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SPECIAL ISSUE

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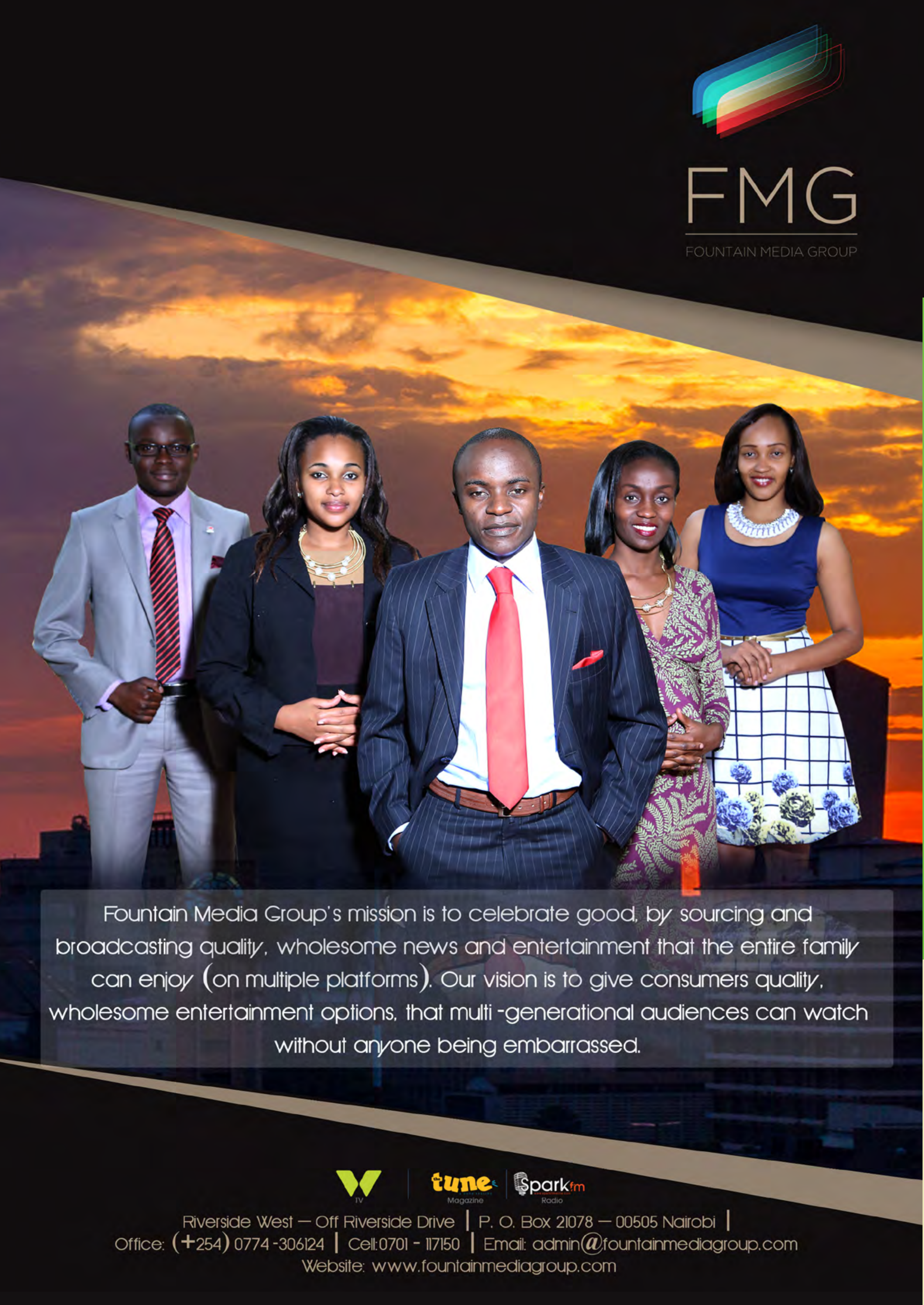

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The African Technopolitan is a biannual publication dedicated to the world of science, technology and development. It informs and provokes debate on critical issues in African development.

IN THIS ISSUE

3D PRINTING AFRICA'S DEVELOPMENT

Hailemichael Teshome Demissie, PhD, Senior Research Fellow, African Centre for Technology Studies (ACTS), Nairobi, Kenya.
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A common perception about emerging technologies in the context of developing countries can be captured by the 'sour grapes' argument – that such technologies are beneficial but unaffordable – a thinking represented in Aesop's fable of the hungry fox who cannot jump high enough to reach the hanging grapes and has to give itself the pretext that they are probably sour.

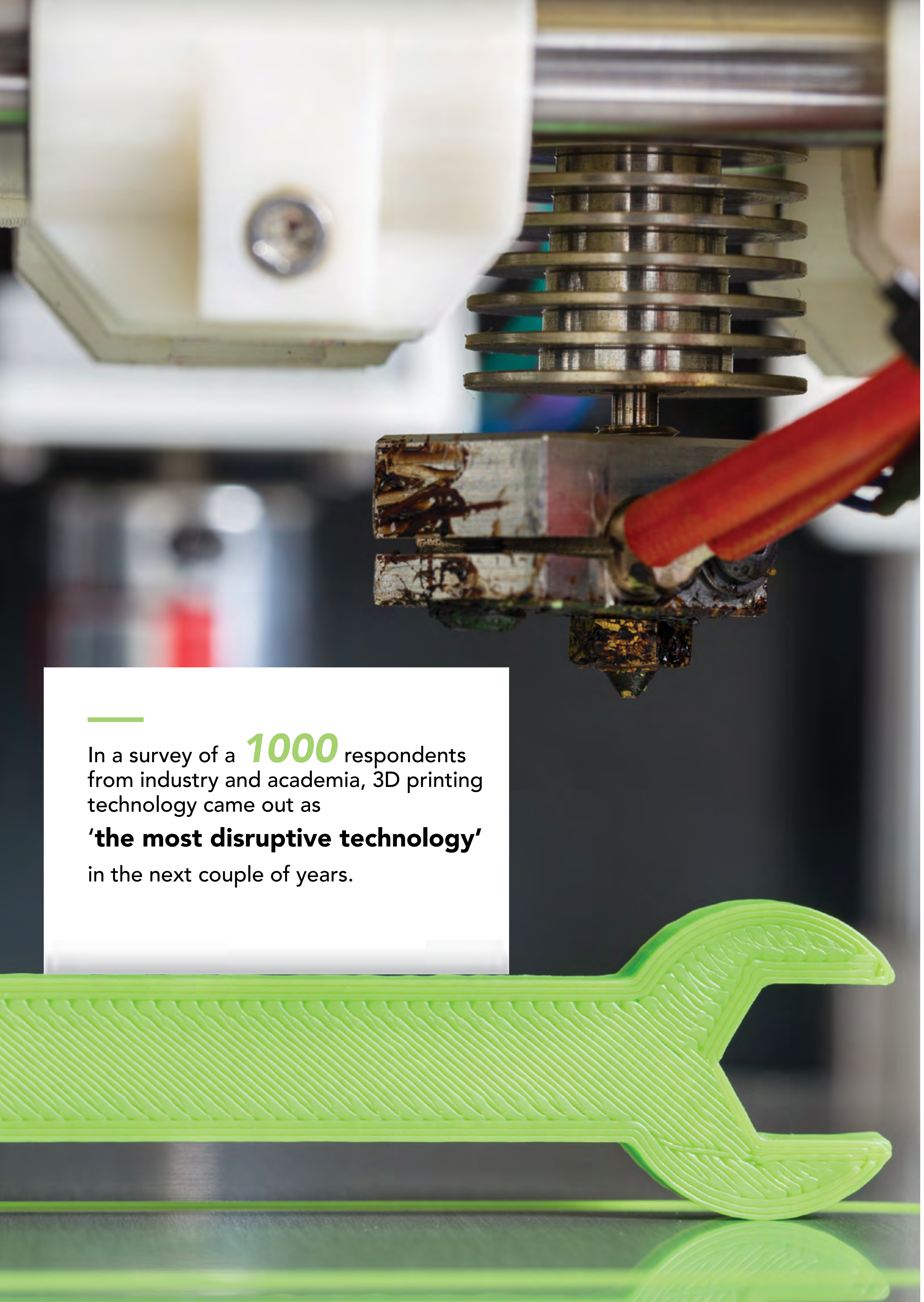
Hailemichael Teshome Demissie, PhD, Senior Research Fellow, Guest Editor to the Special Issue, African Centre for Technology Studies (ACTS) Nairobi, Kenya.

Some in developing countries often resort to the same reasoning that emerging technologies though revolutionary and beneficial as they may be are unaffordable for them and have to wait for years before they can adopt them. This line of thinking needs to be challenged as the reality suggests otherwise.

The adoption lag of technologies has drastically shrunk in recent times. It was once the case that technologies were adopted 45 years after their invention. This has come down to 3-4 years with recent technologies. The world wide release of technologies, as witnessed during the series of launches of Samsung and Apple products, is indicative of the speed at which technologies diffuse around the globe. This is true of 3D printers that are being released more and more as consumer products in ways similar to the release of Samsung or Apple phones.

It is the slow release of 3D printing technology that we are experiencing in Africa even though access to the latest version of 3D printers on the global market is open to Africa in the same way it is open to Europe or America. The story of its slow but audacious adoption is, however, interesting by itself. The world's first 3D printer to be made out of recycled e-waste was made in Africa by an African from the unlikeliest of places. What is more, this work won a NASA prize. Kodjo Afate Gnikou from Lome, Togo built the printer from parts he sourced from the scrapyard in Lome. His award winning project was a hit on the web and the global media - an event that threw the spotlight on African ingenuity and the little known nation of Togo. With his work and in his statements, Afate confronted and challenged the misconception about Africa being always the technologically laggard continent.

Afate's goal in building his 3D printer goes beyond Africa and the planet. He is aiming higher and he wants to make a 3D printer that will build houses and other structures on Mars. With the plan to send humans to Mars underway, his proposition is far from wishful thinking and it was acknowledged with the NASA prize he won. There is now a 3D printer in space and products bearing the 'Made in Space' label are already there. The staggering cost of shipping materials to space that currently stands at $20,000 per kilo simply kills off any idea about building a colony in space with materials transported from earth. It is innovative ideas like Afate's that sustain



In a survey of a **1000** respondents from industry and academia, 3D printing technology came out as

'the most disruptive technology'

in the next couple of years.

the idea of a space colony and the various projects designed around it.

3D printing technology is currently in use in a wide range of activities: From printed prosthetics for war amputees in South Sudan to preserving historical heritage with 3D scanning and printing replicas in Kenya and Nigeria, from 3D printing parts for Airbus planes in South Africa to printing villas in Egypt, the technology is making strides in Africa. However, it is still a far cry from the full utilisation of available capability in 3D printing technology let alone its adoption and mainstreaming in manufacturing. The examples of applications mentioned above are no more than indicators that the technology is here with us and readily accessible.

They are not meant to show that Africa is on the right track towards harnessing the potential benefits of the technology. Shifting gear and accelerating forward is what Africa needs if it is to avoid the cost of being left behind.

The disruptive power of 3D printing technology is perhaps the least contested issue. In a survey of a 1000 respondents from industry and academia, it came out as 'the most disruptive technology' in the next couple of years. Reports prepared by global firms like PwC, E&Y, KPMG and Deloitte have come up with a confirmation of the extraordinary disruptive potential of 3D printing. The report by E&Y regarding the disruptive impact of 3D Printing on government tax revenue is remarkable for its emphasis on the timeline of the development of 3D printing technology. In a report inelegantly yet informatively titled as *3D Printing Taxation Issues and Impacts: Technology is Turning the World Upside Down for Manufacturing and Distribution*, E&Y emphatically stress that now is the time to address 3D printing. They advise that *'now'* may well be the time to begin imagining a world upside down.' They point out that there may not be room for postponing the significant strategic and business process planning decisions for later. Their argument applies to companies and governments alike. Those decisions on how to manage the world that is turning upside down by 3D Printing have to be made now; as E&Y warn, 'it won't be easy to turn it right side up again'.

This special issue of the *African Technopolitan* is intended to convey the sense of urgency with which 3D Printing has to be approached in Africa. The contributors share a similar sense of urgency and take their own perspectives on how Africa should be best placed to harness the technology for its sustainable economic and social development. Highlighting the opportunities that 3D Printing offers in manufacturing, medicine and other fields, Dr Bitange Ndemo critiques the abiding anti-technological pessimism that 3D printing might remove jobs and put livelihoods at risk. He draws on the marvellous job young entrepreneurs in Nairobi are doing.

In the article dealing with the need for political leadership, Dr Cosmas Ochieng and Dr. Hailemichael Teshome Demissie discuss the precedent that President Barack Obama has set for other world leaders in terms of the top-down approach in supporting the development of 3D Printing technology for economic development. Prof Henry Thairu takes aim at the benefits that 3D Printing offers in the education system and the need to adopt the technology as a pedagogical tool at all levels. Prof Berhanu Abegaz and Dr Hailemichael Teshome Demissie examine the baffling intellectual property issues of 3D Printing taking a quick look back at how Africa has been negatively impacted by the global IP regime in relation to antiretroviral drugs for HIV/AIDS and the looting of its genetic resources through biopiracy.

Dr Thomas Woodson looks at 3D Printing in light of the concept of 'inclusive innovation' analysing the various stages where opportunities arise to make the technology inclusive. The contribution by Dr Carmelo De Maria, Licia Di Pietro and Arti Ahluwalia takes on the issue of inclusive innovation approaching it from the discourse on open innovations in biomedical engineering. The authors argue for the extension of the software Open Source model to hardware - an idea whose time has come with the advent of 3D Printing. Moses gichangA, an entrepreneur and innovator in the development of drones, shares his project on 3D Printed Drones - a case of the increasing trend of technological convergence and the critical role of 3D Printing in this convergence. Melissa Menke profiles the first Maker Space in Tanzania that has the vision of becoming Africa's leading maker space and transforming African society. The articles by Moses gichangA and Melissa Menke dispel doubts that the technology has yet to land in Africa. They remind us that a lot is happening in Africa around 3D Printing technology. Nurturing and sustaining these activities is a responsibility that has yet to be allocated to a higher number of stakeholders.

The African Centre for Technology Studies (ACTS) and Kenyatta University (KU) have assumed this responsibility and have entered into a partnership to establish a pan-African Centre for Excellence on 3D Printing. The contribution on the Centre introduces the proposed ACTS - KU African Centre for Excellence on 3D Printing with the backdrop of a review of the 'Centre of Excellence' model and the rise and proliferation of 3D Printing Centres of Excellence around the globe. The last contribution in this edition is a reprint of a widely received article published by the Scidev.net website and provides some policy recommendations for African countries to enable them accelerate the adoption and development of 3D printing. We hope readers will be stimulated to engage the technology in their own respective ways to deploy it for sustainable economic, social and environmental impacts in Africa.

3D PRINTING AND AFRICA'S MANUFACTURING RENAISSANCE

By Dr Bitange Ndemo, Associate professor, University of Nairobi

> "[3D Printing has] the potential to revolutionize the way we make almost everything."
>
> President Barack Obama

Photo by Steve Lagreca| Shutterstock

Local Motors Strati, a 3D-printed concept car, at The Gallery, an event sponsored by the North American International Auto Show (NAIAS) and the MGM Grand Detroit.

Did you know that in 1990 a novel project to manufacture motor vehicles in Kenya was abandoned due to the high cost of building five prototypes? Today new technologies such as 3D printing are making it possible to not only develop prototypes at a fraction of what it cost a few years ago but also provide us with the capacity to create more complex products than ever before.

The automotive industry is in fact among the earliest adopters of 3D printing technology initially using it for making prototypes but now increasingly for the production of end-use products or parts: Ford, GM, Audi, Jaguar and Land Rover have been using 3D Printing for a long time now. The savings on costs and time and on the parts count are enormous. The technology brings down the number of parts in cars from tens of thousands to under a hundred. Ford has been able to slash its production costs replacing its old production methods that used to take four months and cost $500,000 with 3D Printing that would cost $3000 and take just four days.

A US 3D printing company, Local Motors, has made a car, christened as Strati, with a fully 3D printed body and only with 49 parts. Local Motors is also offering its clients a walk-in service where they design the specifications of their car and have it printed in less than two days. It is for this reason that 3D printing is believed to be on track to revolutionize manufacturing in the emerging economies that embrace it.

3D printing is a type of industrial robotics. Sometimes referred to as additive manufacturing, it refers to the use of a computer to produce three-dimensional products of many shapes and forms. Well developed in the United States, Europe and Asia, this new technology is finding its way to Africa. In a recent Blog Post in the *Daily Nation*, I detailed how three University of Nairobi students, Roy Ombati, Karl Heinz and Wendy Banja started a new 3D printing startup, AB3D in Nairobi.

While in college the three students took interest in the Fab Lab at the University of Nairobi, a program started with a partnership from the Massachusetts Institute of Technology (MIT) and spearheaded by Dr. Kamau Gachigi. They partnered in a project supported by the Dutch non-governmental organisation, Hivos, dubbed "Happy Feet", which prints customized shoes for people with feet deformed by jiggers.

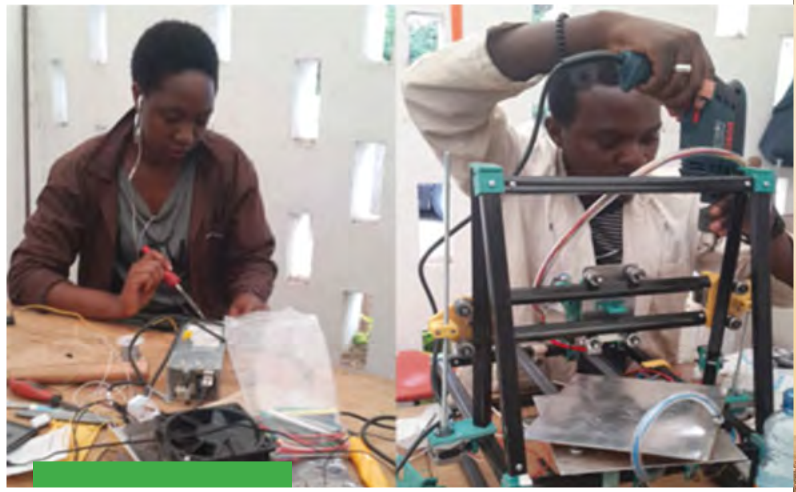
As demand for the service grew across Kenya, they aspired to scale up and take the printers nearer to the people most in need. They soon began manufacturing local 3D Printers instead of importing them. Today, they produce not just the printers but the materials (filament) required to run them and they are on track to be the main provider of all 3D printing services in the region.

The opportunity to manufacture products including dentures, prosthetics and spare parts with 3D printers is enormous. Already AB3D is producing parts for different types of products. A key challenge however remains in nurturing this nascent industry to enable it to scale, which requires investments for capacity building and sustained research and development (R&D). There is greater need now than ever before to develop strong tripartite relationships between universities, industry and government to revive the manufacturing industry and make way for the 3D printing revolution.

The need for 3D printing, especially in the medical field, is expected to increase exponentially. New research increasingly shows that 'stratified' or personalized medicine is the future. A May 2015 report from the Academy of Medical Sciences reported that "the terms 'stratified', 'personalised' or 'precision' medicine all refer to the grouping of patients based on risk of disease, or response to therapy, using diagnostic tests or techniques. This approach provides an opportunity for patients and healthcare providers to benefit from more targeted and effective treatments, potentially delivering more healthcare gain and improved efficiency for the healthcare system, while offering industry an expanded market for specialised treatments and the opportunity to benefit from the incremental value delivered by more effective products."

PHOTOS| BITANGE NDEMO

Wendy, myself, Roy and Karl



Wendy and Karl at work.

Lucas Mearian in an article in the March 2016 edition of *Computer World* entitled "3D printing makes an easier-to-swallow drug" states that the first 3D-printed drug to receive approval from the U.S. Food and Drug Administration (FDA) is now on its way to pharmacies. He notes that the 3D printing technology allows drug companies to better manipulate the composition of drugs compared to traditional press and die pill-making technologies. Both The Academy of Medical Sciences report and the *Computer World* article point to the future of medicine enabled by 3D printing and highlight the enormous opportunity to solve healthcare challenges common in many developing countries.

Questions are being asked about whether 3D printing will destroy or build the world. Some feel the technology will infringe on intellectual property. Others argue that it may shift manufacturing back to the developed world, which is traditionally outsourced to developing countries where labor is cheap. A reversal of this trend could translate into employment losses in developing countries.

But time and again such anti-technology arguments are proven false. In the early 1980's when computers were first introduced, many governments, including Kenya, banned their use in government offices for fear that they would lead to mass redundancies of secretarial jobs. Today, there is a computer in virtually every government office and yet more people are hired to work in government than ever before. More significantly, productive efficiency continues to improve as a result of the adoption of new technologies. We may not fully comprehend the future of 3D printing technology at the moment but we can be sure it will further increase productivity across many sectors.

As we keep improving the materials used by the 3D printing (most commonly called filament), it's plausible that we could be printing body parts to save lives in the near future. Bioprinting of artificial human tissue and organs, or 'bioficials' as they came to be known, is a growth area. 3D Printed blood vessels, liver and eye tissues have been made by Organova, an American bioprinting company that made the world's first bioprinter. The printing of a 'bioficial' heart to be grown from the patient's own fat stem cells is a work in progress that may be realized within the next 5 to 10 years. Bioprinting of organs will do away with the waiting time for organ transplant or the search for compatible donors not least the inhuman illicit trade in organs.

There is no doubt that 3D printing is already a game changer in the manufacturing industry but there is great unmet need in developing countries where the sector has been hindered by high costs. The application of 3D printing in the fields of medicine, art, fashion and retail, gaming and entertaining, and security will enhance employment and create job opportunities across Africa, where an information and communications technology (ICT) boom is rapidly spreading. It is imperative that African countries start to look at how to bring 3D printing to every village and what is required to initiate an aggressive program of capacity development in local polytechnics. Because, it does not take a genius to understand the potential of 3D printing to make a difference but rather a vision. Once again African countries, and other developing countries around the world, have an opportunity to join the industrial revolution that is already underway; it's high time they seize it.

***Dr Bitange Ndemo** is an associate professor at University of Nairobi's Business School and was Permanent Secretary in the Ministry of Information and Communication, Republic of Kenya.*

POLITICAL WILL

THE TAKE-HOME FOR AFRICA FROM OBAMA'S ENDORSEMENT OF 3D PRINTING

Dr Cosmas Milton Obote Ochieng,
Executive Director, African Centre for Technology Studies (ACTS)
and **Dr. Hailemichael Teshome Demissie,**
Senior Research Fellow, African Centre for Technology Studies (ACTS) , Nairobi, Kenya

It is common tradition that every nation wants to make and preserve their leaders' portraitures in the best way possible commissioning the best artists, sculptors and photographers. 3D Printing technology is now providing the most precise portraiture ever. Obama's 3D printed bust will be unique not only for the way it was made but also for being the closest likeness of the President himself. Unlike the other President's busts, Obama's bust includes nearly all details on his face including creases and moles, folds and shades captured with millions and millions of measurements taken during the scanning session of the President himself.

Mr Obama is a big fan of 3D Printing and has publicly praised it as the saviour of manufacturing in America. In his 2013 State of the Union address to Congress he spoke of the technology with emphatic enthusiasm. His enthusiasm was shared and echoed by Congress. CNN reported that 'the shout-out in Obama's State of the Union address was perhaps the biggest public endorsement so far of a technology that has its roots in the 1970s'. In his address he said: 'A once-shuttered warehouse [in Youngstown, Ohio] is now a state-of-the art lab where new workers are mastering the 3-D printing that has the potential to revolutionize the way we make almost everything'.

Obama's enthusiasm is accompanied with a solid show of leadership championing the technology. Besides the repeated praise of 3D printing in his several speeches, he also had first-hand experience visiting facilities with 3D printers dotted across the country. Perhaps the most personal encounter of the President with the technology took place when he himself sat still for 90 seconds to be scanned so that the inputs for a digital file of his bust can be captured. His embrace of the technology and leadership galvanised activities towards an advanced manufacturing initiative to establish a new National Network for Manufacturing Innovation (NNMI) with a budget of $1 billion.
Although he was speaking of his own national constituency, Obama's message does strike a chord with the African audience. The general terms he uses make his statements broad enough to include applications of the technology in Africa. From the following quote, it can be gathered that his words do not seem to discriminate between American and non-American, rich or poor countries:
… because of advances in technology, part of the opportunity is now—to make the tools that are needed for production and prototypes are now democratised. They're in the hands of anybody who's got a good idea.

The President's observation about 3D printing is even more relevant to Africa in a very straightforward fashion. Speaking of the rundown town of Youngstown, Ohio, and the region that came to be known as the 'rust belt' of America, Obama

added that '[t]here is no reason this can't happen in other towns' and laid out his initiative 'to turn regions left behind by globalization into global centers of high-tech jobs.' His general reference to 'regions left behind by globalisation' is perhaps what makes his statement relevant to Africa. Isn't Africa among the regions left behind by globalization? The questions to ask are the same questions Obama raised: if this can be done in Youngstown, is there a reason that this can't be done in other towns in America and in towns and countries of Africa?

Obviously questions about the specific contexts of Africa will come up. The numerous challenges in Africa ranging from the lack of skilled workforce to the poor infrastructure may be cited to question the relevance of what Obama is saying to America for the African context. Certainly, much remains to be done by way of tackling the lack of supporting infrastructure like the supply of electricity and lack of access to web services and electronic hardware. However, it should be stressed that the challenge is not that of the inadaptability of these technologies to Africa's condition. Electricity supply is an issue that is being tackled on its own and Obama's Power Africa initiative to double the number of people having access to electricity within 5 to 10 years is spot on in identifying it as the critical roadblock for Africa's development.

Mr Obama himself is unlikely to doubt the relevance of his statements about 3D printing to African manufacturing. In a different but relevant context during his last visit to Africa, he has reiterated that 'what is true for America is true for Kenya'. African leaders and policy makers need to pay closer attention to what Obama is saying and doing as a matter of great importance to Africa. A major lesson to be drawn from Obama's promotion of 3D printing relates to the role of concept champions. Africa needs to address the challenge of securing political buy-in and getting concept champions who will promote and popularise emerging technologies and their benefits.

Obama's role in championing 3D printing has spurred the growth of the technology in the US and around the world. Political leadership from the highest echelons of power is critical for the timely adoption of the technology. A top-down approach seems to be indispensable for the accelerated uptake of emerging technologies especially in countries with weak private sector players. Concept champions are wanted to spearhead adoption efforts and lobby governments to procure these technologies and to negotiate access to these technologies from suppliers on favourable terms. Policy incentives and supportive policy orientation is required if Africa is to benefit from these technologies. For this to be realized, the role of concept champions is critical and a robust precedent is set by President Obama's proactive promotion of advanced manufacturing in general and 3D printing in particular.

Obama's specific mention of 3D printing says a lot about policy approaches. Currently, the emphasis on building capacity in developing countries is articulated in general terms with broad reference to science, technology and innovation (STI). The specific mention of a particular technology is rather uncommon.

References to emerging technologies like 3D printing are rare. The AU Science, Technology and Innovation Strategy for Africa 2024 (STISA 24), for example, simply seeks to capture technologies like 3D printing in terms of general STI policy and strategy. Indications about such technologies have to be dug out of such expressions as material science, ICT or manufacturing. This blanket and one-size-fits all approach is not the way to go with emerging technologies of immense strategic importance.

Given the enormity of the potential of 3D printing technology converging with other technologies and serving as general purpose platform technology with applications across a whole spectrum of STI activities, designing a specific policy on the technology is of critical importance. Leaving it to be assumed in the generality of STI policies will deny the technology the attention it deserves. Such an approach is being challenged as specific policies for specific technologies are becoming increasingly imperative. In a recent report for the UK government aptly entitled *No Stone Unturned In Pursuit of Growth*, it was recommended that the government should have a 'clear policy for each sector of the economy'. Li Yong, Director General of UNIDO, argues in the same line citing a UNIDO/UNCTAD report that advocates 'tailor made', 'context-specific' industrial policies for Africa. The Obama administration's approach towards 3D Printing is consistent with these recommendations and it is time that Africa should heed these recommendations. The implied policy support that 3D printing may get from the general regional and national STI policies in Africa leaves much to be desired.

In addition to the lack of focussed attention to specific yet general purpose emerging technologies, there are even suggestions implying that developing countries need not engage new technologies like 3D Printing. The justification for this is the intellectual property barriers precluding developing countries from engaging in such technologies and the wide availability of patent-free mature technologies not yet used by developing countries. This is a view that was forwarded by the UN Millennium Project Taskforce. In the specific context of 3D printing, intellectual property barriers have collapsed with the expiry of major patents. What is more the technology is increasigingly developed within the burgeoning culture of sharing and open source. These developments have opened aunprecedented opportunities for developing countries.

The scepticism about the suitability of cutting-edge technologies to the needs in Africa has to be cleared taking into account the incredible malleability of emerging technology applications irrespective of sheer variations in context. The attitude that Africa needs in this respect is that if it can be done in the developed world, it can be done here. It will be a cliché worth emulating if Africa can also say 'Yes we can' with respect to the adoption of 3D printing for manufacturing.

In an earlier issue of the African Technopolitan, it was argued that 'No American President ever came to office with more political capital in Africa than Barack Obama. No American President ever ruled at a more hopeful time for Africa.' This was a reflection on the various initiatives of the Obama administration like the Power Africa, New Alliance for Food Security and Nutrition, and Young African Leadership (YALI) initiatives. It was also noted that compared to Chinese engagement in Africa which is relatively less knowledge and tech intensive, the Obama administration tends to focus its intervention in knowledge intensive sustainable long term initiatives in the sectors of energy and human capital development. Just like the Power Africa Initiative, a 'Manufacturing Africa Initiative' that mirrors the Administrations' initiative of the National Network for Manufacturing Innovation (NNMI) would not only leave a lasting eternal legacy of Mr Obama's Presidency but it would also accelerate the total success of the existing initiatives. This is after all a vision that is hardly foreign to the letter and spirit of President Obama's public statements on 3D printing and its potential to lift 'regions left behind by globalisation'.

> "*Unlike* the other President's busts, Obama's bust includes nearly all details on his face including creases and moles, folds and shades captured with millions and millions of measurements taken during the scanning session of the President himself."

3D Printing for Sustainable Manufacturing in Africa
International Conference and Exhibition on 3D Printing

26th-27th May 2016

Kenyatta University, Nairobi, Kenya

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NACOSTI · KAM Kenya Association of Manufacturers · UNIDO · The African Academy of Sciences · Stratasys Objet · Kenya Vision 2030 · Ethiopian · KIRDI · IFEES · GEDC Global Engineering Deans Council

LEARNING **BY TOUCHING**

3D PRINTING FOR EDUCATION

Prof Henry Thairu
Chair of the Commission for University Education, and Director of Consultancy Services, Kenyatta University, Nairobi, Kenya

Early this year, the BBC ran a headline story by the Director of the OECD's Directorate of Education and Skills, Andreas Schleicher, titled 'China opens a new university every week'. At this rate China is set to overtake the total number of graduates in the Western world and perhaps in the rest of the world.

This change is not only in the numbers but also in the type and quality of education. The preferred subjects are STEM (science, technology, engineering and maths) subjects with 40% of the graduates in 2013 having completed their studies in STEM subjects. Recent years have witnessed nearly a million PhDs in STEM being awarded each year in China. The bar is higher for the new graduates as new thresholds are awaiting them in the world of innovation and technological advancement. The graduates are trained for high value, high earning jobs requiring high skills and are required to equip themselves with the new skills the future market wants them to have.

The mismatch of skills with the jobs on the market is a serious issue around the globe: In the US, 83% of manufacturers recently reported an overall shortage of qualified employees. The story is not different for Africa. A survey of experts in 36 countries for the 2012 Africa Economic Outlook found out that 54% of the respondents identify the skills mismatch as a major obstacle for business. Citing the survey, Betty Maina, former CEO of the Kenyan Association of Manufacturers (KAM) pointed out that the mismatch of skills is a persistent challenge to Kenyan manufacturing. She added that 'university graduates do not have the right skill mix to drive competitiveness for the country at large'. It is this scenario that the Chinese are tackling head-on. Besides the all-important transition to high value manufacturing, China's focus on education is aimed at pre-empting similar scenarios of a mismatch of skills and jobs. Their new graduates will have familiarised themselves with a universe of technologies that their immediate forebears couldn't even have imagined.

3D Printing or additive manufacturing is among these technologies that China is teaching its next generation work force. The plan is to offer 3D Printing lessons and services in early education starting this year with the installation of the printers in each of the more than 400,000 elementary schools in China. Similar plans are underway in other countries too. The UK is rolling out these lessons for 8 year olds while the US has started to offer them in middle and high schools. The Defense Advanced Research Projects Agency (DARPA) Manufacturing Experimentation and Outreach (MENTOR) program, has provided 3D printers to more than 1,000 high schools breaking with tradition that kept 3D printing as a preserve of higher education in the US. A similar trend is observed in Kenya where some elementary and high schools are experimenting with 3D Printers as teaching aids.

The introduction of 3D Printing tech to schools is revolutionising education in a big way. The technology as a general purpose technology has a huge variety of applications in schools. As one commentator puts it: 'The application of this technology is only limited by the ambition of the teacher and the creativity of the students — and there's no cap on either of those things here.'

The applications of 3D Printing with the most profound impact in education is as pedagogical tools. 3D Printing is bringing tactile, touch and feel experience to pupils and students on subject matters ranging from mathematical formulas to biological processes, from chemical formulas to physics theories. Subjects that were once too abstract to understand can now be reduced to concrete solid models that learners can explore and examine using additional sensory powers. This is no small feat and its tremendous impact has yet to be fully appreciated. While it is no new experience that technology is oftentimes 'crash landing' in schools and dazzling educators, the advent of 3Dprinters in schools is certainly ushering in a profound revolution in education.

Computers in schools are a familiar scene in OECD countries. However, the results achieved as a result of the deployment of computers in the learning –teaching process is 'at best mixed' according to Andreas Schleicher, who led the 2015 OECD report, Students, *Computers and Learning: Making the Connections.* The report's finding is deeply disconcerting given the huge investments made on ICTs for schools even in non-OECD countries: The report says there are 'no appreciable improvements' in reading, mathematics or science in the countries that had invested heavily in information technology. Countries providing greater access to computers are not performing better than those whose students have relatively limited access to computers. 3D Printing is the perfect complement to existing digital learning tools and is expected to rectify what has gone wrong with schools that are failing to deliver results despite the ease and availability of technology and internet access. 3D printing could help 'make the connections' as it will liberate those ideas, concepts, diagrams, models and designs that have hitherto been imprisoned behind the computer screen and that were mainly and essentially experienced as a little more than digital *trompe-l'oeil.*

In their article entitled *Illustrating Mathematics Using 3D Printers,* Oliver Knill and Elizabeth Slavkovsky identify 3D printing as 'the latest piece in a chain of visualization techniques'. They argue that despite the huge array of applications that enable highly enhanced visualisations, 'the possibility to manipulate an object with our bare hands is still unmatched. Knill and Slavkovsky also observe that '[v]isualization is especially crucial for education and can lead to new insight'. This finds no better evidence than in the case of visually challenged persons. 3D printing is of particular importance for the visually challenged persons who cannot use printed or digital text or pictorial representations of concepts. The blind can now 'see' Mona Lisa thanks to a 3D printed relief of the masterpiece that can be experienced using the tactile sense.

THE APPLICATIONS OF 3D PRINTING WITH THE MOST PROFOUND IMPACT IN EDUCATION IS AS PEDAGOGICAL TOOLS.

Illustrations in books are coming to life with richer details in their 3D printed enhanced versions.

The benefits of 3D printing to the visually impaired also extend to those with learning disabilities and even those without disabilities and the wider public at large. Educators have long realised not only that 'technologies allow us to do old jobs in new ways', but also 'that they can be used to help us do things in education that were heretofore impossible.' Educating the wider public in either formal or informal education is made easier with 3D printing. The disposition that mathematics or physics is too hard to communicate could be tackled using 3D printed models and it can be made more accessible to the public and this may in turn reverse the decline in enrolment levels in STEM education.

The urgency of stimulating students to take up STEM subjects is observed in both developing and developed countries. Among the measures employed in the developed countries is encouraging students through advertising campaigns. Advertising and appealing to students to enrol in STEM subjects may not do the trick as it does not bode well with the continual volley of news about mass layoffs, factory closures and outsourcing of jobs that the global manufacturing sector has seen recently. Even where one decides to ignore or otherwise downplay the impact of these depressing events, encouraging enrolment in STEM subjects remains a challenge due to the deep-seated perception that these subjects are difficult. 3D printing has the potential to change this perception by providing a hands on experience to learners from early education all the way to higher education. The perception of learners would take a turn for the better when they see what they thought was too abstract come to life turning abstract theories practical, and making conceptual models touchable and testable.

As pedagogical tools, 3D printers will help in expanding the imaginations of students. With the freedom to innovate afforded by the technology, learners will not be constrained by equipment and materials that do not allow them make whatever they imagine. The constraints with cardboard or paper mash models can no longer inhibit the creative drives of students who can now manipulate their models on the screen and test it with a printed model in their palms. It is rightly observed that 3D printing is 'giving students extraordinary levels of motivation and the opportunity to exercise their imaginations'. With time and as prices for printer feedstocks come down, students can test their ideas by printing models as many times as they wish. This capability will boost their confidence by allaying fears of failure. On top of this, they can collaborate on the design of what they want to print with any one on earth irrespective of the location where they live. Sharing the files of their designs with someone at the other end of the earth and collaborating on project work is indeed an extraordinary opportunity that 3D Printing offers.

The benefits of 3D printing for education cannot be exhaustively listed for the simple reason that the benefits to be drawn from the technology depend on the imagination of the users of the technology. However, there is one use of the technology that is worth mentioning here because of the immediate relevance to developing countries. Laboratories in developing countries are either poorly equipped or totally non-existent. The cost of lab equipment and running labs is prohibitive for schools and universities in many developing countries. 3D Printing could alleviate and eventually do away with this problem as labs can print their equipment at a fraction of the cost of purchasing them. From beakers to measuring jugs from goggles to spare parts for the more sophisticated instruments, schools and universities can have them printed off their computers.

This possibility was demonstrated to the world when the University of Nairobi students captured the attention of global media with their project to turn the labour ward in Kenyatta Hospital from an equipment graveyard to a life-saving fully-functioning facility. They have shown to the world that parts for incubators, examination lights, and vacuum delivery and phototherapy machines could be fabricated at low cost to keep the labour ward up and running. There is a lesson for labs in developing countries that are not functioning due to the lack of spare parts for broken equipment. The cheaper and efficient way is to scan the broken part and print it. And for this to happen, developing countries need to invest in skills development. The relatively low capital outlays required for acquisition of 3D printers should enable developing countries to focus their investments on skills development in 3D printing.

THE BENEFITS OF 3D PRINTING FOR EDUCATION CANNOT BE EXHAUSTIVELY LISTED FOR THE SIMPLE REASON THAT THE BENEFITS TO BE DRAWN FROM THE TECHNOLOGY DEPEND ON THE IMAGINATION OF THE USERS OF THE TECHNOLOGY.

3D PRINTING AND THE POLICY IMPLICATIONS

SOME THOUGHTS FOR THE POLICY LANDSCAPE ON IP

Berhanu Abegaz, Prof, Executive Director, The African Academy of Sciences(AAS), Nairobi, Kenya and Hailemichael Teshome Demissie, PhD, Senior Research Fellow, African Centre for Technology Studies (ACTS), Nairobi, Kenya

The unveiling of the 30cm long 3D replicas of the Ishango bones by HE Dr Ameenah Gurib-Fakim, President of The Republic of Mauritius and AAS Fellow at the African Academy of Sciences (AAS) premises in Nairobi, Kenya

Additive manufacturing, popularly known by the colloquial '3D printing', is a process of making three dimensional solid objects from a digital file by laying down successive layers of material until the entire object is created.

Ranging from bionic ears to hand guns, from car parts to prosthetics, from printed houses to printed drones, there is now an inexhaustible list of artefacts that are now 3D printed. 3D Printing is becoming increasingly popular around the globe and is expanding at an incredibly fast rate.

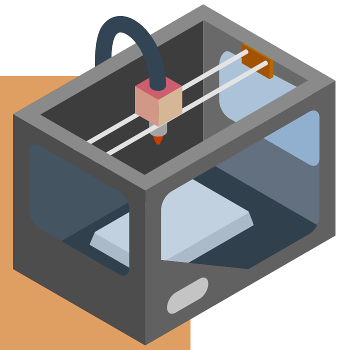
Although it is still to take off fully in Africa, the continent needs to be prepared for the policy and legal implications that it might create. Some of the uses of the technology will re-introduce previous regulatory conundrums that dominated the debate on the international IP regimes. Africa was subjected to the harsh consequences of the international IP regime and emerged out of it as a victim rather than a beneficiary. The IP issues surrounding 3D printing are likely to put Africa in a similar situation unless a fresh approach to IP policies and laws is negotiated with regard to 3D Printing. The technology is poised to bring about changes to the IP regimes and Africa needs to keep abreast of these changes to avoid a repeat of the dispute over lifesaving drugs that led to millions of deaths.

3D Printing Riding Roughshod over IP laws

The Ishango bone is a bone tool, ca 20,000 years old, with complex markings on it, and widely acknowledged as a testament to the pre-historic literacy and practice of arithmetic in central Africa. It was discovered in 1960 by Jean de Heinzelin de Braucourt in the Belgian Congo and kept at The Royal Belgian Institute of Natural Sciences in Brussels. Based on an official request by the Belgium-based International Organization of Chemical Sciences for Development (IOCD), on behalf of the African Academy of Sciences (AAS), the museum was willing to give a 3D scan of the bone to a group which provided an enlarged 3D replica of the bone. The replica of the bone obtained with help from other partners was unveiled in a colorful ceremony in Nairobi and is on permanent exhibition at AAS Headquarters in Nairobi.

Unfortunately, this kind of cooperation is not always achieved and some will pursue some unusual tactics to achieve what could have been achieved through cooperation. This is what happened with the Neues Museum in Berlin. In February of this year, the three and a half thousand-year-old bust of Queen Nefertiti, 'one of the world's most celebrated ancient treasures, was secretly scanned from the heavily guarded Neues Museum in Berlin. Two German artists who posed as ordinary visitors used 3D scanners to produce the exact replica of the bust which was then 3D printed and subsequently displayed in Cairo. It is reported that the Neues Museum was unwilling to provide free access to this Egyptian art and so the motive of the two 'thieves', or 'guerilla artists' as *The Times* described them, was to shame the German Museum for its continued possession of the bust that was taken from Egypt in 1912. The replica they produced using 3D printing was described as 'a breathtakingly precise copy'. The artists have vowed to make their file freely available for anyone anywhere in the world to 3D print a copy.

This anecdote demonstrates the power of 3D Printing to run roughshod over the IP systems that are in place at the moment. Like the Queen's bust any other physical object can be scanned and its precise replica can be 3D printed. Where does that leave IP protection? If a physically protected object can be snapped away in the presence of watchmen and in the glare of security cameras, what would become of less stringently protected items? 3D printing of artefacts and sharing of the files with the rest of the world has become easier and file sharing



***WHERE DOES* THAT LEAVE IP PROTECTION? IF A PHYSICALLY PROTECTED OBJECT CAN BE SNAPPED AWAY IN THE PRESENCE OF WATCHMEN AND IN THE GLARE OF SECURITY CAMERAS, WHAT WOULD BECOME OF LESS STRINGENTLY PROTECTED ITEMS?**

and hosting websites such as Thingiverse and Shapeways are proliferating. Existing IP regimes are not adequate to deal with the impacts of 3D Printing and a new round of the IP policy debate is in order.

3D printing as such presents an opportunity to revisit the undesirable effects of the existing IP regime that negatively impacted Africa in particular. It is still fresh in our memories that millions of HIV/AIDS patients died because they were denied access to lifesaving anti-retroviral drugs – denial of access that the international IP regime sanctioned. There were 2.4 million deaths and 3.5 new infections in Africa in 2002 alone. Many more millions of deaths and infections took place in the years that followed. Bowing to internal and foreign political pressures, the US abandoned its push for pharmaceutical patent protection through the WTO. It was, however, too late for millions of Africans.

Like the bust of Queen Nefretiti, Africa's genetic resources were plundered with impunity and the IP regimes did not help prevent this. Nor did the regimes help in rectifying this act of plunder after the fact. During the negotiations of the *Nagoya Protocol on Access and Benefit Sharing* of genetic resources, it was clear that the genetic resources that were taken from Africa will not be recognised as African resources. The retroactive application of the Protocol tabled by the resource rich developing countries was rejected by the developed countries The genetic resources remain the property of those who appropriated them through biopiracy. Overall, it is hardly possible to find any positive assessment of the impact of the international IP regime on Africa's development.

While this is no place to review the pros and cons of IP protection, it suffices to say that no one is under any illusion that existing IP regimes are ideal. While IP laws were designed to incentivise innovators and reward them with a monopoly right for their inventions, the laws have not always been applied towards the fulfilment of this objective. Incumbent interests are claiming their IP rights to maintain their market share and to block rising innovators. 3D Printing will eventually replace existing methods of manufacturing material artefacts disrupting existing industries. It is natural that incumbent industries will react in every way they can and IP rights are the first thing they will be invoking.

The IP regimes are in need of serious overhauling and 3D Printing is certainly to speed up this process. It is not difficult to imagine that the development of 3D Printing technology is currently driven not only by the R&D sections of companies, university and research institutes, but also the hobbyists and hacktivists tinkering with existing technology in their back yard garages, hackerspaces, fab labs and public libraries and museums. Companies developing the technology want to protect their achievements and exploit the monopoly they can muster using existing IP laws. This might slow the spread of the technology and the improvements that may result from the widespread sharing of the technology. The applications that may benefit Africa might be delayed as a result. With 3D Printing, Africa has a real opportunity to leapfrog cumbersome and polluting industrialisation stages that the developed countries passed through. The scientific community especially in Africa, needs to ensure that IP laws will not be a hindrance to the accelerated development of the technology.

Major patents on 3D printing expired in the last few years and this has led to the recent remarkable advance of the technology. Africa is urged to make use of this opportunity to tap into the benefits of the technology before proprietary enclosures are built around it. Developers of technology have come up with their own methods of enforcing IP protection. One of the scary applications of this technology is the 3D-printing of guns and fire-arms. But, this is being tackled with an application that can prevent the printing of a gun - like the copy protected CD with inbuilt mechanisms that prevent sharing of music and data. A Danish company, "Create it REAL", has developed a software to detect and prevent the printing of guns.

***LIKE THE BUST OF QUEEN NEFRETITI,* AFRICA'S GENETIC RESOURCES WERE PLUNDERED WITH IMPUNITY AND THE IP REGIMES DID NOT HELP PREVENT THIS. NOR DID THE REGIMES HELP IN RECTIFYING THIS ACT OF PLUNDER AFTER THE FACT.**

The software recognises the patterns and stages of printing guns and halts the printing process. The same technology could be used to prevent the sharing of beneficial applications of 3D Printing. As sharing becomes more mainstream, the motivations to create robust enclosures become even stronger and the means to guard them more sophisticated. Africa may be excluded from utilising the technology by the various exclusionary techniques that will be developed for the purpose of creating a monopoly and the extraction of rents. The negotiations Africa will be having on the IP issues of 3D Printing should extend beyond changes in the legal and policy instruments into the very code that will be integrated into the technology to make it inaccessible to wider users.

AFRICAN COUNTRIES NEED TO START DEBATING THE IP ISSUES OF 3D PRINTING PAYING ATTENTION TO THE FOLLOWING RECOMMENDATIONS

• African governments need to prepare for negotiations with the developed world about the use of 3D Printing.
Sooner or later, African countries might need to talk about the IP regulations governing it at WIPO and WTO levels. Developing countries have lost negotiations in the past because they don't have the capacity and expertise. This is the time to gain and develop the skills and knowledge to strengthen their position while the technology is still in its early stages.

• Africa needs to draw lessons from the IP debacle over anti-retroviral drugs.
Africa should heed the lessons from the disastrous application of IP laws that led to millions of deaths and build internal capacity to avert any similar eventuality. Countries should also draw lessons on how to strengthen their negotiating position and to govern the use of 3D printing internally.

•African countries need to be strengthening and creating dynamic IP laws.
To ensure that IP laws achieve their intended purposes of spurring innovation and development, African countries need to adopt laws that are responsive to global developments in the technology.

• Scientists will need to be proactive in talking to governments about this issue
Governments will need expertise from scientists and science organisations such as the AAS and ACTS to govern 3D printing. Scientists provide the evidence to inform policies to create the optimal environment for the beneficial advancement of the technology.

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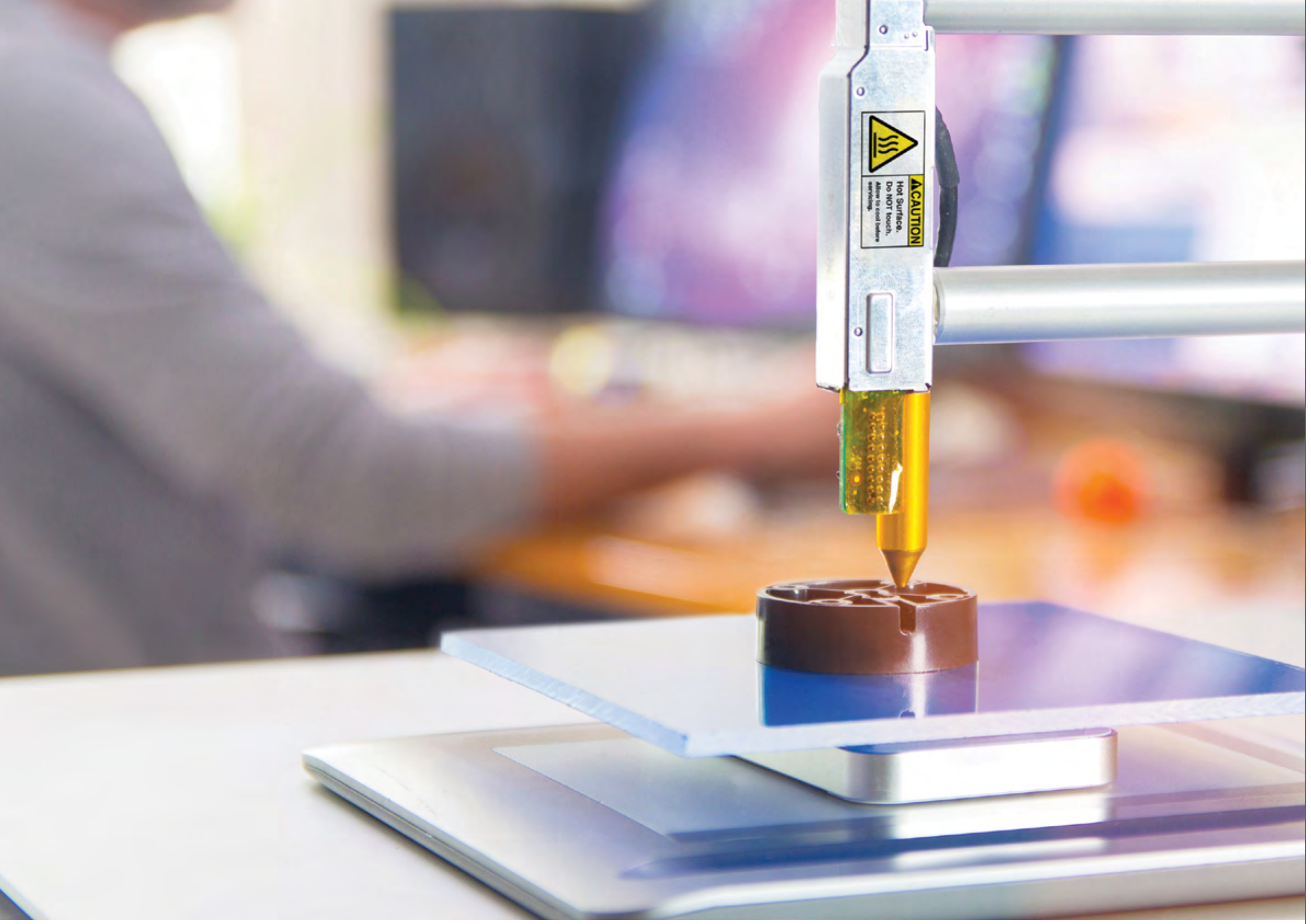


3D PRINTING FOR INCLUSIVE INNOVATION

Dr. Thomas S. Woodson, Stony Brook University, New York, USA

INTRODUCTION

3D printing, or additive manufacturing, is a technique to build models, prototypes and finished products from a data file in a computer. The most common method is the layering of materials from the bottom up to produce a three dimensional structure. Over the past 5 years, 3D printing has grown in prominence from a niche activity for large companies and technology hobbyists, to becoming a mainstream technology and an industry of its own right - 'the 3D printing industry'.

As the technology spreads far and wide, there is growing excitement that 3D printing will lead to the next industrial revolution by allowing people to design and print complex customised products without specialized training and without long lead times. 3D printing proponents believe that eventually, people will be able to print any item from their personal 3D printer.

While the future benefits of 3D printing are all the rage receiving widespread attention, there are fewer discussions on the impacts of 3D printing on inequality and poverty. The history of technology is full of examples of commercially successful technologies and devices that do little to improve the lives of the poor, or that actually decrease inequality. Enthusiasm aside, a thorough and timely examination has to be carried out to inform policy development on the potential of 3D printing as an inclusive innovation and the challenges of realizing this potential together with the possible vulnerabilities that the technology might create. This contribution is a call for such examination.

BACKGROUND

Inclusive innovation is interpreted and framed in diverse ways. Richard Heeks and his co-authors define inclusive innovation as "the means by which new goods and services are developed for and/or by those who have been excluded from the development mainstream; particularly the billions living on lowest incomes"(Heeks, Foster, and Nugroho 2014). This concept has close connections to innovation theories like appropriate technology, bottom of the pyramid innovation, frugal innovation, grassroots innovation or pro-poor technology which also explore technology development for poor and marginalized communities. Of these theories, however, the inclusive innovation framework is particularly interesting for its richer analysis in identifying the various stages at which opportunities open up for innovation to be made inclusive.

To characterize the different levels of innovation for excluded groups, Heeks and his co-authors developed a model represented by a ladder with six rangs which they describe as follows:
The levels are akin to steps on a ladder because each level involves a gradual deepening and/or broadening of the extent of inclusion of the excluded group in relation to innovation. In general, each level accepts the inclusion of the levels below, but pushes the extent of inclusion further.

Many of the traditional processes and products that people consider innovative impact the lower levels of the innovation ladder. For example, a pioneering water pump built for a poor rural village is an innovation on the first few rungs of the innovation ladder. However, a post-structure innovation (rung 6) considers the framing of the goals and questions. Does the language further ingrain existing power dynamics? Is inclusivity imbedded in the dialogue of innovation? As Heeks and his co-authors argue the framings of key actors determine whether innovation is genuinely inclusive or not.

INCLUSIVE INNOVATION AND 3D PRINTING

Given the potential importance of 3D printing, it is important to map the technology onto the Heeks et al inclusive innovation ladder to see if the initial applications of the technology are inclusive.

Rung 1(intention): ***"an innovation is inclusive if the intention of that innovation is to address the needs or wants or problems of the excluded group"***

The first rung of inclusive innovation is the easiest step because the innovation does not actually have to be adopted or be beneficial. Rather, only the intent of the innovation has to address excluded groups. There are countless examples of development projects, ranging from cooking stoves to water filtration systems, that were not successful, yet they meet the requirements of the first type of inclusive innovation because the innovation was intended to help an excluded group. With regards to 3D printing, a number of primary schools, libraries, and Maker spaces around the world have installed 3D printers with the intention of helping underserved communities. Even though some of these spaces fail to attract users from marginalized communities, they still achieve the first level of inclusive innovation because the spaces were intended to be used by citizens from marginal communities.

Rung 2 (consumption): ***"an innovation is inclusive if it is adopted and used by the excluded group"***

This rung judges an inclusive innovation based on the actual use of the innovation by a person from an excluded group. The most prevalent example of 3D printers being used by excluded groups is the manufacturing of prosthetics. People who are disabled face many unique challenges, ranging from job discrimination to inaccessible infrastructure that lead to the marginalization of this community. Developing 3D printed prosthetics can greatly improve the lives of the disabled by providing them cheap, custom designed prosthetics that conforms to the specifications of the user, and increase the functionality and comfort of the device. Over the past few years, several organizations have developed 3D printed prosthetics. In South Africa, Robohand prints prosthetics for children and in Uganda, a Canadian professor and a charity called Christian Blind Mission used a 3D printer to create prosthetics for about $250. With a wider goal for 3D printing beyond the making of prosthetics, the Uplift Prize was created to reward a team who could develop a low cost, self-replicating 3D printer for poverty alleviation ("The Uplift Prize", 2015).

At the early stages, there is evidence that 3D printers and their prints are being consumed by a few individuals in marginalized communities and it is expected that as the technology diffuses, even more marginalized communities will have access to the technology. However, the actual proportion of marginalized groups compared to privileged groups using 3D printing technology is yet to be seen. If excluded groups use the technology at significantly lower proportions than privileged communities, then the technology cannot be said to be inclusive as it may have actually increased inequality within the system despite the incremental gains by underserved communities.

Rung 3 (Impact): ***"an innovation is inclusive if it has a positive impact on the livelihoods of the excluded group"***

Inclusive innovations that reach the third rung must have a positive impact on excluded groups. Though this is the goal of most innovations and development projects, countless projects fail to benefit a community, and even worse, some projects actually harm a community. Using the prosthetic examples, it is clear that a new prosthetic will improve a disabled person's life. However, there are skeptical views that the benefits of 3D printed prosthetics are exaggerated. 3D printed prosthetics might not offer ten-fold cost savings as expected, the cheap 3D printed prosthetics can break easily, and the homemade prosthetics have not been fitted by a medically trained specialists; and therefore, they do not meet the same strict guidelines as real prosthetics. The development community lacks evidence of whether homemade 3D printed prosthetics are a long term solution for disabled persons or if the technology provides a temporary solution until professionally fabricated device can be manufactured.

In order to determine whether an innovation has a positive impact on an excluded group, an analysis of the multiple effects of the technology on the livelihoods of excluded groups has to be done. It is not enough to simply examine the direct influences of a technology in isolated cases, but it is important to understand the consequences of the technology for the broader excluded community.

Rung 4 (process): ***"an innovation is inclusive if the excluded group is involved in the development of the innovation"***

The fourth rung of inclusive innovation begins to consider comprehensive social issues beyond the particular technology. On this rung marginalized communities help make the technology. In the 3D printing space, even though most of the technology was developed and commercialized by individuals in wealthy countries, the technology is rapidly expanding to unprivileged communities in developing countries. For example, the first 3D printer to be made out of e-waste was made in Africa by Kodjo Afate Gnikou from Lome, Togo who won a NASA prize for his printer built using recycled computer and electronics parts. Similarly, in Kenya entrepreneurs at Africa Born 3D (AB3D) build and sell 3D printers constructed from recycled e-waste, and in Brazil, at least two companies, Metamaquina and Cliever, are selling Brazilian designed 3D printers.

IN THE 3D PRINTING SPACE, **EVEN THOUGH MOST OF THE TECHNOLOGY WAS DEVELOPED AND COMMERCIALIZED BY INDIVIDUALS IN WEALTHY COUNTRIES, THE TECHNOLOGY IS RAPIDLY EXPANDING TO UNPRIVILEGED COMMUNITIES IN DEVELOPING COUNTRIES.**

The spread of 3D printing to low and middle income countries is one example of excluded groups using the technology. However, within low and middle income countries, the technology is not broadly diffusing across society. Rather, university trained engineers and export oriented companies are the main actors involved in 3D printing innovations. For 3D printing to be a truly inclusive innovation at level four, the excluded groups within emerging economies must also be involved in 3D printing innovation. For this to happen and to avoid a scenario where marginalized communities are mere passive consumers, conducive policy and funding incentives need to be put in place in the low and middle income countries.

Rung 5 (structure): ***"an innovation is inclusive if it is created within a structure that is itself inclusive "***

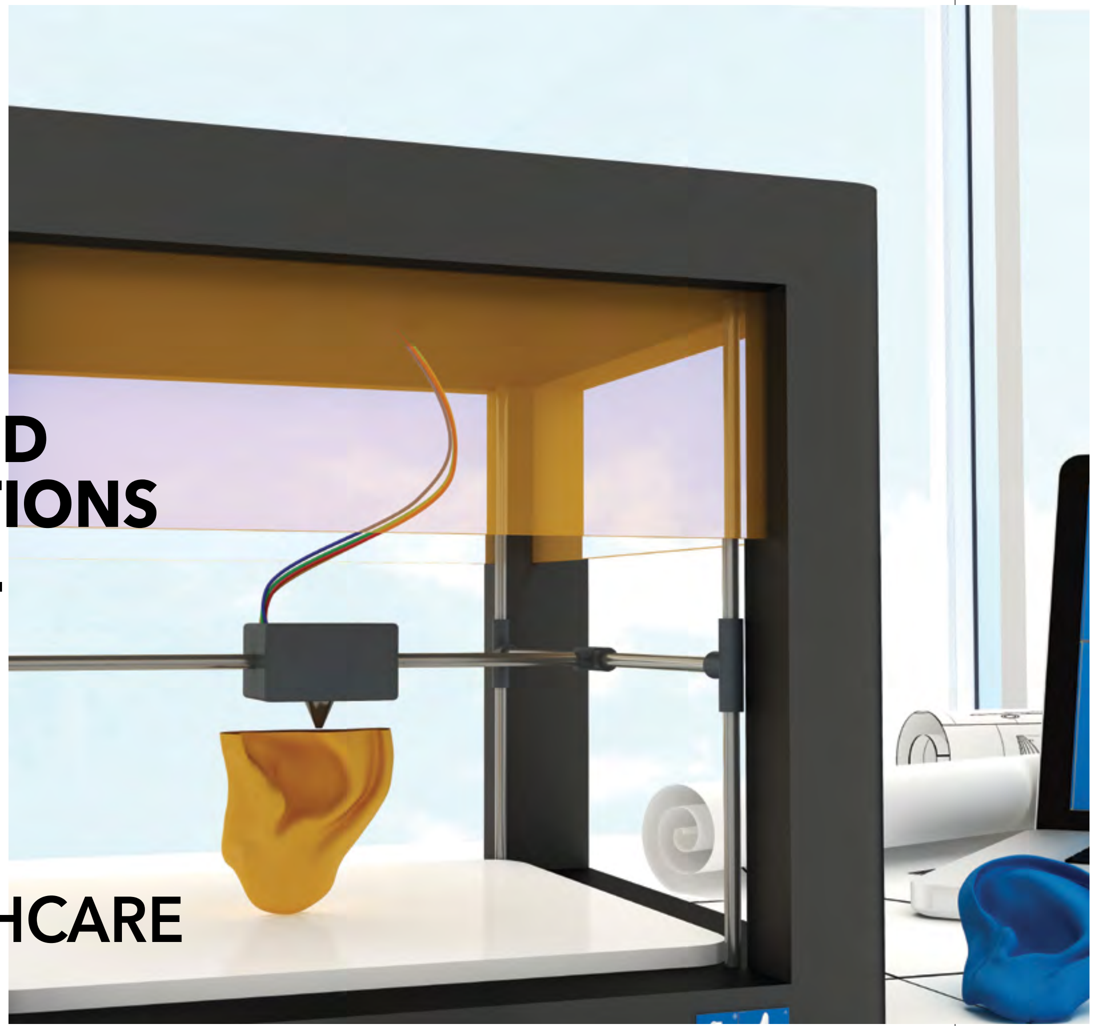
It is very difficult for inclusive innovations to reach level 5 because the wider society at large, as opposed to innovators, need to ensure that that structure is inclusive. Currently many structures, like patent laws, taxes, and the high cost of education create unequal systems that hinder inclusive innovation.

Will 3D printing create or destroy jobs? Will it cause more inequality within a society by providing the rich with a competitive advantage? Much of the current development scholarship suggests increasing property rights for poor families among the most meaningful approaches to decrease poverty. 3D printing will raise new problems with property rights. There are no clear guidelines on the intellectual property of 3D designs or 3D printed products, and historically, excluded groups had very little power to influence the policy on intellectual property. As a consequence, it is unlikely that intellectual property laws for 3D printing will benefit excluded groups more than the rich, well-connected groups of society. For the technology to have the biggest effect on excluded groups, it has to target broad issues of structural inequality. As 3D printers become more common, industry, government and civil society must find ways to change the innovation system to be more egalitarian. Most likely this will entail specific interventions, like a pro-poor scientific initiative, that prioritize equality.

Rung 6 (post-structure): ***"an innovation is inclusive if it is created within a frame of knowledge and discourse that is itself inclusive"***

This is the hardest rung to achieve because it requires society to reframe its approach to inequality. Society has to put such a high value on equality that even the underlying language changes to be more inclusive. This type of change will take generations to come to fruition. Governments may enact and implement new laws and standards to encourage inclusive innovation, but intrinsic biases that encourage exclusion are hard to change. 3D printing could be expected to achieve level 6 if the mindset driving all innovations changes.

In sum, the ladder of inclusive innovation is a simple framework to characterize the nature of inclusive innovation. The framework highlights that there are different levels of inclusive innovation depending on who uses and designs the technology. 3D printing is an inclusive technology at lower rungs, but it has not become an inclusive innovation at higher levels of inclusivity. Although the technology is not quite an inclusive innovation, it is possible to change its development to be more inclusive. For example, research donors may put emphasis on inclusion and 3D printing for poverty alleviation as a condition in their calls for proposals that emphasize inclusion. Scientists and engineers can actively engage with excluded communities to guide the direction of 3D printing. A third way to make the technology more inclusive is to expand access to 3D printing facilities installing the printers and their accessories in schools and community centers so that all of the community, and not just influential or privileged groups. Finally, global organizations need to develop standards that allow excluded groups to benefit from the technology and to reduce the level of vulnerability from the negative implications of the development of the technology, like job losses and environmental pollution, among marginalized groups.



EDUCATION AND OPEN INNOVATIONS IN BIOMEDICAL ENGINEERING

A SUSTAINABLE APPROACH FOR AFRICAN HEALTHCARE

Carmelo De Maria, Licia Di Pietro, Arti Ahluwalia

Today, Africa's healthcare systems are at a turning point. Donors and governments are now beginning to provide better healthcare facilities and increased access to medicine, at least in urban areas. In Africa, the privilege of quality healthcare comes with a price tag that can bear heavily on the limited resources of many African countries.

To be able to function properly and safely, it requires an appropriate physical environment, proper care and maintenance, and skilled operators. However, Africa lacks the human resources needed to install, maintain, manage, upgrade, design and produce medical devices, leaving it ever more reliant on foreign technical expertise. Indeed, up to 85% of African hospitals surveyed about their medical device maintenance services declared having trouble finding qualified engineers locally [1]. This continuously results in significant wastage of valuable resources as well as in the fast deterioration of the healthcare facilities, making it difficult to develop a sustainable, cost-effective and self-sufficient healthcare system.

Wealthier means healthier and healthier means wealthier

A well-established healthcare sector indicates a good economic status of a country. Odrakiewicz [2] examined the existence of a two-way relationship between health and income. Based on different case studies, his research resulted in the phrases "Wealthier is Healthier" and "Healthier is Wealthier", which means that wealthier individuals tend to spend more money on better quality nutrition which again has a positive impact on their health status [3]. Conversely, it was observed that health has a positive influence on the economic growth (e.g. due to less sick days) and that an increase of only one year life expectancy in the population can lead to a 4% increase in national production [4].

Open source in biomedical engineering

There is no question that technology has played a key role in improving the quality and cost effectiveness of health services as well as access to healthcare facilities. Technology is at the heart of effective healthcare services helping medical and paramedical personnel in all stages of their work: from prevention to diagnosis, treatment and monitoring. Yet, technology entails huge investments in economic, physical and human resources.

While, a couple of years ago, the development of biomedical devices was essentially linked to companies and universities, now several examples of open source biomedical devices have appeared on the web [5], but seldom are they designed to be compliant with safety standards [6]. Although, at present, some of these instruments are not accurate or safe enough to be inserted in the clinical routine, their use can probably save a life more than a damaged, unused (e.g., for high cost) or useless (e.g., because no one knows how to operate) Magnetic Resonance Imaging machine.

Open means safer and more reliable Indeed, software-reliant devices have also brought on new types of potential risks for patients. Given that medical software (and hardware) is proprietary and patent-protected, thus veiled in secrecy [7,8], there are difficulties in exposing specific problems with these products. The open-source approach could, in theory, make it easier to fix, or even avoid, dangerous flaws before they hurt or kill hundreds or thousands of patients.

The importance of web-based co-creation for fostering innovation has been highlighted in several works [9,10] and it has been demonstrated by the fast growing market volume of ideation contests (to which many co-creation contests can be counted) as a part of the open innovation market [11].

Furthermore, the more the team is multidisciplinary the more the project can benefit from such variety, especially in the early phases of the design process, when alternative technologies and solutions are chosen [12].

Today, thanks to crowd-thinking and crowd-sourcing, the design of several products has an intrinsic revision process, driven by a virtual community, composed of a heterogeneous and large population (from highly skilled designers to laymen), which has become an active player, and no longer a passive element: from Wikipedia (www.wikipedia.org) to Open Source Ecology (www.opensourceecology.org), there are several example of virtual and physical results.

This community is the best analyst in terms of quality, reliability and feasibility. While this philosophy is now well accepted in the "software" world, there is still an unjustified unbelief in open "hardware", because many people are anchored to the consolidated production processes, in which product development is affected by high costs due to the inflexibility of high throughput fabrication technologies (e.g., injection molding). Today, 3D printing technologies (known also as additive manufacturing) are giving everyone, companies, makers, and inventors, the tools that were the exclusive prerogative of a few companies less than ten years ago [13].

These alternative design methods can contribute to economic growth: Open Source does not mean free and different business models are available [14]. Furthermore, attempts for quantifying the value of open source hardware development have been proposed [15].

We believe that academia, and specifically biomedical engineers in higher education, must embrace these new tools, and pass on the message that an Open Source product, developed by a community, without a multinational brand is not equal to un-reliable.

A note of caution however; the freedom given by the Web, and by the possibility to share, fork and re-implement projects, which characterises the Open Source Software, Electronic, and Hardware world, has one major drawback: organizing information (schematics, blueprints) and quality control are the boring parts that are not always pursued in a passion-driven and self-assembled community. In the context of biomedical engineering however, this latter aspect is critical for ensuring safety and efficacy of biomedical devices, and must go hand in hand with the adoption of open resources for medical applications. A possible structure of a web-platform for co-designing and sharing blueprints was already outlined [16].

ABEC: Capacity building for innovation

It is not trivial to define what exactly biomedical engineering (BME) is: BME is often regarded as an application of engineering concepts, mathematics, analysis, design, and possibly other methods to unsolved problems in biology and medicine [17]. This approach places great emphasis on niche subjects like MicroElectroMechanical Systems (MEMs) and cell engineering and less on the learning of new, hard technologies and equipment management, maintenance and repair [18]. In our opinion, very few graduates in Biomedical Engineering actually know how to design a device, or what it is required from a regulatory point of view. Five main areas of teaching are necessary for opening BME education:

- rapid prototyping through 3D printing (additive manufacturing) technologies;
- electronic prototyping systems;
- content management and sharing platforms;
- regulatory and safety compliance in design;
- Business development for medical technology.

These elements need to be integrated into a BME curriculum and adapted to the local social, economic and cultural needs.

A new type of BME is needed

The need to strengthen higher education in BME in Africa is strongly

Students, Lecturers and Stakeholders group photo at the Innovator Summer School 2015 (Addis Ababa University 11-15 January 2016

felt by the African Universities, which is why they agreed to pool their resources and work together as a consortium, ABEC (African Biomedical Engineering Consortium, www.abec-africa.org), at a review meeting held at Kenyatta University, in December 2012. ABEC recognises the peculiarities of the biomedical sector and the need for a more innovative way of teaching, learning and sharing information to complement traditional academic curricula. At present, ABEC is composed of 16 members from North, East, West and Southern Africa. The authors, from University of Pisa (Italy), are helping this process, providing external support as part of the ABEC secretariat.

Innovators Summer Schools: speeding up the ingenuity of African students

ABEC, in the framework of the United Nations Economic Commission for Africa (UNECA) initiative "Promoting BME Youth Innovations for Improved Healthcare Outcomes in Africa" (part of the activities of the New Technologies and Innovation Section (NTIS)) launched an annual series of university design competitions, offering winners a place at an Innovators Summer School, where practical courses on subjects such "Open Health Technology Design and Fabrication" (Kenyatta University, Kenya 2013), "From Making to Marketing" (Muhimbili University of Health and Allied Sciences, Tanzania 2014) and "Mobile Health Design" (Addis Ababa University, Ethiopia 2015) were held. Over 35 students, technicians and lecturers per year from 13 African Universities attended the Courses [19].

Next steps on the roadmap: Harmonization of medical device regulation

To ensure safety and health in a country it is essential to have regulations especially in the field of medical products. A widely held belief is that African countries do not have any regulations on medical devices, but this is not a correct assessment. About 10 years ago, the WHO performed a study on the presence of National Regulatory Authorities (NRA) in the 46 sub-Saharan African countries. The responsibility of NRAs is to regulate and control medical devices besides medicines, vaccines and blood products. Only 7% of these countries had a National Regulatory Authority (NRA) in place, while 63% had minimal and 30% no regulations [20]. Thanks to the international efforts and collaborations with African organizations (like the African Union or the African Organization for Standardization) as well as African governments and physicians, single guidelines and regulations were implemented in some countries.

ABEC universities, with their focus on safety and regulations and with their dissemination activities, both on the ground (i.e. students and academic personnel) both through policy making at government level, will promote and push harmonization on medical devices throughout the ABEC countries and beyond.
We thus argue that the new virtual sharing mentality should be wholeheartedly embraced, valorised and overseen by African (and indeed all) universities through the development of a dynamic needs-based curriculum and a common web-platform rendering the design, development, and maintenance of medical equipment accessible to trained Biomedical Engineers. However, the adoption of the new methods of thinking and creating like 3D printing needs to be coupled with open standards and regulations for medical device safety.

ABEC participants at the Expert Group meeting " Promoting BME Youth Innovations for Improved Healthcare Outcomes in Africa": (United Nations Economic Commission for Africa - UNECA - Addis Ababa, 9-10 January 2016)

Students group at the Innovators Summer School 2015 (Addis Ababa University, 11-15 January 2016)

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THE MARRIAGE OF TECHNOLOGIES

3D PRINTING DRONES FOR AFRICA

Moses gichangA Mwaura,
Principal Engineer, Autonomous System Research (ASR),
Nairobi, Kenya

The remotely piloted aerial system (RPAS) commonly referred to as drone is a technology that has been identified as a strategic platform for wildlife conservation, forestry conservation, data driven agriculture and many other critical areas of economic and environmental activities in Africa.

Professional drones require redundant systems, airworthiness certificates from the Civil Aviation Authorities, operator licenses and other legal requirements including insurance. They are, therefore, prohibitively expensive and many organizations that stand to leverage this technology opt to forego them. We at Autonomous System Research (ASR) decided to manufacture our own drones with locally available materials to make prototypes and an airworthy platform marrying it with 3D printing technology.

Additive manufacturing or 3D printing offers an avenue to affordably manufacture these and other technologies with cost optimizations and expedited schedules. In 3D printing an item of interest is manufactured through sequential layering of materials under numerical computer control. The layered materials range from concrete to plastic, from metals to biological materials. It is now possible to print with more than 250 materials and various combinations of materials. The most commonly used material is plastic as it is affordable and easily workable - one need only heat it up and extrude it through a nozzle to form layers. 3D Printing creates manufacturing capability right at the laboratory or office level and designs can be tested immediately without having to send designs to a manufacturer. Prices of 3D printers have gone down following the lapse of patents that hindered many companies from developing this technology. This has facilitated the realization of final products in a timely and cost effective manner.

The primary activity that requires a lot of attention during the 3D printing process is the design phase, specifically creation of 3D models and assemblies using Computer Aided Design (CAD). It must be noted that gadgets such as drones require electrical assemblies and mechanical linkages which cannot be easily and affordably 3D printed in one step. While the trajectory of the technology is towards the 3D printing of such gadgets in one go, the current cost effective method is printing and assembling of parts.

In the course of developing our 3D printed drone, we went through a few considerations, such as the maximum print volume of our printer, the materials we will use, their strength especially bearing in mind airworthiness and sufficient light materials for optimal aerodynamic efficiency, cost, and time of delivery of the product. Herein is an account of our experience using the technology to elaborate what one can expect in using these technologies.

The Design Stage

There are a few processes conducted prior to a good print, and like any engineering undertaking, these processes start with planning. Object planning for manufacturing, be it conventional or additive manufacturing, is done using Computer Aided Design (CAD) software. CAD software is used to create precision drawings or technical illustrations of the object being modelled. There are proprietary software versions, such as Autodesk and open source versions such as FreeCAD. We used CAD to create 3 dimensional models and illustrations of our drone. These are models that precisely describe an object within all physical dimensions of that object: length, breadth and height represented by the x, y and z axes.

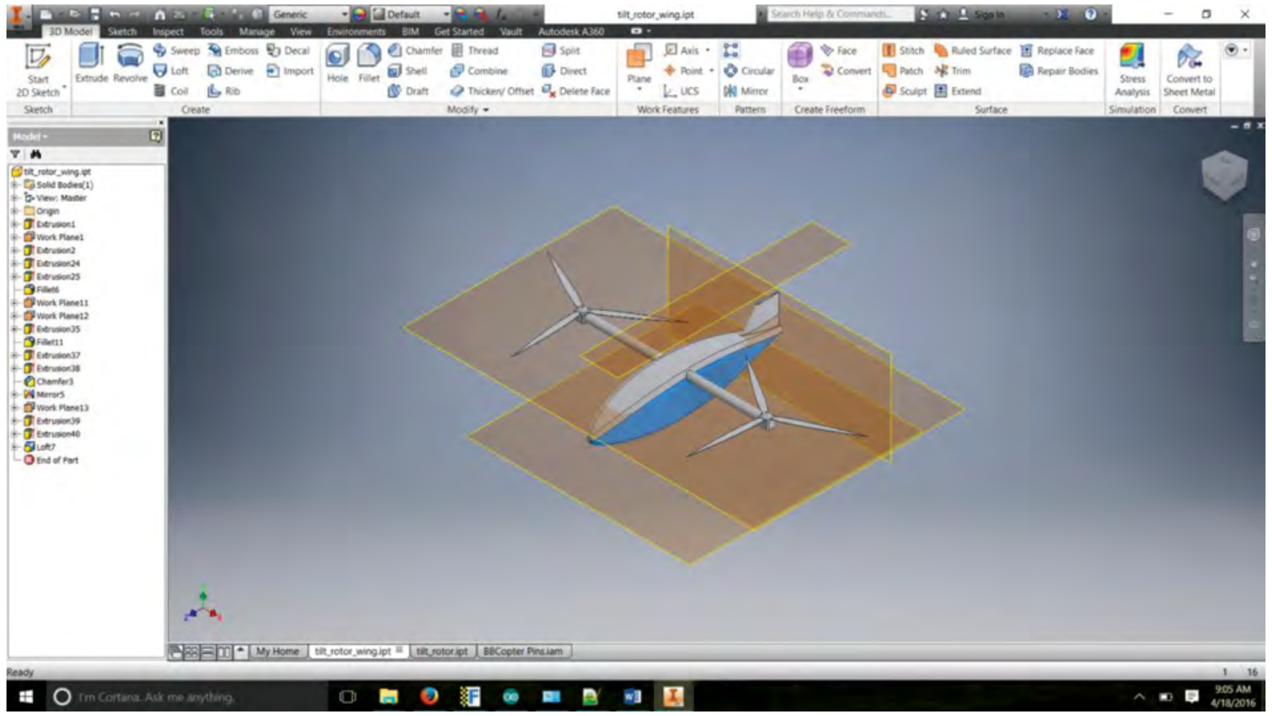

Fig 1.0 Designing the drone using 3D CAD software

3D printers vary in their print volume - a measure of the maximum size of an object that can be printed using that printer. The variation is huge as there are now 3D printers with print volumes from the nanoscale to the megascale. BAAM (Big Area Additive Manufacturing) systems can print large volumes like whole cars or large scale signage and statues. An Israeli company called Massivit is one of the companies specialising in large scale 3D printing and has printed a two-meter shark figurine for a campaign for the protection of sharks. The printing technique of the particular printer is a crucial factor that determines the print volume.

The design of the object to be printed will have to take into account the print volume of the printer available to us. We, thus, made subassemblies from the main drawing to fit in the printer. CAD enables creation of distinct parts which form the whole assembly, as a way of managing the design. It was then possible to print a large drone on a relatively small printer by printing the parts and assembling them later.

The Slicing

Once all modelling has been made, the next step is to pre-process the part model or subassembly CAD file with a program that analyses it and creates layers or slices of the model that can be incrementally printed to realize the object. This process is referred to as slicing; a number of proprietary and open source programs are available. Open source slicers include KSlicer, Cura, MatterControl, to name but a few. At this juncture the operator should optimize the print to avoid material wastage as well as the speed of the print, accuracy, overall finish quality, and other parameters of interest.

> *ONE MAY* SAY THE MARRIAGE OF THESE TWO TECHNOLOGIES IS FAR FROM CONSUMMATED AS APPLICATIONS OF THE TWO TECHNOLOGIES IS JUST BEGINNING.

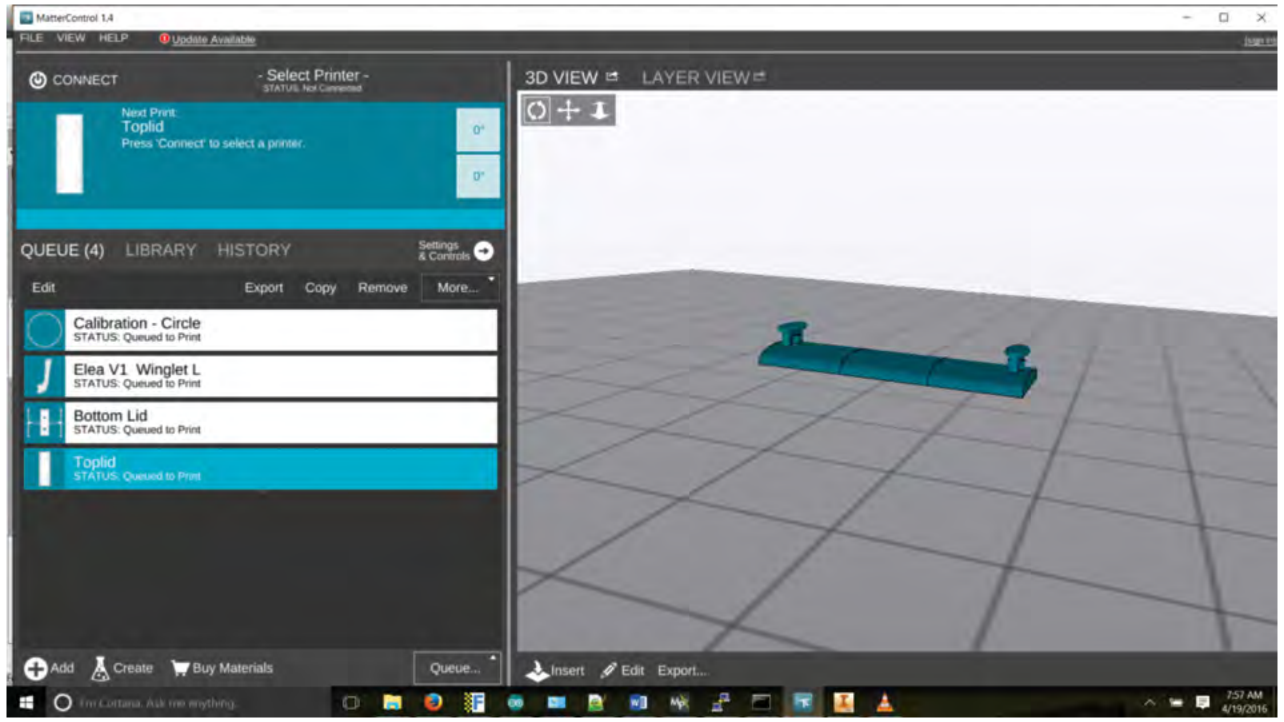

Fig 2.0 Slicing the model part using MatterControl

Once the slices are analysed and seen to be workable (meaning there are no errors found such as gaps in slices or other errors which would result in an unprintable object), the user then prepares the print by generating the step by step instructions that are read by the printer by saving the model ready for a particular printer. These instructions are saved in a numerical control programming language, such as G-Code, the most common language. These machine instructions guide the printer when to extrude the material, in what quantity, at what parameters such as temperature, at what position within an X, Y, Z framework of dimensions among other parameters.

The Printing

Precision through which layers are added is measured as the tolerances through which the extrusion process is able to accurately replicate the model part from which the object is being made, as well as the precision with which the extruder is moved within the X, Y, Z coordinates. The higher the precision, the better the quality of the part. Printers with high precision are costly at the moment. Using relatively inexpensive but low precision printers requires that the settings are optimized to ensure correct part printing. This involves temperature setting, nozzle adjustment, and other parameters.

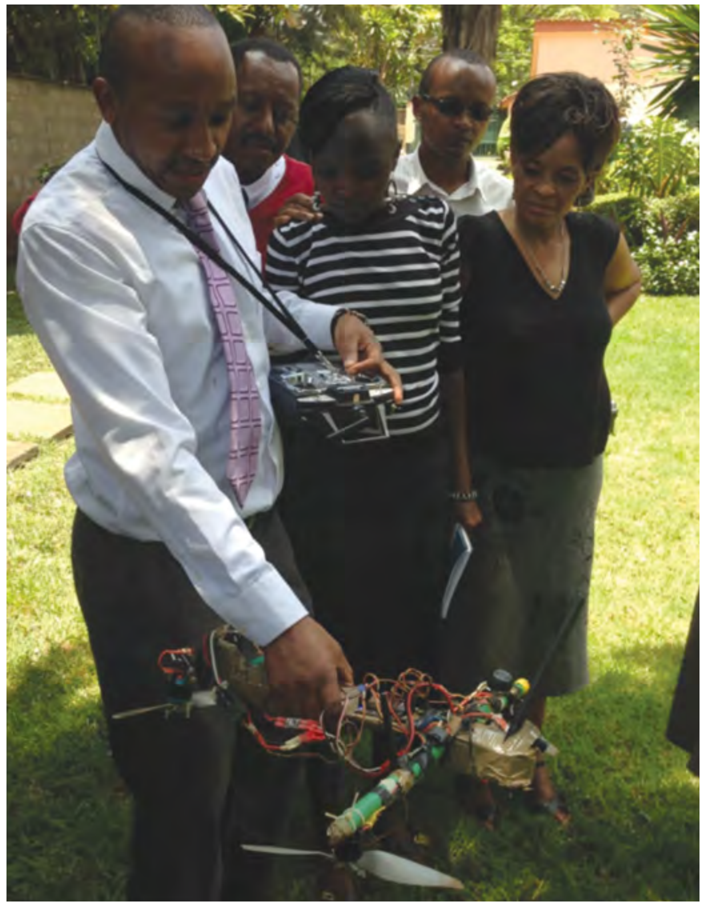

Fig 3.0 Demonstrating an earlier version of the drone to ACTS staff. No 3D Printed parts yet.

Before printing the operator needs to ensure that there are sufficient materials to the job to be printed, to avoid reloading in the middle of a job which could affect quality.

Once the parts are printed they are inspected for quality control to make sure they meet the required standards. Some augmentation may be necessary to get them to interconnect with other parts.

Fig 4.0 Assembling the parts

Any electrical and mechanical linkages necessary for the functioning of the object are installed prior to final assembly of the object. Provisions are also made to reinforce the structure with composite materials including carbon fibre, Kevlar and Teflon impregnated with epoxy or polyester resin to ensure structural integrity and to comply with stringent airworthiness criteria set forth by Civil Aviation Authorities.
Testing according to a test plan is the next activity to be conducted. This may include full functional testing and part or subassembly testing, with score cards for assessing the outcome. Once all tests are passed, the printed object, our drone, is now ready for flight test.

Fig 5.0 Flight testing the drone after assembly of parts including 3D printed parts

The benefits of drones have become evident even as regulators continue to impose restrictions and drone – free zones. Enforcement mechanisms from trained birds that bring down drones like their prey to the hacking of their programs causing them to crash-land are under development. These developments have been given headline story status while the advantages of drones and the various innovative applications do not receive as much attention. However, the benefits of drones by far outweigh their real and alleged disadvantages. Drone technology is still at its early stages and most, if not all, of the disadvantages will be removed with more research and innovation.

The particular relevance of the use of drones in the African context can be illustrated with the experiment in Malawi. Drones are being used to take blood samples from the remote regions of the country to the labs for HIV tests. This will drastically cut the waiting time for the results from months to weeks. It was a similar use of drones that was a finalist in the Dubai 'Drones for Good' competition. The project to use drones to airlift donated organs from accident victims from the site of the accident to the hospital is under development in India. The developers are working with a hospital in India to launch the organ transport service. Back here in Africa, this year Rwanda will start using drones to deliver blood and vaccines to half the transfusion centres in the country and will cover the entire country of 11 million people next year. The drones will make the deliveries 20 times faster than by land. This is just a tiny bit of the iceberg for the applications of drone technology in the African context. One may say the marriage of these two technologies is far from consummated as applications of the two technologies is just beginning. It is not only the 3D Printer printing drones but also the drones being used to 3D print structures that demonstrates the wide open possibilities of using the two technologies. When a 3D Printer is mounted on a drone and is used to print structures in disaster areas, it is even confusing to identify which technology is playing the major role - the '3D printed drone' or the 'drone 3D printer'. Certainly we need more of the drones with more functionality and payload and 3D printing is the way forward to build them part by part and eventually in their entirety in one step.

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DIGITAL BLACKSMITHS AT WORK IN AFRICA

Melissa Menke, Techfortrade, Nairobi, Kenya

Down a winding road of rolling dirt hills fifteen minutes from the Dar Es Salaam International Airport in Kitunda, Tanzania, is a plot of land seemingly like all of the others. As you enter you will hear welding and cutting. Further in, you will see a concrete and canvas structure housing fish with an array of accompanying boxes and tanks. If you pause to look, someone from STICLab will quickly start to explain to you the array of sensors and controls for automating fish feeding, monitoring temperature and circulating water.

Past the urban aquaculture set-up is a concrete building with four rooms. Inside the first room, 3D printers are whirring and a structure made of metal and electronic waste, hardly recognizable as a homemade CNC machine, sits in the corner. The next room over is a physical science lab, followed by the open makers space, and then finally a small office at the end, and there you find Mr Stanley Mwalembe, the founder of the first Tanzanian Maker Space, STICLab (STIC stands for Stamwa Technology Innovation Center), launched in 2015. It is not only the first Maker Space in Tanzania. It is also a centre hosting a state of the art digital fabrication lab. Furthermore, what makes it exceptionaly unique is the fact that 80% of the equipment being used including tools such as CNC Milling Machines and 3D printers are made locally by STICLab itself.

Mr Mwalembe's office at the Dar Institute of Technology (DIT) looks like a miniature lab, with catfish cultivation overflowing into the main campus. His passion for technology, design and innovation has always been tangible to his students and those around him. A research scientist at his core, Mr Mwalembe's talents and interests are broad and his lectures at DIT include electronics and computer hardware, game design, multimedia, 3D visualization and animation. Mr Mwalembe is a teacher, innovator, entrepreneur and professional with a reputation for being able to pull teams together to contribute to a wide range of projects from traffic control systems to curriculum design.

STICLab is progressively demonstrating its potential to achieve its vision of becoming Africa's leading Maker Space, providing cutting edge technology solutions that transform African Society. STICLab is equipped with the people, machines and tools ready to provide engineering solutions to community challenges. Mr Mwalembe brought on two former students and an electronic artisan to form the lab, and they were registered as a private limited company - STICLab Ltd. The lab has now people with skills ranging from electronics and computing to mechanics and engineering design, just to name a few.

Working alongside STICLab Co-Founders are community fundis (Swahili for craftsman, artisan, or mechanic) who use the metal shop, located opposite the main building. While their focus is on innovative engineering projects, their openness to share space and resources for a fair deal have made them an asset to people in the community—making doors, benches and other items for sale. Students from DIT conducting practical coursework or consulting on projects with Mr Mwalembe filter in and out.

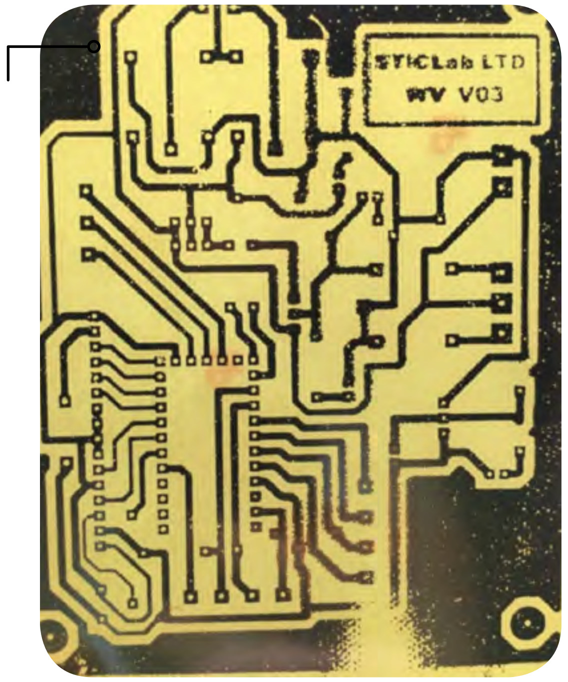
Interested locals drop in to learn about the latest projects, and others from central Dar Es Salaam or semi-rural Tanzania are making the trip to the workshop. The group of people at the workshop are getting increasing recognition by the community as innovators, machine builders and problem solvers. The problems in the community range from water resource management to safe communion systems for churches and the workshop has proved itself as a favourite destination for seeking advice and solutions. The workshop deployed its retr3d printers in addressing these problems and in the design and prototyping process for making custom gears or bespoke LCD screen holders, and sometimes producing full products made primarily from 3D printed parts.

Printing Digital Beehives

STICLab has come up with an innovative application of 3D printing for beekeeping. Bee colonies are an important part of the agricultural ecosystem providing pollen to plants and honey, which is enjoyed by people too. In Tanzania, many farmers struggle to finance investments in bee keeping due to long payback periods caused by the slow, unpredictable process of waiting for bees to swarm.

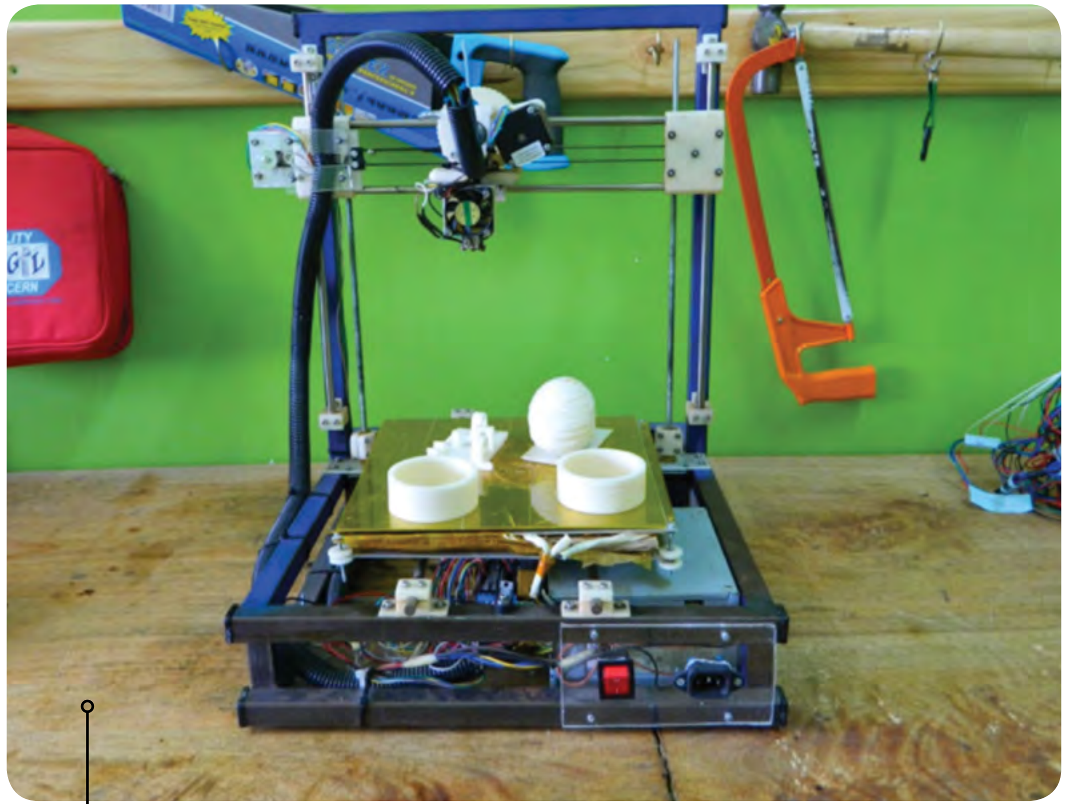
STICLab has designed a digital beehive to support queen bee production. Queen bees are incubated in 60 custom 3D printed queen cups. The hive has two windows in the wooden box frame where cameras record the activity inside. Sensors measure temperature, humidity and sound. Information is sent via GSM (Global System for Mobile Communications) network to remote computers set up to monitor hive activity such as egg laying and queen hatching.

Printed circuit board, made in the physical science room at the lab



ON TOP OF EQUIPMENT CHALLENGES, DESIGN EDUCATION HAS NOT OFTEN CAUGHT UP TO MODERN RAPID PROTOTYPING TECHNIQUES.

Digital Beehive and remote monitoring system



The retr3d printer at STICLab

The research from this project showed promising results, spurring the creation of a Bee Lab at the STIClab facilities in Kitunda where research on digital beekeeping is ongoing.

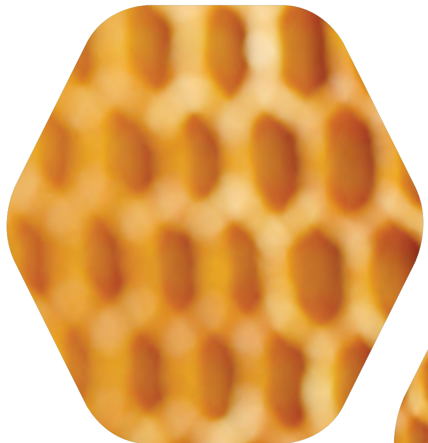
STICLab is part of the Digital Blacksmiths Network, a techfortrade initiative. techfortrade is a young charity that works at the intersection of technology and economic development. It has established itself as a leader in 3D printing for Development, working to systematically break down barriers to 3D printing adoption.

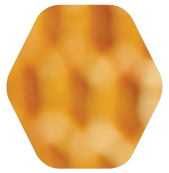
Digital Blacksmiths are engineers and makers in the developing world who are interested in using 3D printing to develop meaningful community projects and nurture a workforce knowledgeable in science, technology, engineering, and mathematics (STEM) disciplines. Network members share designs, supply chain challenges and tips. Other Digital Blacksmiths shops are located in Nairobi, Kenya and Kumasi, Ghana with more coming online soon.

While STICLab demonstrates the potential of 3D printing to contribute to community development, the challenges faced by potential Blacksmiths are many and can appear insurmountable. 3D printers are relatively expensive and are not readily available in developing markets. A broken part can render a full machine unusable with customer support and repair pieces in another continent.

The filament that is used as the feedstock for a 3D printer is also not available in local markets. On top of equipment challenges, design education has not often caught up to modern rapid prototyping techniques. Even if an entrepreneurial engineer wants to face all of these challenges, the perennial issues surrounding access to capital and a viable business plan for the enterprise would remain.

In response to these challenges, the techfortrade team started work on the design of a 3D printer that could be easily made with materials available in most developing countries, adjusted according to part availability, and powered by electronic waste. This printer can be built and sold by the Digital Blacksmiths in their countries, providing revenue to sustain their businesses. Version 3 of the retr3d printer is currently being collaboratively built by seven blacksmiths and techfortrade Technical Director Matt Rogge across three countries. The machine prints similar quality to a MakerBot, but costs only $350 and can be locally repaired if needed.





On the heels of the retr3d printer, techfortrade is working on the design of an open source extruder that takes PET plastic flakes and turns them into usable 3D printer filament. This would make it possible to capture waste from plastic bottles and upcycle it into inputs for the products made by Digital Blacksmiths.

We need to see more partners supporting hardware innovation and homegrown manufacturing to make this model work. Materials testing is getting cheaper and needs to spread, which will provide essential product integrity testing for distributed filament production. Additionally as Digital Blacksmiths develop new products and prepare to scale production they will need further investment in building up manufacturing capabilities, and possibly for R&D on new community challenges.

We see 'made in Africa' as a stamp of pride for the products that come out of these shops, and the solutions as those that could only be conceived with the localized knowledge and networks of the Blacksmiths themselves.

WE SEE 'MADE IN AFRICA' AS A STAMP OF PRIDE FOR THE PRODUCTS THAT COME OUT OF THESE SHOPS, AND THE SOLUTIONS AS THOSE THAT COULD ONLY BE CONCEIVED WITH THE LOCALIZED KNOWLEDGE AND NETWORKS OF THE BLACKSMITHS THEMSELVES.

Further reading
http://sticlab.co.tz/
http://creativemachines.cornell.edu/free-loader
http://www.amazon.com/Printing-Development-Global-South-Challenge/dp/113736565X

Melissa Menke is working on growing the Digital Blacksmiths network with techfortrade, a UK based charity working at the intersection of technology and economic development. techfortrade provides start-up investment, training, business coaching and in house design support to network members. Melissa has spent a decade working in economic development with an emphasis on market-based solutions. Melissa started Access Afya, a low-cost health enterprise working on community based care models. She currently lives in Nairobi, Kenya.
@melissa_menke
www.techfortrade.com

ON BOARD AND IN REAL TIME

AN AFRICAN CENTRE FOR EXCELLENCE IN 3D PRINTING

Hailemichael Teshome Demissie,
PhD, Senior Research Fellow, African Centre for Technology Studies (ACTS), Nairobi, Kenya

3D Printing Technology Centres of Excellence of various sizes are sprouting around the world. The US, UK, the EU states, and Australia have established national centres for 3D Printing. The US with an outlay of 1 billion USD is setting up a network of 15 such centres under President Obama's proposal for the National Network for Manufacturing Innovation (NNMI).

The UK on its part has earmarked £15 million for a national centre for 3D Printing that will mainly serve the aerospace and automotive industries. The UAE launched the International Centre for 3D Printing at Dubai Industrial City implementing the directives of the Dubai 3D Printing Strategy that aims at making Dubai an international destination for 3D printing by 2030. Singapore established the Singapore Centre for 3D Printing with $107.7 million in government and industry funding. This is a continuation of the ever expanding trend of a stronger university-industry linkage that the OECD countries embarked on in the early 1970s followed by emerging and developing countries in the 1990s and 2000s.

The jury is still out on the economics, success and impact of centres of excellence, also known as science and technology parks (STPs), incubators, innovation hubs or the more generic label of 'Areas of Innovation' that the International Association of Science Parks (IASP) uses. The studies by the 'triple helix' scholarship on the academia-government-industry interactions, the analysis by the 'national innovation system' literature and the management sciences has come up with evidence on the impact of centres of excellence that only shows 'a mixed record of success'(Mowery and Sampat,2006). This assessment, however, does not sit well with the perception of the public and policymakers about Centres of Excellence and the phenomenon of the proliferation of such centres around the world.

As Manuel Castells and Peter Hall observed in their book *Technopoles of the World: The Making of 21st Century Industrial Complexes,* Silicon Valley, despite the myths of its origin and the metrics and factors of its success, has 'a guaranteed place in history as the original industrial core' of the ICT revolution. If we go by the success story of Silicon Valley that has its roots in the first tech park in the world, there can be little doubt as to how valuable science and technology parks or centres of excellence are irrespective of the contested factors for their success. The uncertainties as to the metrics of their impact aside, researchers who studied these centres simply acknowledge that they are 'decidedly important for the emergence of innovations'. This is well received by policymakers as country after country continues to build centres of excellence particularly for research and development on emerging technologies.

The global proliferation of centres of excellence is indeed proof of the significant roles they play in expediting innovation and commercialisation of research outputs. Since the first tech park was set up in 1951 near Stanford University, the number of such institutions around the globe has risen to more than 400. Initially, limited to developed countries, the tech park idea has caught on with emerging and developing economies. The idea has even got a momentum of its own and entire cities have adopted the role of technology parks. The Siberian city of Akadegomorok, the King Abdullah Economic City (KAEC) project, Japan's Tsukuba and Kansai, South Korea's Daedoek Science Town, the Gauteng City-Region in South Africa and the proposed Konza Technology City in Kenya are good examples as to how the idea has evolved from a reference to parks tethered to a university into mega projects of science cities.

The justification for centres of excellence or science and tech parks lies in their critical role in generating scientific and technological synergy from academic research, government and industry funding, and business incubation. The following definition of science parks by the International Association of Science Parks (IASP) - an international network established in 1984, captures the essence of what centres of excellence are designed for.

A Science Park is an organisation managed by specialised professionals, whose main aim is to increase the wealth of its community by promoting the culture of innovation and the competitiveness of its associated businesses and knowledge-based institutions... To enable these goals to be met, a Science Park stimulates and manages the flow of knowledge and technology amongst universities, R&D institutions, companies and markets; it facilitates the creation and growth of innovation-based companies through incubation and spin-off processes; and provides other value added services together with high quality space and facilities. (quoted in Mowery and Sampat, 2006)

The Centres bring together academia, the government, public and private funding agencies offering technical infrastructure, logistics and administrative support for their tenants. They are the scientific equivalent of the Agora where researchers and developers from various disciplines meet and interact.

Centres of Excellence in Africa

The concept of Centres of Excellence has gained firm ground in Africa with an even more significant purpose than in the developed countries. Such Centres are thought to serve as magnets for investment for the technology-based growth that is lacking in the mainly resource based African economies. With the understanding that centres of excellence could be a solution for initiating and stimulating technology based growth for Africa, they have been adopted in several countries including Algeria, Egypt, South Africa, Senegal, Kenya, Botswana, Morocco, Ivory Coast, Rwanda, Zimbabwe, Namibia, and Tunisia. While only 15 science parks from six African countries are admitted to the international network of IASP, many African countries are aggressively building new centres and strengthening old ones. Tunisia plans to have 10 more science parks within a decade while Botswana will be opening the buildings constructed for the Botswana Innovation Hub this year - five years since the establishment of the Hub.

Apart from the efforts at the national level, there are a number of projects at the regional and continental level. The AU Science, Technology and Innovation Strategy for Africa 2024 (STISA 24) puts particular emphasis on the role of networks of centres of excellence for realising the full potential of science, technology and innovation to support sustainable socio-economic growth and development, and improving African competitiveness in global research and innovation. The Centres of Excellence in Africa focus on ICTs, Biotechnology and energy technology. The focus on emerging technologies is understandable given the newness of the technologies and their strategic importance. As pointed out by Corbin Guedegbe and his co-authors in their contribution entitled 'Creating New Centres of Excellence in Africa', the strategic importance of the technologies, the need for new firms commercialising the technology applications and meeting the rising demand for the applications are some of the reasons that bring together academia, governments and industry in pursuit of these technologies.

As yet Centres of Excellence on 3D Printing have not been introduced in Africa but it is merely a matter of time before we see them around the continent. The Consolidated Plan of Action (CPA) that STISA 24 is to implement has flagship programs on fields that contribute to 3D Printing, namely, laser, material science and engineering for manufacturing. 3D Printing Centres of Excellence will accelerate the development of these flagship research and development programs while at the same time utilising their applications to develop 3D Printing technology. These flagship programs will offer the fertile ground for Centres of Excellence on 3D Printing to grow sooner than expected. Mr Alan Boshwaen, the CEO of Botswana Innovation Hub observed that centres of excellence are rising at a phenomenal rate on the African continent. The theme of their activities will certainly respond to emerging technologies like 3D printing.

An African Centre for Excellence in 3D Printing Technology

In the developed countries, centres of excellence on 3D printing are being quickly set up with the aim of capturing the benefits of the technology for competitiveness in manufacturing and other sectors. Africa could not be a mere spectator while the rest of the world forges ahead with the technology. It was in reaction to these developments that the African Centre for Technology Studies (ACTS) and Kenyatta University (KU) took the initiative to set up the African Centre for Excellence in 3D Printing Technology. The Centre is to serve as a platform for capacity building, policy research and knowledge and technology brokerage on 3D printing. The principal aim of the Centre is to foster the next generation of the African manufacturing workforce by providing opportunities for capacity development and exposure to 3D Printing that cuts across disciplinary boundaries both within and between the natural and social sciences.

The Centre will engage in three interlinked streams of work: research, capacity development, and policy engagement through knowledge sharing and advocacy. The project also involves a set of activities relating to the governance and management of the Centre, including the setting up of research labs, systems and processes for ensuring the Centre's sustainability over the long term. ACTS and Kenyatta University partnered to formally establish this pan-African Centre as a leading interdisciplinary research centre on various methods and techniques of 3D printing technology, its underlying science and engineering concepts and the policy issues impacting its development and diffusion including the disruptive effects it may have on the African economy and the livelihoods of its people.

Chandaria Innovation Centre where the ACTS-KU African Centre for Excellence in 3D Printing Technology will be housed

The key emphasis of the Centre is to develop practical tools and human capital to enable African countries harness the benefits of 3D printing technology and allied fields of research. The Centre aims at harnessing emerging technologies in digital manufacturing for purposes of poverty eradication and achieving global economic competitiveness.

The Centre will inform and accelerate the policy making process regarding 3D printing in Africa to harness the technology and related business and innovation ideas to spur sustainable development. It will work towards achieving policy buy-in from African governments by providing the forum for policy discourse in order to realise the objective of harnessing 3D printing for sustainable development in Africa. Through research, capacity building, policy dialogues and knowledge and technology brokerage, the Centre will support the national priorities of African countries to develop their manufacturing sectors by realigning them with the technological advances changing the entire face of manufacturing.

The work of the Centre will result in the recognition of 3D printing technology as a strategic technology for an industrial revolution in Africa. The Centre will initiate policy dialogues on the role of the technology in accelerating economic development in the region and in mitigating the risk of costly disruptions the technology is inevitably triggering. The economic, environmental and social benefits accruing from the adoption of the technology will be determined by the conducive policy environment that policy makers need to put in place. Advocating policy buy-in and public acceptance is a central objective of the project. The project aims to impact the rate of adoption of the technology by highlighting the benefits of the technology and the opportunities that will be missed as a result of an undue lag in the adoption of the technology. The project will thus aim at directly reaching out to policy makers and major players in the various sectors of the economy highlighting the configuration of emerging value chains that the adoption of 3D printing technologies is set to create.

Fig 1

ACTS staff took part in the 3D Printer Assembly workshop at Kenyatta University during the ICAT (International Conference on Appropriate Technology) conference. (Fig1&2)

Fig 2

THE GLOBAL PROLIFERATION OF CENTRES OF EXCELLENCE IS INDEED PROOF OF THE SIGNIFICANT ROLES THEY PLAY IN EXPEDITING INNOVATION AND COMMERCIALISATION OF RESEARCH OUTPUTS.

Centre of Excellence vs Centre for Excellence

Researchers that have looked at the African centres of excellence throw criticisms of various nature. Corbin Guedegbe *et al* have examined the accusation that the Centres are run more like real estate operations than centres of knowledge production and commercialisation. The motivations of their establishment in their particular locations are questioned as some are said to have been located on a specific area for political considerations rather than the potential for the synergy they are to generate. Even charges of over-capacity are also raised claiming that they are built without having regard to the potential tenants and the requisite network needed for the proper running of the centres.

These criticisms are credible and ACTS and KU are aware of the shortcomings that will crop up when the centre starts fully operating. For this reason, careful consideration was given in naming the centre as a 'Centre for Excellence' rather than as a 'Centre of Excellence'. The preferred name of the Centre reflects the ambitions of the core partners of the project to build competence and excellence. In addition to expressing the ambitions for the Centre, the name is also realistic and inculcates the lessons from the criticisms thrown at the already established Centres of Excellence in Africa. ACTS and KU believe the name will be inspiring to those who work in the Centre guiding them to work towards transforming the 'Centre for Excellence' to a globally competitive 'Centre of Excellence in 3D Printing'.

The Centre will work to ensure that Africa will not just be a follower but a leader in the field - a potential the signs of which were observed when the first ever 3D Printer to be built out of e-waste was made in Africa. Budding African entrepreneurs and innovators are showing the world that Africa is already on the revolutionary technological trajectory that 3D printing has opened up. ACTS and KU are committed to make sure that Africa remains on board and moves on with the latest development in the technology in real time as it happens.

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AFRICA SHOULD TURN TO HIGH-SKILL MANUFACTURING TO AID SUSTAINABLE GROWTH

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One of the most puzzling paradoxes of the much lauded recent African growth is its bizarre matrix of high growth and high unemployment.

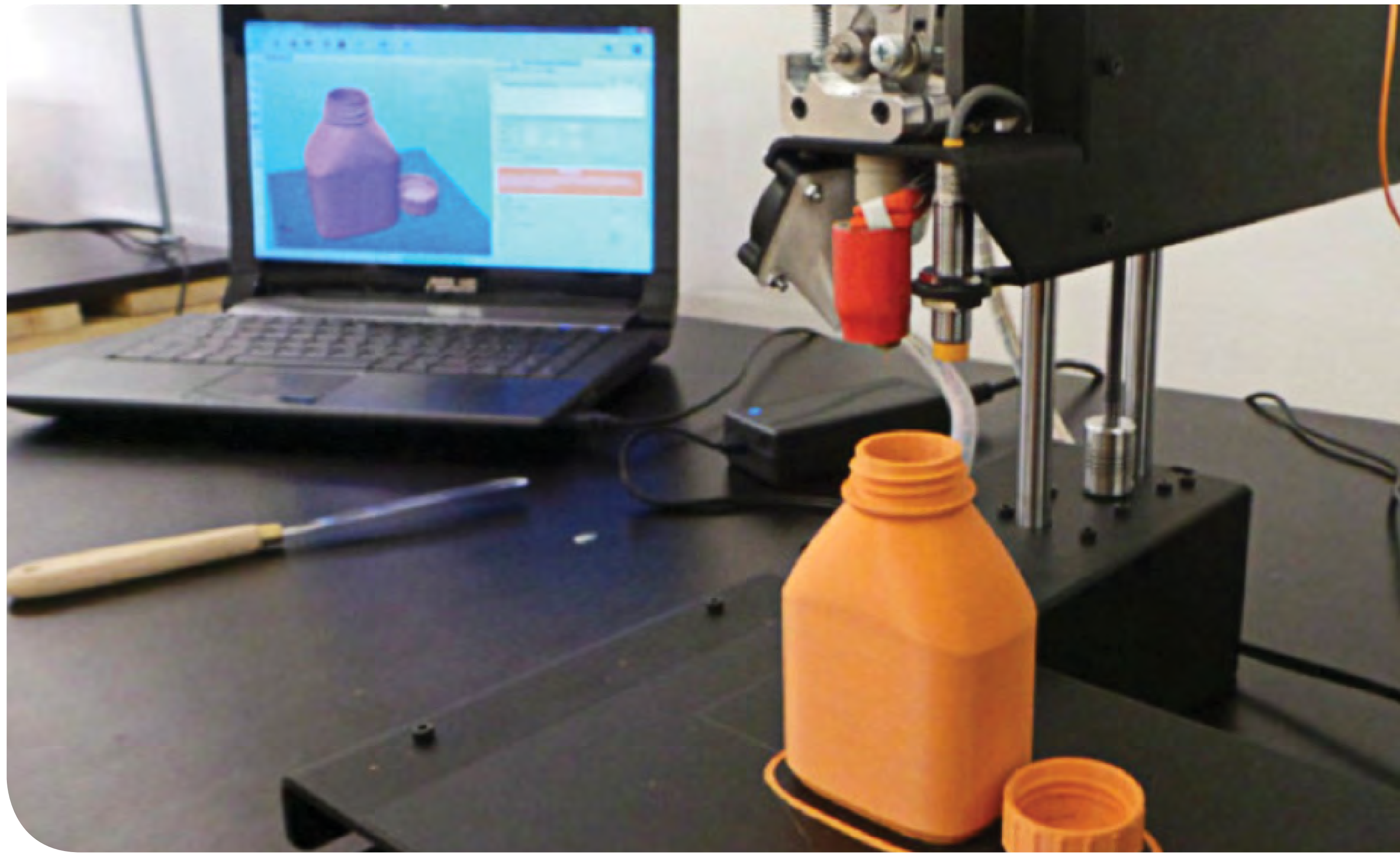
The low impact on poverty reduction and unemployment of the otherwise impressive growth has, in turn, been attributed to the low contribution of the manufacturing sector. Manufacturing has stagnated and contracted while the service sector continues to grow at a strong rate, leaving economists pondering whether Africa is undergoing a premature de-industrialisation. [1]

Africa is expected to benefit from more manufacturing jobs due to China's rising wages and transition to high-value, high-skill manufacturing.
But the likelihood of attracting these jobs is likely to suffer setbacks as a result of the rapid rise of digital manufacturing, especially 3D printing.

The insourcing boom in developed countries should be disquieting for developing countries awaiting their manufacturing moment: it is a trend that marks the beginning of a reversal of the migration of jobs to low-wage regions.

In 2013, President Obama celebrated the return of manufacturing jobs back to the United States from Japan and Mexico by hailing 3D printing technology as offering the potential to resuscitate and revolutionise manufacturing in the country.

3D printing tech: 3D printing technology, also known as rapid prototyping, additive or digital manufacturing, has been around for at least the last three decades.



3D printing technology, also known as rapid prototyping, additive or digital manufacturing, has been around for at least the last three decades. However, it is only in the last five years that it has come to widespread use in the manufacturing sector. 3D printers turn digital design data into a three-dimensional tangible, physical object.

Various materials and processes are being used to print solid 3D objects: plastic resins, metals, wood fibre, carbon fiber, construction waste, desert sand, human tissue and many others. New materials, methods and combinations of materials and methods are being introduced to perfect the technology.

Initially, 3D printing was used as a niche activity in big manufacturing firms that mainly used it to develop prototypes. The technology is invariably described as disruptive. For example, in one survey, respondents from industries and academic institutions said they expected 3D printing to be "the most disruptive technology" in the next three years.

Surveys carried out by global accounting firms such as PwC and Deloitte have shown a similar result concerning the disruptive potential of 3D printing technology, suggesting it could be on a level never seen before. [2,3]

The technology's impacts

Africa is certainly to be impacted by the disruptions 3D printing technology is set to trigger. The continent's position as a preferred destination for low-wage jobs from Asia is now being undermined by the advent of the technology, which can do manufacturing at a negligible cost, with little or no wage labour.

Of the 100 million jobs expected in developing countries as a result of China's transition to high-value, high-skill manufacturing, Africa is to land none or very few.[4] The destination of these jobs remains unknown.

It is not another region with cheap labour that is thwarting Africa's ambition to succeed China as the factory of the world. Rather, it is technology that promises to slash the cost of manufacturing to a "near zero marginal cost".

The exploitation of cheap labour can no longer serve as the comparative advantage in the face of the relatively cheap, yet highly efficient technology that is radically overhauling the manufacturing sector around the globe.

Even in the scenario where Chinese factories relocate to Africa, it is questionable whether these factories will be competitive (assuming that they will still have to incur considerable cost of labour).

Given the rapid obsolescence of conventional manufacturing models, it is also uncertain whether these factories will be sustainable in the short-run or the long-run.

What Africa should do

In order to remain economically competitive, Africa should accelerate the process of transitioning to high-value manufacturing by acquiring and developing capabilities in 3D printing technology. This transition cannot be realised by merely repeating what China has done, to relocate Chinese plants to Africa.

Calestous Juma, an expert in science and technology for development, draws attention away from advice that Africa should follow on China's footsteps in the context of the rise of 3D printing technology. Instead, he argues that Africa should emulate Taiwan — that "the rise of 3D printing could do for Africa what semiconductors did for Taiwan in the 1960s".

The fate of manufacturing in Africa is increasingly tied to emerging technologies, particularly 3D printing technology, that *The Economist* labelled as "the third industrial revolution". Yet uptake of the technology has been slow and the discussion about its relevance and potential for African development is rather muted.
Africa needs to take advantage of 3D printing, drawing lessons from the developed world's engagement with the technology.

President Obama's pledge to turn America's 'Rust Belt' into a 'Tech Belt' deploying 3D printing technology is instructive for Africa too. The US government's decision to open several 3D printing manufacturing hubs in a bid "to turn regions left behind by globalisation into global centres of high-tech jobs" is not only a precedent to emulate, but also a serious warning if Africa chooses to ignore it.

The opportunity to turn the towns and countries of Africa into centres of high-tech manufacturing needs to be seized with no less vigour than that shown in the developed world.

> *The opportunity* **to turn the towns and countries of Africa into centres of high-tech manufacturing needs to be seized with no less vigour than that shown in the developed world.**

African countries should consider the following recommendations for harnessing 3D printing technology for sustainable development (see Below).

1. Initiate and foster trans- and interdisciplinary collaboration in the development of additive manufacturing or 3D design and printing technology in Africa.

2. Create the innovation ecosystem for 3D printing technology by bringing together funding agencies, academic institutions, governments, non-governmental agencies, entrepreneurs, industries and research institutions.

3. Support the design and adoption of local, national, regional and continental policies, regulatory frameworks, guidelines and funding strategies to facilitate the adoption of the technology.

4. Support the development of 3D printing curriculum and its integration in existing engineering, materials science or other curriculums or its offering as an interdisciplinary stand-alone course at undergraduate and postgraduate levels.

5. Undertake innovative high-quality and internationally competitive research in collaboration with major national and international centres and research programs to help strengthen research and maintain and raise Africa's research excellence in additive or digital manufacturing research.

6. Support workforce development and the development of expert networks, R&D infrastructures through human resource development and acquisition of software and hardware.

7. Initiate and support start-up and spin-off companies and foster entrepreneurship creating technology jobs in the making and servicing of both the hardware and software tools of 3D printing technology.

8. Draw resources and expertise from governmental and non-governmental organisations, academic institutions, industries, international and regional funding agencies into a cooperative endeavour to keep abreast of the latest advances in additive manufacturing.

9. Monitor and create awareness about the state of the technology, its potential and the disruptive impacts with regard to African economies, drawing attention on how the disruptive innovation can be turned into an opportunity that contributes to national and regional renewal of the manufacturing sector and, ultimately, to socio-economic development in general.

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