone learns from each other and collaboration is key (Bastawy interview). At FabLab ENIT, users are all university students and innovation is not viewed as a competitive, business-oriented pursuit. This translates into a willingness by the student makers to share their models and work on an open source basis (Ben Rejeb interview).

Scaling

For some interviewees, scaling was seen as a necessary stage and an opportunity for entrepreneurs wishing to grow their businesses and penetrate markets based on their innovations. Other interviewees emphasised the fact that scaling's opportunities also come with associated risks, and that makers need to be wary of these risks before seeking to scale up.[1]

Fab Lab Egypt general manager El Safty believes that scaling of innovation represents both an opportunity and a threat for nascent entrepreneurs. Scaling is an opportunity for growth, and it is a desirable outcome from a business point of view. Nevertheless, many makers delve into projects too quickly without conducting the needed feasibility studies for scaling their innovations. This results in a growth rate that is not supported by the maker's capabilities and is potentially threatening to the entire project. Thus, "scaling is a double-edged sword that you must take step by step" (El Safty interview). To the extent that it is pursued, the key to scaling, according to El Safty, "is working on the horizontal by giving every maker the same attention, and not just makers who have products that we think are marketable or profitable" (El Safty interview).

FLiNC's manager El Raffei feels that scaling can be a threat because it requires additional sets of skills that are often beyond the capabilities of the founders of a start-up. Nevertheless, FLiNC does host workshops to promote the scaling of products (El Raffei interview).

Karakeeb Makerspace's Effat and Hassan argue that the key to scaling is not to focus on only one product. Instead, it is important to be involved in many innovative initiatives at the same time. The space sees its role as providing the necessary technical assistance and know-how. At the same time, at Karakeeb there are makers who primarily seek to create for the enjoyment and satisfaction of it, and who do not wish

1 For an in-depth treatment of approaches to innovation-scaling by makerspaces and other knowledge-based enterprises in African settings, see Open AIR (2020), *Scaling Innovation: How Open Collaborative Models Help Scale African Knowledge-Based Enterprises*.

to burden themselves with thinking about scaling an innovation and establishing a business (Effat and Hassan interview).

icealex co-founder Bastawy sees scaling as a key and desirable outcome for makers working with products. icealex's aforementioned use of human-centred design methodology seeks, among other things, to enhance the potential for scalability. icealex seeks to encourage scaling by connecting its makers to the demand side of the market, where they can provide their innovations as meaningful solutions to existing challenges. For example, when the importing of Ramadan lanterns was restricted in Egypt, icealex makers produced them on a medium-scale, thereby filling a market gap during that season (Bastawy interview).

Fablab Casablanca's directors Abouch and Kouska believe scaling is a desirable outcome and, accordingly, their space aims to support makers in formalising and growing their innovations. The lab regularly informs its makers of competitions that can allow them to share their prototypes and to grow into enterprises. The role of the makerspace is to ensure that makers create a high-quality product or innovation on a small scale that will later enable the maker, if the maker so chooses, to scale the innovation independently of Fablab Casablanca (Abouch and Kouska interview).

Alex Hackerspace co-founder El Shaer views scaling as an opportunity for nascent entrepreneurs, but warns that scaling is not always desirable (El Shaer interview). The space's aforementioned purchase of MOOC access for its makers included MOOC content on the skills needed for entrepreneurship and scaling-up businesses, to ensure sustainable knowledge-sharing and scalability, according to the Alex Hackerspace co-founder (El Shaer interview).

At the time of our research, LEVEL1 Tunisia had not yet reached the stage where its makers were tackling the issue of scalability. However, co-founder Bouslama said that while he acknowledges that every business opportunity includes risks, he believes that scaling is an important opportunity for makers. A main aim of LEVEL1 is to provide a space where makers can develop their innovations to a point where they become more suited for entry into the market (Bouslama interview).

FabLab AUC co-founders Shalaby and Ragab see their makerspace as primarily seeking to aid makers in creating prototypes, without having a significant role to play in relation to scaling. Additionally, they were of the view that Egyptian entrepreneurs tend not to have a strong orientation towards scaling (Shalaby and Ragab interview).

FabLab ENIT Director Ben Rejeb believes that scaling is a great opportunity, and is usually the ultimate goal for nascent entrepreneurs. Accordingly, ENIT seeks to provide makers with the opportunity to test and develop their products to the point where they can enter the market. ENIT also aims to create more funding opportu-

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nities for innovation, such as via investment opportunities and crowd-funding (Ben Rejeb interview).

The Qafeer Makerspace Director felt that scaling was an opportunity and always a desirable outcome for nascent entrepreneurs. However, in the case of makers at Qafeer, scaling of an enterprise needed to be achieved through connections external to the makerspace. In cases where the scaling of an innovation from Qafeer led to the formalisation of an enterprise, the makers went beyond the makerspace to start-up accelerators in order to get the help they needed to establish their formal businesses (El Zoughby interview).

In terms of scaling the work of the makerspaces themselves, Fab Lab Egypt offers its paid B2B services in an effort to find a balance between having a community-based makerspace that is affordable for makers and at the same time scaling-up via an external source of revenue that does not affect the essence of the space (El Safty interview). A key scaling risk for a makerspace is, of course, that it may, in seeking scale, take on additional functions and obligations too rapidly, thus placing strain on already-stretched financial resources. Indeed, most of the spaces spoke of the need to access more funding. And, as mentioned above, one of the spaces studied, Qafeer Makerspace, closed down in 2019 due to financial difficulties.

Fab Lab Egypt also seeks to scale the national presence of the maker movement, through its FabLab on Wheels initiative, to which FLiNC also contributes. At the time of our research, FLoW had toured three Egyptian governorates, and was planning future visits to two more (El Raffei interview). The Alex Hackerspace interviewee also had a vision for scaling the Egyptian maker movement as a whole, calling for more support for existing makerspaces and for the introduction of the concept of making within formal educational structures (El Shaer interview).

5. Conclusions

It is clear from the findings generated by this study that the maker movement has significant momentum in Egypt, Tunisia, and Morocco. The movement has taken root in a relatively short period of time, in tandem with the changes in the region set off by the Arab Spring from 2011 onwards. There is clear evidence, based on the 10 makerspaces investigated, of dynamic approaches to knowledge-sharing, innovation, and scaling, all of which augur well for strengthening the spaces' communities of practice. At the same time, there is still a degree of fragility in the movement, with most of the spaces that we studied citing inadequate funding, and with one of the spaces, Qafeer Makerspace, closing down due to financial difficulties.

It is likely that the future sustainability of the makerspaces in Egypt, Tunisia, and Morocco will be reliant, to a great extent, on their ability to continue providing

dynamic knowledge-sharing opportunities for users, via the continued offering of dynamic mixes of informal and formal learning opportunities of the kind outlined above in the research findings. Makerspaces across the countries under study have the potential to act as a bridge, connecting knowledge creation with entrepreneurship, for many young graduates of secondary or tertiary education as they confront the gap between what is taught in a classroom and what is needed in the job market—in line with the perspective of Van Holm (2017).

A second core element of the spaces' sustainability is likely to be their ability to evolve into increasingly vibrant hubs for social innovations that can be spun off, at or beyond the makerspaces, into job-creating enterprises. Our research findings found clear evidence of social innovation work at some of the spaces studied—e.g., at icealex (the portable Risha Laser Cutter, the water purification filter), at Karakeeb Makerspace (the emergency lamp powered by discarded mobile phones, the smart trash bin), and at Fab Lab Egypt (the 3D-printed artificial limb). These kinds of innovations likely hold the greatest promise for the makerspaces in their roles as prototyping, pre-incubation spaces for aspirant entrepreneurs.

Finally, there is a need for continued research into the dynamics and activities of makerspaces in Egypt, Tunisia, and Morocco. Among the makerspaces examined, it is clear that there is a diversity of approaches and models emerging, all of which require further investigation. In particular, further research will be needed in order to shed better light on linkages between makerspaces and entrepreneurship, and on the roles makerspaces can play in influencing socio-economic development. We have seen in the findings presented in this article that makerspaces are highly dynamic entities, and the Egyptian, Tunisian, and Moroccan maker movements can be expected to evolve in myriad ways, in the years and decades to come, that will offer insights and lessons that can help inform policy and practice in the North African region and elsewhere in Africa and the Global South.

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Appendix: Interview Protocol: Semi-Structured Questions

1. About the makerspace (for makerspace director/staff)

a. When did you first hear of the concept of a makerspace?

b When was this makerspace established?

c. Tell us about the model that this makerspace follows.

d. Was this makerspace built from scratch, or is it upgraded from a previous older space (like a library)?

e. Where any of the tools you purchased brand new? Or are they mostly refurbished unused products?

f. Did you receive financial support in purchasing these tools? If yes, from who? And how long will the support last?

g. Are there any charges incurred on the makers to cover costs, like using a 3D printer?

h. What is the gender ratio in your makerspace?

i. How is maintenance and repairs performed on certain tools within that makerspace? Is it done via a professional service or by makerspaces?

j. Do you collaborate with other makerspaces, locally or globally? If yes, how?

k. How are (can) linkages across informal enterprises (be) stimulated in various contexts?

2. Creative processes and knowledge-sharing (for makerspace director/staff)

a. What type of innovation takes place in this makerspace?

b. What type of learning occurs in this makerspace?

c. What type of skills (if any) are introduced to the makers?

d. Among those that attend and use the makerspace, do any of them learn skills that help them find employment later on?

e. If there are people working in groups, do they learn from each other? Or do they learn from a teacher or mentor?

f. What is the group size of people working on a single project?

g. How can makerspaces help attract new potential entrepreneurs?

h. Are there any specific examples or cases where a product was created to solve a specific problem in your area?

i. Do people drop in at the last minute, or do they plan to come?

3. IP and informality

a. What, if any, are the specific IP-related solutions and unique challenges for scaling up informal businesses?

b. Have there been any social issues or arguments between makers regarding ownership? If so, how were they resolved? Were these issues resolved legally or through arbitration?

c. What rules govern the relationship between informal businesses and formal counterparts if and when they decide to engage?

d. Which online portals do you go to, to find 3D models to download?

e. Does the space play a role in deciding who owns specific inventions created there? Or is there no monitoring of the process?

f. Is there any assisted legal process for makers who wish to implement copyright their inventions?

4. Scalability

a. Does scaling of innovation represent an opportunity or a threat for nascent entrepreneurs, and how can makerspaces play a part in ensuring sustainable access to knowledge for all?

b. Is scalability a desirable outcome?

c. In cases where scalability leads to formalisation, are we dealing with the formalisation of the innovation itself or the formalisation of the "informal" entity?

d. How can we upscale informal innovation in a way that creates more informal innovation—"scaling out"?

e. Were there any products that were produced, which were eventually manufactured?

5. Measuring innovation

a. How can the innovation taking place in makerspace contexts be better accounted for and documented?

b. How can we measure the creative output of the maker and the informal entrepreneur?

c. Investigating specifically knowledge creation within the sphere of the maker, the informal entrepreneur and the formal entrepreneur: can we assess the openness of innovation? How?

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Social Entrepreneurs' Use of Fab Labs and 3D Printing in South Africa and Kenya

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Abstract
This article outlines findings from a study in South Africa and Kenya that explored social entrepreneurs' use of fabrication laboratories (fab labs), and in particular fab lab 3D printing services, in order to advance their social innovations and enterprises. Based on interviews with representatives of fab lab initiatives and social enterprises, the study found strong linkages between social entrepreneurship and fab labs, and between social entrepreneurs and the use of 3D printing technology. However, it was also found that social entrepreneurs tend not to rely primarily on fab labs for access to 3D printers, preferring to buy and build their own printer units—a practice made cost-effective through the selection of low-cost, open source models. In respect of the computer-aided design (CAD) software used to design the files for 3D printing, it was found that social entrepreneurs prefer the stability and user-friendliness of proprietary CAD software, despite the cost implications. At the same time, it was found that social entrepreneurs frequently use free and open source CAD files available online, and that they seek, in turn, to share their designs on a free and open source basis.

Keywords
social entrepreneurship, social innovation, informal sector innovation, social enterprises, fabrication laboratories (fab labs), additive manufacturing, computer-aided design (CAD), 3D printing, collaboration, knowledge-sharing, knowledge appropriation, knowledge governance, maker movement, scalability, intellectual property (IP), openness, open source, high technology hubs, South Africa, Kenya

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Acknowledgements
The research for this article was carried out under the auspices of the Open African Innovation Research (Open AIR) network, which is a partnership between the University of Cape Town, the University of Johannesburg, The American University in Cairo, the Nigerian Institute of Advanced Legal Studies, Strathmore University in Nairobi, and the University of Ottawa. We acknowledge the support provided for this research by 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. This article draws on elements of a working paper (Schonwetter & Van Wiele, 2018).

DOI: https://doi.org/10.23962/10539/30356

Recommended citation
Schonwetter, T., & Van Wiele, B. (2020). Social entrepreneurs' use of fab labs and 3D printing in South Africa and Kenya. *The African Journal of Information and Communication (AJIC), 26*, 1-24. https://doi.org/10.23962/10539/30356

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1. Introduction

3D printing technology has been touted as revolutionising manufacturing and entrepreneurship, and, in African contexts, serving as a tool to help African nations, inter alia, overcome their "resource curse" (Mathers, 2015; Ortolani & Di Bella, 2014) and "leapfrog" the industrial revolution (Jacobs, 2015; Mungai, 2015). One potentially vibrant field of application for 3D printing in Africa is the work of social entrepreneurs, i.e., application in support of those focusing their efforts on achieving positive societal impacts through enterprises targeting pressing social, economic, environmental, or cultural problems. According to one report, 3D printing in developing-world countries "could enable locally designed solutions for local problems, potentially bringing large benefits to these economies" (WIPO, 2015, p. 98).

In an effort to shed light on the degree to which 3D printing is relevant to the work and business models of social entrepreneurs in African settings, we conducted this study focusing on two modes of 3D printer access currently present in South Africa and Kenya: via fabrication laboratories (fab labs), and via the use of low-cost, locally made 3D printers. Our core data collection consisted of interviews with

representatives of fab lab initiatives and social enterprises. The selection of South Africa and Kenya was based on the fact that these two countries are widely regarded as two of the Sub-Saharan African countries that are furthest down the road in terms of 3D printing initiatives. It is hoped that our findings, as presented in this article, represent a useful contribution to the emerging bodies of literature on the maker movement (of which fab labs are a part) and social entrepreneurship in African settings. While the study did not seek to develop new, or challenge existing, concepts of social innovation and social entrepreneurship on the continent, it was grounded in a recognition of the important roles they play on the continent.

2. Research context

Social entrepreneurship

According to Rivera-Santos et al. (2015),

> [t]he 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)

These observations concerning the links between social challenges and entrepreneurship in African countries form an important conceptual bedrock for this study. Even though social entrepreneurship is still a relatively new phenomenon in the available literature, there are already myriad existing definitions and conceptions of social entrepreneurship. Many of the initial definitions have been summarised and outlined by Abu-Saifan (2012) and Mair and Noboa (2003). Newer conceptions, found in Barnard (2019), Brindle and Layton (2017), Maseno and Wanyoike (2020), Nwuneli (2016), and Oriakhogba (2020), are particularly relevant to this study. These conceptions recognise the links between social challenges and entrepreneurship as observed by Rivera-Santos et al. (2015), and add valuable nuance through bridging the fields of social entrepreneurship and development, and emphasising the importance of context and local dynamics. Building on these nuanced frameworks, and at the same time recognising the limitations of one-size-fits-all definitions, we sought to adopt our own broad yet context-specific and development-oriented definition of social entrepreneurship to guide our identification of relevant enterprises and products.

In our definition, social entrepreneurs are: *entrepreneurs who are primarily interested in achieving positive societal impacts through developing market-oriented innovative solutions to address (local) social needs and to solve pressing social, economic, environmental, or cultural problems.* This definition draws on commonalities across the key definitions as compiled by Abu-Saifan (2012) and Mair and Noboa (2003),

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and also echoes elements concerning development and local contexts as suggested by Maseno and Wanyoike (2020), Barnard (2019) and Oriakhogba (2020). It is important to acknowledge, however, that social entrepreneurs' focus on social return does not preclude them 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 them apart from narrower non-profit projects.

3D printing

3D printing, also known as additive manufacturing, refers to a class of technologies that physically construct objects by consecutively adding layers of material based on computer-aided design (CAD) files. These technologies allow for localised, decentralised production of myriad 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 also manufacturing knowledge and CAD 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.

In this study, we focused on the most common and recognisable form of 3D printing: material extrusion, which 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, its use of low-cost materials (commonly plastics), and its speed of production make it a preferred type of manufacturing for rapid prototyping and small-scale modelling or manufacturing (Lipson & Kurman, 2013, p. 68). Basic material extrusion printing techniques allow only 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. That being said, basic 3D printing can facilitate quick and increasingly cost-effective local production of much-needed goods, thus empowering local actors and reducing reliance on imports and industrial-scale supply/value chains.

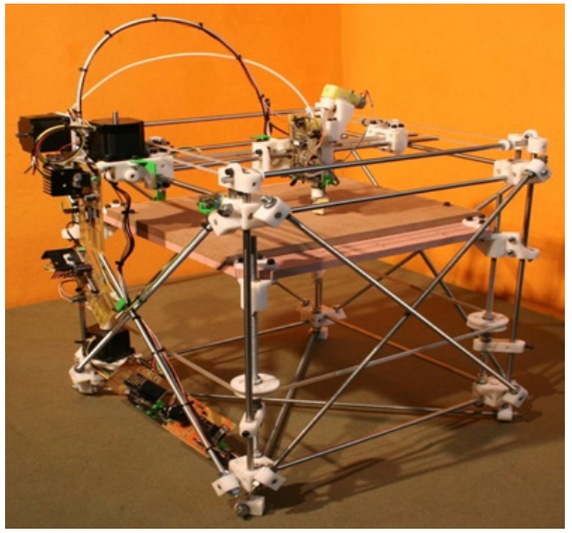
3D printing, social innovation and social entrepreneurship

Examples abound of 3D printing technology being used by social innovators and entrepreneurs for prototyping and end-product manufacturing in developing-world contexts, including African settings. Birtchnell and Hoyle (2014) demonstrate that 3D printing offers a wide range of applications that address social needs for users and communities in the developing world. The international 3D Printing for Development (3D4D) Challenge, in which entrants from around the Global South seek to

produce the most scalable grassroots community action project involving 3D printing, illustrates the technology's use in the production of objects that can empower people in the developing world (3D4D, n.d.). In African settings, extrusion printers have been used for the localised and customised production of, inter alia, prosthetic fingers, prosthetic hands ("robohands") and prosthetic legs (Bashir, 2016; MakerBot, 2013), weather stations (Freitag, 2015; Walker, 2016), and medical equipment (Clarke, 2017).

While commercial hardware producers play an important role in the 3D printer market, the rapid rise in consumer-level 3D printers is in part attributable to the emergence of various open source 3D printer initiatives (Tech et al., 2016). The open source character of these printers generally provides for free access to the underlying blueprints, combined with the permission for third parties to freely use and adapt the designs. One of the best-known open source printers is the RepRap (see Figure 1), a largely self-reproducing open source 3D printer that has gained wide popularity among communities of researchers, hobbyists, and hackers (RepRap, n.d.). RepRap printers use the materials extrusion printing process and are able to manufacture many of their own components (Jones et al., 2011). (The name RepRap is derived from the printer's ability to function as a "replicating rapid" prototyper.) Currently there are over 60 different RepRap designs available online for free, under open licences (General Public Licence (GPL) or Creative Commons), and there are localised African RepRap printer models, including the RepRap Morgan (Molitch-Hou, 2013; RepRap, n.d.) and the RoboBeast (Krassenstein, 2014; MakerBot, 2013).

Figure 1: The first version of the RepRap printer, the RepRap 1.0 Darwin, developed in 2008



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

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Fab labs

Several studies have looked at the work of fab labs as part of the broader maker movement in Africa (Armstrong et al., 2018; De Beer et al., 2017; ElHoussamy & Rizk, 2018; Kraemer-Mbula & Armstrong, 2017). Fab labs, as with makerspaces, hacklabs, tinker spaces, and other maker movement entities, typically offer to the public a range of digital fabrication tools, including 3D printers. In addition, they typically aim to create environments that facilitate innovative activity, entrepreneurship, and peer-to-peer learning.

The first fab lab was established in the early 2000s, in the US, at the Massachusetts Institute of Technology (MIT) as part of the outreach component of its Center for Bits and Atoms (CBA). Today, there are more than 1,700 fab labs around the world, in more than 100 countries (Fab Foundation, n.d.a). To officially qualify as an MIT-affiliated fab lab belonging to the MIT-established Fab Foundation, a lab must: (1) be open to the public (ideally free of charge); (2) support and subscribe to the Fab Charter; (3) provide a common set of tools and processes, based on the Fab Foundation's inventory; and (4) participate in the global fab lab network. According to the Fab Foundation, fab labs are "a global network of local labs, enabling invention by providing access to tools for digital fabrication" (CBA, 2012). According to the draft Fab Charter of 2012:

> 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)

The Fab Foundation has created an inventory of recommended hardware and materials to be deployed in a full fab lab. Fab lab core equipment typically includes 3D printers and a variety of cutting and milling machinery. The full list of recommended equipment is available on the Fab Foundation website (Fab Foundation, n.d.b). (It should be noted that there are many fab labs around the world that have adopted the fab lab name, or refer to themselves as fab labs, without joining the international Fab Foundation network. Thus, the term fab lab has taken on a generic meaning, and we use it in that way in this article.)

The fablabs.io website, which is the online social network of the international Fab Lab community, indicates that there are, as of mid-2020, fab lab initiatives in the following 24 African countries: Egypt, Libya, Tunisia, Morocco, Mauritania, Senegal, Mali, Burkina Faso, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, Chad, Cameroon, Democratic Republic of the Congo, Djibouti, Ethiopia, Kenya, Rwanda, Namibia, South Africa, Madagascar, and Réunion (Fablabs.io, n.d.).

3. Research design

Data collection and analysis

Our study was qualitative, based on contextual data collected via desk research and primary data collected via interviews. The desk research consisted of reviewing relevant literature and the websites and social media pages of fab labs and social entrepreneurs in South Africa and Kenya. We identified existing fab labs in each country based on their current or past use of "fab lab" and their names or missions, with key guidance provided by the international Fab Lab network's listing of labs (Fablabs.io, n.d.). We also included three of South Africa's eKasi Labs, all of which incorporate fab lab elements. The interviews, which were semi-structured and guided by an interview protocol, were with representatives of (1) fab lab initiatives providing access to 3D printing; and (2) social enterprises using 3D printing technology. The interviewees at fab lab initiatives comprised individuals involved in lab management. The interviewees from social enterprises were founders and, in one case, the person currently running the enterprise. Our data analysis consisted of qualitative coding and categorising the content of the interview transcripts.

Interview protocols

Fab lab initiatives

The interview protocol for the interviewees representing fab lab initiatives covered matters of the initiatives' funding, structure, user access, users, uses, use of 3D printing technology, efforts to grow the user base, internal collaboration and knowledge-sharing, knowledge appropriation, and scaling.

Social enterprises

The interview protocol for the interviewees representing social enterprises covered matters of the enterprises' origins, use of 3D printing technology, funding, internal collaboration and knowledge-sharing, knowledge appropriation, and scaling.

Interview subjects

The interviews consisted of:

- nine interviews with individuals in leadership positions at eight fab lab initiatives in South Africa and Kenya that provide access to 3D printing; and
- four interviewees with social enterprises in Kenya making use of 3D printers.

The eight fab lab initiatives from which interviewees were drawn are listed in Table 1.

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Table 1: Fab lab initiatives

Initiative	Year(s) of Establish-ment	Location(s)	URL
Bloemfontein FabLab Central University of Technology (CUT)	2006	Bloemfontein, Free State Province, South Africa	https://www.cut.ac.za/fablab
North West FabLab North-West University Potchefstroom Cam-pus	2007	Potchefstroom, North-West Province, South Africa	https://www.fablabs.io/labs/northwestuniversity
Sebokeng FabLab Vaal University of Technology (VUT) Southern Gauteng Science Park	2014	Sebokeng, next to Vander-bijlpark (60 km south of Johannes-burg)	https://www.vut.ac.za/fablab/
FabLab Nairobi University of Nairobi Upper Kabete Campus	2009	Nairobi	https://www.fablabs.io/labs/fablabnairobi
Limpopo FabLab University of Limpopo Turfloop Campus	2009	Turfloop, 32 km from Polokwane, Limpopo Prov-ince, South Africa	https://www.fablabs.io/labs/limpopofablab
Ekurhuleni FabLabs	2011–17	Thokoza, Tembisa, Tsakane, Duduza and Vosloorus Ekurhuleni Municipality (next to Johannesburg)	https://www.fablabs.io/labs/ekurhulenifablabs
CDI Product Support Space Craft and Design Institute (CDI)[1]	2006	Cape Town	https://www.thecdi.org.za/page/dev_product
eKasi Labs	2014–16	Lynnwood (Pretoria), Ga-Rankuwa (Pretoria North) and Soweto (Johan-nesburg)	https://www.facebook.com/ekasilabs/

1 The CDI Product Support Space includes the former Cape Town FabLab, which was launched in 2006 at the CDI (which at that time was called the Cape Craft and Design Institute (CCDI)).

The social enterprises from which interviewees were drawn are listed in Table 2.

Table 2: Social enterprises

Name	Year of Establishment	Location(s)	Products	URL
African Born 3D Printing (AB3D)	2015	Nairobi	Low-cost open-source 3D printers	https://www.ab3d.co.ke/
Happy Feet	2013	Nairobi	Customised shoes for individuals with foot deformities	https://3dprint.com/25587/happy-feet-3d-printed-shoes/
Artisan Hive	2016	Nairobi	Headlamps, micro-scopes	https://www.linkedin.com/pulse/artisan-hive-a-light-david-ismail/
Kijenzi (Med-Tech Kijenzi at the time of the research)	2014	Multiple locations, Kenya	Medical equip-ment	https://www.kijenzi.com/

4. Background: The fab lab initiatives and social enterprises studied

The fab lab initiatives

University-driven fab lab initiatives

Bloemfontein FabLab and North West FabLab are both located on university campuses in urban environments. Bloemfontein FabLab, in the city of Bloemfontein, is located on the premises of the Central University of Technology (CUT). North West FabLab, in the city of Potchefstroom, is on the campus of North-West University, hosted by the Engineering Faculty. Both labs were initially established and funded by the South African Department of Science and Technology (DST), with funding later taken over by the universities.

Sebokeng FabLab, which is part of the Vaal University of Technology (VUT), is in fact not located on the VUT's main campus in the city of Vanderbijlpark. The lab is in VUT's Southern Gauteng Science and Technology Park, in the township of Sebokeng next to Vanderbijlpark. [2]

2 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.)

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FabLab Nairobi is part of the University of Nairobi's Science and Technology Park, on the university's Upper Kabete Campus. It was initially on the university's City Campus, established with funding from the Ministry of Science and Technology, before the university took over the funding and moved it to Upper Kabete. In addition to its day-to-day funding by the university, the lab raises its own funds through providing services, including on-demand design and fabrication, and facilitating projects.

University/government-driven fab lab initiative

Limpopo FabLab is located at the Science Education Centre on the University of Limpopo's main campus in Turfloop, a township next to the city of Polokwane. Although physically located at the university, Limpopo FabLab is not run by the university. Its funding is provided by the university and by the Limpopo Province Department of Economic Development. Like the Bloemfontein and North West FabLabs, the Limpopo FabLab was originally established by the national government's DST.

Government-driven fab lab initiatives

The Ekurhuleni FabLabs initiative, funded and run by the Ekurhuleni Metropolitan Municipality next to Johannesburg, consists of five fab labs, in the Thokoza, Tembisa, Tsakane, Duduza, and Vosloorus townships.

The CDI Product Support Space is part of Cape Town's Craft and Design Institute (CDI) (formerly known as the Cape Craft and Design Institute (CCDI)). The CDI is a non-profit company funded by the City of Cape Town, the Western Cape Government, national government, and other supporters. The Product Support Space incorporates the equipment that was used by Cape Town FabLab before that lab's functions were taken over by the Product Support Space.

The eKasi Labs initiative is run by the Gauteng Province's Innovation Hub in Lynnwood, next to Pretoria. The three eKasi Labs we focused on, because they all incorporate fab lab elements, were the main eKasi Lab hub at the Innovation Hub, and eKasi Labs Ga-Rankuwa (in Ga-Rankuwa, 37 km north-west of Pretoria), and eKasi Lab Soweto (next to Johannesburg). The eKasi Labs, primarily funded and run by the Gauteng Government, are co-creation and innovation spaces linked to the Innovation Hub's enterprise incubation and commercialisation programmes.

Fab lab users

We found that fab labs are being used by a variety of different user groups, including entrepreneurs (among them social entrepreneurs), makers, hobbyists, high school learners, university students, and the general public. In the case of the CDI Product Support Space, users also include craft producers and designers. Two initiatives in

particular, eKasi Labs and the CDI Product Support Space, are primarily used by entrepreneurs, including social entrepreneurs. The four labs driven by universities—Bloemfontein FabLab, North West FabLab, Sebokeng FabLab, and FabLab Nairobi—are predominantly used by students from their respective universities. There is also some use of these fab labs by secondary and/or tertiary educational institutions. For instance, some of Bloemfontein FabLab's users are students from a nearby high school and from the University of the Free State. The majority of the fab lab initiatives studied—all except Sebokeng FabLab and Ekurhuleni FabLabs—reported that they are predominantly used by males. The majority of users across all of the fab labs are aged 35 or younger. In the case of Ekurhuleni FabLabs, the majority of users are schoolchildren between the ages of six and 16.

The social enterprises

Our first point of contact in Kenya's social entrepreneurship sector was the aforementioned African Born 3D Printing (AB3D) enterprise, a manufacturer of low-cost, open source 3D printers. We then became aware of three additional social enterprises in Nairobi that use low-cost 3D printing technology, specifically printers derived from the aforementioned RepRap model.

AB3D

AB3D designs, produces, and sells 3D printers that are made from electronic waste and locally available materials and sell for 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 e-waste 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 printing services, education, and training, all based on 3D printers. Both of AB3D's co-founders, Roy Ombatti and Karl Heinz Tondo, are long-standing social innovators.

Happy Feet

AB3D's co-founder Ombatti's intensive immersion in the use of 3D printing has come about through his work on the Happy Feet social enterprise. Happy Feet uses 3D printers to manufacture low-cost, customised shoes for people with deformed feet. Such deformities are the result of infestation by chigoe fleas (jiggers), an ailment that is particularly prevalent in Kenya's impoverished areas. The project emerged from the international 3D for Development Challenge (3D4D Challenge), in which the UK-based charity TechforTrade (n.d.) donated a 3D printer to FabLab Nairobi and invited its users to submit ideas. Having volunteered with an NGO in the field of sand flea infestation, Ombatti decided, for the 3D4D Challenge, to create the prototype for the aforementioned customised shoe. Working with colleagues at FabLab Nairobi, he developed the Happy Feet prototype, which was a finalist in the 3D4D Challenge (Goehrke, 2014).

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Artisan Hive

AB3D's other co-founder, Tondo, founded Artisan Hive, which seeks to create designs and sustainable business models for 3D-printed social innovations that solve or mitigate problems in Kenyan communities. Artisan Hive has developed a 3D-printed headlamp made from locally available components, which aims to solve the problem of insufficient lighting for local fishermen working in morning or evening darkness. In the future, Artisan Hive aims to train and equip local fishermen so that they themselves can produce and sell the product at a profit. Artisan Hive also 3D-prints microscopes. It does its 3D printing, with low-cost 3D printers that it owns, at FabLab Nairobi. Its eventual goal is to set up community-based 3D printing kiosks to bring additive manufacturing to new potential users. Through education and training in 3D printing, Artisan Hive also aims to have "foot soldiers" who can go to communities to solve everyday problems.

Kijenzi

The Kijenzi project (known as "MedTech Kijenzi" at the time of the data collection) is using 3D printing to help mitigate equipment supply shortages faced by rural medical facilities in Kenya. The project also aims to train clinic personnel in the use of 3D printing technology so that they can engage in equipment replacement more efficiently and independently. The project started in 2014, and the project team comprises professors, engineers, students, and makers. In its initial phase, the project assessed eight hospitals in Kenya to establish which items were in store, which needed replacement, or which were difficult to obtain. Thereafter, the team established to what extent these items could be produced locally by using 3D printing technology. Examples of products it prints include an aperture adjustment knob, a blood pressure cuff tubing coupler, a finger clamp pulse oximeter, and an incubator door hatch (Kijenzi, n.d.).

5. Findings

We now present findings in terms of five of the most prominent themes identified in the interview data, as follows:

- fab lab accessibility for users;
- social entrepreneurs' use of fab labs and 3D printers;
- 3D printing hardware and software;
- knowledge-sharing and knowledge appropriation; and
- approaches to scaling.

Fab lab accessibility for users

In the interview data, we were able to establish three main factors that play a role in determining the lab's degree of accessibility to users seeking to make use of 3D printers: openness to the general public, fees, and location.

Openness to general public

We found that all but one of the fab lab initiatives are open for use by the general public. The exception is the eKasi Labs initiative, whose labs in Lynnwood, Ga-Rankuwa and Soweto are open only to those who are part of the eKasi incubator programme based at the Innovation Hub. However, we found that the eKasi labs were considering opening their doors to the general public in the future.

Fees

FabLab Nairobi charges fees on a case-by-case basis, with individual users typically charged a membership fee, except when the use is for mere experimentation purposes, provided the production work is not extensive. Start-ups and established companies are charged fees, including membership fees and additional fees based on their individual requirements. None of the South African fab lab initiatives studied charges general membership fees for all users. Limpopo FabLab charges a small fee to students using the lab as part of their coursework. Bloemfontein FabLab, North West FabLab, and Sebokeng FabLab charge their users for machine time and materials used. Limpopo FabLab charges fees to users who exceed an allocated maximum amount of use. The labs' charges are generally set at low levels, aimed at covering operating costs. But even small fees can present an access barrier for some (potential) users. As one interviewee put it:

> [...] you've got a lot of people coming from streets, and you've 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. […] these people are coming to you to acquire skills and they don't have funding.

Location

We found that location is a potential barrier for accessing fab labs, with three factors playing key roles: availability of transport to and from the lab, physical barriers to access at labs located at universities, and bias. Representatives from fab labs located in urban areas indicated that transport to and from the lab can be a major problem for those who reside outside these urban areas. Similarly, an interviewee from Limpopo FabLab reported that its location in the Turfloop township near Polokwane presents an access barrier for users from rural areas. An interviewee from North West FabLab, located at North-West University's Potchefstroom campus, shared with us their perception that people from the community often find it cumbersome and difficult to access university premises.

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Similarly, FabLab Nairobi interviewees raised the concern that the fab lab's location on a university campus might negatively affect the use of these facilities by the general public. It was pointed out that those who are not affiliated with university campuses are usually unfamiliar with, and in some cases intimidated by, the university's access procedures. Another concern raised was that FabLab Nairobi is now located at the Upper Kabete campus, which houses the College of Agriculture and Veterinary Sciences—yet the typical users of the fab lab are engineering students. (The fab lab was initially housed in the School of Engineering on the University of Nairobi's City Campus.) Engineering students might now be reluctant to commute to another campus, while those working or studying at the lab's current campus typically did not use the fab lab's facilities—at least not until now.

Several of the fab lab interviewees said that biases against a fab lab's location can also present an access barrier, e.g., biases based on assumptions about the lab's users and the lab's safety. For instance, interviewees from fab labs located in townships indicated that people from the adjacent cities do not typically use the labs, and that location bias probably plays a role in this. In the words of interviewee 4 from Ekurhuleni FabLabs, "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".

Social entrepreneurs' use of fab labs and 3D printers

Several of the fab labs—Limpopo FabLab, CDI Product Support Space, Bloemfontein FabLab, Ekurhuleni FabLabs, North West FabLab, Sebokeng FabLab, and FabLab Nairobi—indicated that their facilities are being used for social entrepreneurial activities. Notably, however, only North West FabLab and Limpopo FabLab in South Africa, and FabLab Nairobi in Kenya, have hosted 3D printing work by social entrepreneurs. At North West FabLab, 3D-printed components have been combined with plexiglass in order to create scale models of potential adaptations to used shipping containers so that they can house toilets. At Limpopo FabLab, scale 3D models of toilets were used to pitch ideas to the municipality. FabLab Nairobi is the only fab lab that had, at the time of our research, seen end-product manufacturing of social entrepreneurial goods, via the work of the Artisan Hive project it houses. As described earlier, Artisan Hive uses the physical space of the Nairobi FabLab to run its own low-cost 3D printers.

In our interactions with social entrepreneurs in Kenya, we learned that while social entrepreneurs make only limited use of the fab labs and their 3D printers to carry out their social entrepreneurial activities, many do use the labs, or other makerspaces, to acquaint themselves with 3D printing technology. And, in some cases, fab labs play advisory roles for social enterprises, or serve as backup facilities when an enterprise's 3D printer breaks down.

While the link between social entrepreneurship and the use of fab labs to gain access to 3D printing technologies is, apparently, not as pronounced as we initially expected, we did find a close link between social entrepreneurship and the availability of affordable and openly accessible 3D printing technology. As described above, 3D printers are the primary manufacturing tool for Artisan Hive, which resorts to other means of manufacturing only if the production cannot be done with 3D printing. In the words of interviewee 11 of AB3D and Artisan Hive, 3D printing is "the easiest and cheapest way". In using 3D printing as the main production method, Artisan Hive is less dependent on supply chains, and the investment cost in a printer repays itself in a short time period. For instance, with respect to the Artisan Hive's plan to support local fishermen to produce and use 3D-printed headlamps, an initial investment by the fishermen in two low-cost 3D printers could potentially repay itself in a month. Similarly, according to interviewee 8 of AB3D and Happy Feet:

> 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. 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.

3D printing hardware and software

Hardware

All of the fab labs studied have at least one proprietary material extrusion 3D printer. The CDI Product Support Space in Cape Town had, at the time of the research, four such printers, and Sebokeng FabLab had eight. The high number of 3D printers available at Sebokeng FabLab is due to the fact that the lab has links to its university's (VUT's) Idea to Product (I2P) initiative, situated in the same science park. North West FabLab also has an open source RepRap printer, and the 3D printers being used by Artisan Hive at FabLab Nairobi are all open source.

Software

Most of the fab labs provide access to both open source and proprietary software for generating the CAD file necessary for 3D printing. The majority (all but two) of the labs indicated a preference for proprietary CAD software, on the grounds of the software's apparent user-friendliness, conformity with industry standards, and absence of bugs. The two exceptions were the CDI Product Support Space and Limpopo FabLab, both of which mainly use—and encourage the use of—open source software, on the grounds that their users can get free copies for use outside the fab lab facilities. At the same time, both the CDI Product Support Space and Limpopo FabLab continue to also provide access to proprietary software at their labs.

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One lab, Sebokeng FabLab, employs a "use appropriate approach" (interviewee 5) when it comes to software. For introduction to, and training in, CAD software, the lab was, at the time of the research, using Autodesk 123Design, under a freemium licence (i.e., a licence allowing free use of basic features, with a fee required for access to the premium version with additional functionality). Students are able to get a two-year free licence for Autodesk 123D when registering on the Autodesk website. In addition, the lab provides access to Autodesk Fusion 360. The lab also delivers commissioned work for clients through the use of more expensive proprietary software such as Solidworks and Solid Edge.

We found that the social entrepreneurs interviewed generally prefer and use proprietary CAD software, due to its perceived ease of use and reliability.

Knowledge-sharing and knowledge appropriation

We found that while all the fab labs offer some kind of formalised training—typically through seminars, workshops, and one-one-one training—informal peer-to-peer learning also plays a critical role. All fab labs encourage peer-to-peer learning, where users teach one another how to improve designs and use machinery. For instance, while the participants in the eKasi programme received training on the machines at the beginning of each programme, users who join after a programme has begun need to catch up, and that knowledge gap is filled through peer learning from more experienced users. Another example is Limpopo FabLab, which has a tutoring system in place whereby experienced users teach and assist new users.

Most fab lab interviewees reported that issues around formalised knowledge appropriation—e.g., in the form of a proposed non-disclosure agreement (NDA) or a desire to secure intellectual property (IP) rights—arise regularly. Most of the labs have been asked by a user to sign an NDA or a memorandum of understanding (MOU). The labs have differing approaches to handling such requests.

The CDI Product Support Space does not sign NDAs, on the grounds that the space is an open access facility where non-disclosure cannot be guaranteed. Bloemfontein FabLab provides and uses a standardised NDA form. The eKasi Labs programme offers its users consultations with the Innovation Hub's legal advisors on IP matters. Sebokeng FabLab refers users seeking IP protection to the university's (VUT's) Enterprise Development Unit. Users of FabLab Nairobi are given access to the University of Nairobi Intellectual Property Management Office. None of the fab labs asserts any claims on innovations resulting from the use of their facilities. The Ekurhuleni FabLabs initiative does, however, require express recognition if a product is developed using its facilities.

Interviewees at Limpopo FabLab and FabLab Nairobi stated that the sharing of ideas is essential for product development and market success, and that users who are reluctant to share typically do not successfully complete their projects. According to interviewee 6 of 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 […] moving forward.

In the words of interviewee 10 at FabLab Nairobi:

> 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 at FabLab Nairobi stated:

> It's the only way ideas are improved. But there's the culture [of] '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 fab labs, 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.

All four of the social entrepreneurial projects investigated are generally committed to the open sharing of their designs and other data. Kijenzi is dedicated to open source, and, at the time of the research, aimed to eventually share its data, printer, and object designs through open source licensing. At ABD3D and its spin-off projects, many of the designs produced are based on available open source designs. For instance, Artisan Hive's 3D-printed microscope is based on an open-licensed design by Richard Bowman from the Department of Physics at the University of Bath in the UK.

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According to interviewee 11 of AB3D and Artisan Hive:

> 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 [...]. On our website you […] have the files for anything we make. Anything we make is open source.

This said, Artisan Hive may consider looking into a formal form of IP protection at a later stage, once people have been widely exposed to their designs and creative efforts.

Interviewee 8 of AB3D and Happy Feet said that "it's ethical, to be fair and give back". And in the context of his work with AB3D, he is in favour of sharing ideas, and widely shares his technical knowledge through teaching and other activities. However, with respect to the Happy Feet project, he feels the need for some form of limit on the openness of the sharing. He would ideally like to have some form of formal IP protection in order to preserve the original vision for the project:

> It's less that others cannot copy, but more so that my initial vision [for] 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.

Approaches to scaling[3]

For the social entrepreneurs we interviewed, the issue of scaling is mainly perceived as being linked to becoming (more) sustainable, and increasing the impact of their work and products. For AB3D, scaling up will ideally include a broader offering. Interviewee 8 of AB3D and Happy Feet envisions developing an umbrella platform offering health care, educational, and agricultural hardware solutions. Such a platform would include alternative manufacturing methods to supplement current offerings, including the use of computer numerical control (CNC) machines such as laser cutters. AB3D would aim to build these machines themselves, making them low-cost. "That is my vision of scaling [for AB3D]: Touching more lives, but not just with one thing, […] with different things", interviewee 8 said.

For Artisan Hive, part of its future vision of scaling, if and when external funding becomes available, is a desire to make 3D printers, knowledge, and locally relevant

3 For an in-depth treatment of approaches to innovation-scaling by makerspaces and other knowledge-based enterprises in African settings, see Open AIR (2020), *Scaling Innovation: How Open Collaborative Models Help Scale African Knowledge-Based Enterprises*.

products more available in the remote areas of Kenya. (The project was, at the time of the research, exclusively funded by its founder, and external funding was considered essential for it to scale up.) In the short term, in the absence of external funding, Artisan Hive aims to make its projects more sustainable by offering training for a fee. At the same time, however, Artisan Hive is committed to keeping its designs open and free to access and use, as its core aim, in the words of interviewee 11, is "to inspire and create".

6. Analysis and conclusions

A number of notable dimensions, including some conflicts and contradictions, emerge from the research. A core finding is the social entrepreneurs' preference for open source 3D printers—because their speed and quality is often equal or superior to the performance of proprietary 3D printers. The fact that these printers can be more easily repaired locally, and thus cheaply, is also beneficial. And the designs the social entrepreneurs use tend to be free and open source CAD files created by third parties, with the social entrepreneurs publicly sharing back the designs they generate (or planning to share back in the future, in the case of Kijenzi), on a free and open source basis. However, the social entrepreneurs' preference for open source hardware and open approaches to using and sharing designs is coupled with a preference for using proprietary software when designing and producing CAD files. This preference for proprietary CAD software, even with its higher cost, is a result of its perceived greater user-friendliness and reliability. Thus, rather than opting for openness in all areas and at all costs, the social entrepreneurs also base their decisions on useability.

Another key finding is that while the fab labs studied do host numerous social entrepreneurs, most of these social entrepreneurs do not use 3D printers provided by the fab labs. The social entrepreneurs studied who need to use 3D printers are more likely to purchase or build their own. This can be explained by the fact that the social entrepreneurs in this study are utilising 3D printing not to prototype, but rather to execute the products that are core to their social enterprises. This type of manufacturing does not fit well with the core stated objectives of most fab labs, which are aimed at facilitating product development rather than large-scale production.

Where fab labs apparently do play a crucial role for the social entrepreneurs studied is in providing space for knowledge-sharing. Evidence was found of social entrepreneurs having previously worked in fab labs and other maker spaces, where they had gained 3D printing knowledge and developed the expertise necessary to run their enterprises and develop their products. This is in line with the notion that an open approach to sharing of ideas and knowledge is crucial to the value of these spaces. At the same time, however, some evidence was found of social entrepreneurs adopting protective approaches, within these labs, to their products. Thus, as with their software choices, the principle of openness is not absolute in social entrepreneurs' choices when making use of fab labs. This non-absolute adherence to openness also apparently extends

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to the studied social entrepreneurs' perceptions of the potential value of formalised intellectual property (IP) protections. While the social entrepreneurs appear to be, at present, prioritising social value over commodification, formal modes of IP protection may come more into play in the future, as the entrepreneurs explore available options for sustaining and scaling their businesses.

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Research interviews

Interviewee 1. Representative of CDI. Interviewed in-person, 23 February 2017.

Interviewee 2. Representative of North West FabLab. Interviewed via phone, 6 April 2017.

Interviewee 3. Representative of FabLab Bloemfontein. Interviewed via phone, 6 April 2017.

Interviewee 4. Representative of Ekurhuleni FabLabs. Interviewed via phone, 6 April 2017.

Interviewee 5. Representative of Sebokeng FabLab. Interviewed via Skype, 7 April 2017.

Interviewee 6. Representative of Limpopo FabLab. Interviewed via phone, 19 April 2017.

Interviewee 7. Representative of eKasi Labs. Interviewed via phone, 15 May 2017.

Interviewee 8. Representative of AB3D and Happy Feet. Interviewed in-person, 4 July 2017.

Interviewee 9. Representative of FabLab Nairobi. Interviewed in-person, 5 July 2017.

Interviewee 10. Representative of FabLab Nairobi. Interviewed in-person, 5 July 2017.

Interviewee 11. Representative of AB3D and Artisan Hive. Interviewed in-person, 5 July 2017.

Interviewee 12. Representative of eKasi Labs. Interviewed via phone, 12 July 2017.

Interviewee 13. Representative of MedTech Kijenzi. Interviewed via Skype, 30 August 2017.

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The African Journal of Information and Communication (AJIC)

Published by the LINK Centre
University of the Witwatersrand (Wits)
Johannesburg, South Africa
https://www.wits.ac.za/linkcentre

ISSN 2077-7213 (online version)
ISSN 2077-7205 (print version)

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