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ISSUE BRIEF

3D Printing: Shaping Africa's Future

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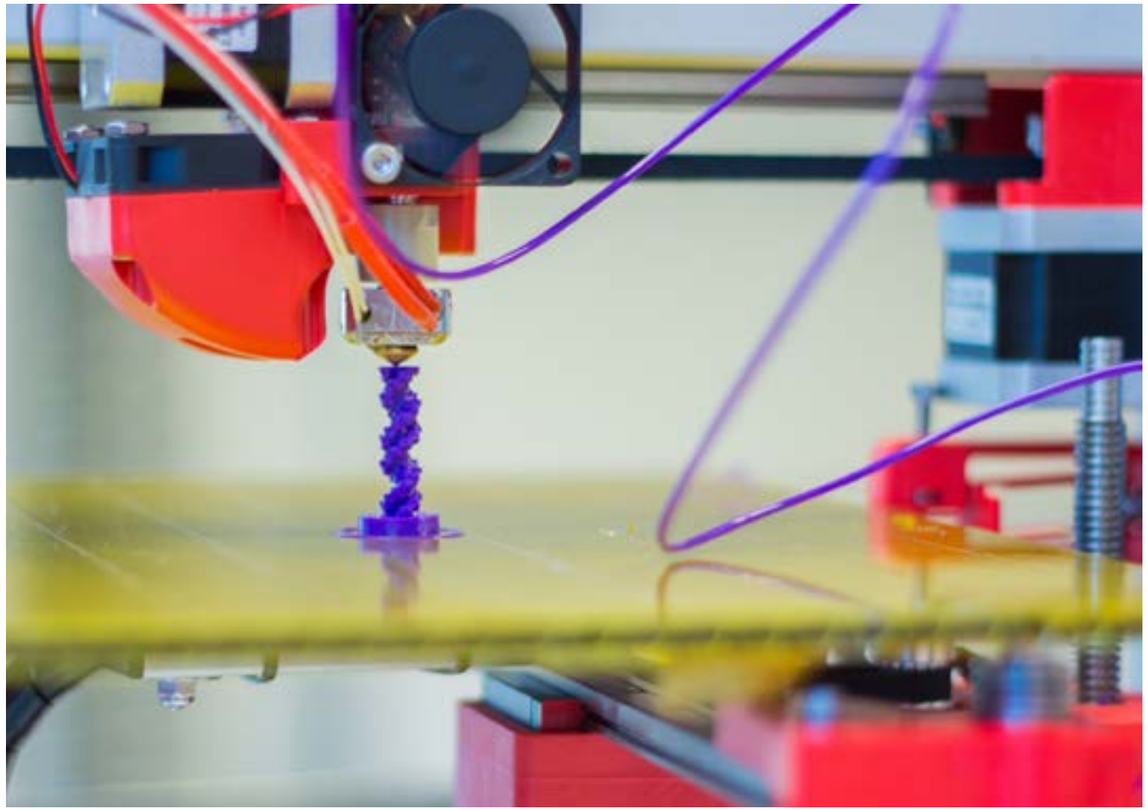
According to the global consulting firm McKinsey & Company, one out of four workers worldwide may be African by 2030.[1] The global center of gravity of labor-intensive manufacturing is expected to shift to poorer economies with lower labor costs—including those in sub-Saharan Africa—and the African region could emerge as "the next factory of the world."[2] Yet, this is not certain. The adoption of technologies associated with "Industry 4.0"—the Internet of Things (IoT), robotics, and three-dimensional (3D) printing—in China and high-income economies in Europe and the United States is reducing the importance of low labor costs in determining overall production location and may, in the long term, lead to a reshoring of global supply chains.

For African economies, this may mean fewer entry points into global supply chains and may make industrialization more difficult to achieve. Because most African countries generally lack essential technology and industry skills, there is no near-term scenario under which they would be able to leverage technologies like 3D printing and automation to compete globally in manufacturing. While there are opportunities to "leapfrog" to new technologies, developing the relevant worker know-how, infrastructure, and corporate capabilities are likely to be a gradual process. African policy makers must therefore pursue disparate strategies to ensure relevance as 3D printing and automation move into the mainstream. The experiences of other countries facing similar challenges may provide valuable lessons. This brief explores how the approaches pursued by India, Cambodia, and South Africa might inform African development strategies.

1 J. Peter Pham, "Assessing China's Role and Influence in Africa," Prepared statement presented at a Hearing before the House Subcommittee on Africa, Global Health, and Human Rights, 112th Congress, March 29, 2012: 49–64.

2 Irene Sun, *The Next Factory of the World: How Chinese Investment is Reshaping Africa* (Watertown: Harvard Business Review Press, 2017).



Unlike traditional manufacturing methods, 3D printing processes create objects by adding materials, allowing engineers to produce complex geometries. In Africa, 3D printing and other cutting-edge technologies could allow the continent to bypass industrialization and leapfrog further into the future. *Photo credit:* Jonathan Juursema/Wikimedia Commons.

The Muddled Promise of 3D Printing in Africa

3D printing—also known as additive manufacturing—is attracting more attention as it steadily matures and moves into the mainstream. In 2016, total global revenues from 3D printing systems totaled more than $6 billion, representing a 17.4 percent expansion of the industry.[3] In emerging markets, 3D printing is expected to become a $4.5 billion industry by 2020, as the range of printable materials expands beyond its currently limited array.[4] Some estimates suggest that if the current growth of investment in 3D printing continues, 50 percent of all globally manufactured goods will be printed by 2060.[5]

Commonly referred to as a "disruptive technology," additive manufacturing often conjures up images of a future that is utopian or dystopian, depending on one's outlook. At its core, however, 3D printing is just another manufacturing process. According to the National Institute of Standards and Technology, 3D printing is "the process of joining materials to make objects from three-dimensional (3D) models layer by layer as opposed to subtractive methods that remove materials."[6]

3 Ian Campbell et al., *Wohlers Report 2017: 3D Printing and Additive Manufacturing State of the Industry,* Wohlers Associates, 2017, https://wohlersassociates.com/2017report.htm.

4 Swapnil Shende, *3D Printing Market in Emerging Economies – China, India, UAE, Brazil, South Africa (Components and Applications) – Opportunities and Forecasts, 2013 – 2020*, Allied Market Research, September 2014, https://www.alliedmarketresearch.com/3D-printing-emerging-economies-china-india-UAE-brazil-south-africa-market.

5 Raoul Leering, *3D Printing: A Threat to Global Trade*, ING, September 28, 2017, https://think.ing.com/uploads/reports/3D_printing_DEF_270917.pdf.

6 Douglas S. Thomas and Stanley W. Gilbert, *National Institute of Standards and Technology Special Publication 1176: Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review and Discussion*, US Department of Commerce, December 2014, https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf.

While traditional manufacturing creates forms by removing layers of material, 3D printing processes create objects by adding material; much like how a pastry chef might assemble a layer cake, the materials are shaped into designs to fulfill specific functions.

3D printing offers several advantages over traditional manufacturing processes. Among them is the ability to create objects with complex geometries and internal cavities. Using sunglasses as an example, wherein a manufacturer would normally produce the sunglass pieces separately and then assemble them, 3D printing allows for sunglasses to be produced as a whole with the material varying in different areas of the frame; the earpieces are soft and flexible, while the rims supporting the lenses are hard. This has applications ranging from jet engine components to hearing aids. GE Aviation produces fuel nozzles for its next-generation turbofan engines using 3D printing. Ninety-eight percent of hearing aids worldwide are manufactured through 3D printing processes, each being custom-made to fit the user's unique ear shape.[7] Because each printed object is produced independently, it can be easily modified to meet particular needs or to accommodate updates.

The ability to create highly customized or differentiated products in small batches further sets 3D printing apart from traditional manufacturing. While 3D printing does not have the advantage of economies of scale, making it unsuitable for high-volume manufacturing, it does allow for rapid prototyping, shortening the time it takes to move a product from design to production. This may, for instance, allow entrepreneurs to more swiftly manufacture products that address locally entrenched challenges from the ground up. For example, a consortium of Canadian organizations in partnership with the Comprehensive Rehabilitation Services (hospital) in Kisubi, Uganda, is trialing 3D printing of prosthetic limbs for amputees. Rather than being casted with plaster, the damaged limbs are digitally scanned and the prostheses are digitally modeled before being sent for production. This method has produced better-fitting limbs at a quarter of the usual production time.[8] In Togo, a 3D printer built from electronic waste has been used to print prototypes of designs by local entrepreneurs—items like anti-theft products for motorcycles, for example, which are often stolen.[9]

Another Challenge for Africa's Industrialization

To the extent that there is enthusiasm for 3D printing and Industry 4.0 in Africa, it is rooted in the hope that it will enable economies to leapfrog industrialization to development. Many African countries have been able to overcome decrepit telecommunications infrastructure to develop advanced mobile technology capabilities and, as the thinking goes, they should be able to do the same in manufacturing. However, it is not that easy to replicate and build sophisticated 3D printers or to develop the specialized skills needed to know how to produce durable and reliable products. Many 3D-printed products often require a number of postproduction steps and tests, which require their own specialized knowledge, machinery, and infrastructure.[10] Small-scale personal printers may address distinct local challenges but are unlikely to contribute to Africa's industrialization en masse. The potential gains from 3D printing in Africa are likely to be limited.

Currently, the United States, Germany, Korea, and Japan lead in 3D printing.[11] Among emerging economies, the biggest growth is expected to come from China and India. In China, the government is aggressively pushing technologies associated with Industry 4.0. In 2015, China unveiled its "Made in China 2025" initiative to foster advanced technologies, emphasizing 3D printing as a key enabler. The Ministry of Industry and Information Technology then released the "National 3D Printing Industry Promotion Plan (2015–2016)," which has since been complemented by a new "Additive Manufacturing Action Plan (2017–2020)." In 2017, Chinese institutions spent $1.1 billion on 3D printing.[12]

7 Consumer Technology Association and United Parcel Service, *3D Printing: The Next Revolution in Industrial Manufacturing*, 2016, https://www.ups.com/media/en/3D_Printing_executive_summary.pdf.

8 Rob Goodier, "Nia's 3D-Printed Prosthetic Limbs Cut Costs and Production Time," *Engineering for Change*, April 18, 2016, https://www.engineeringforchange.org/news/nias-3d-printed-prosthetic-limbs-cut-costs-and-production-time/.

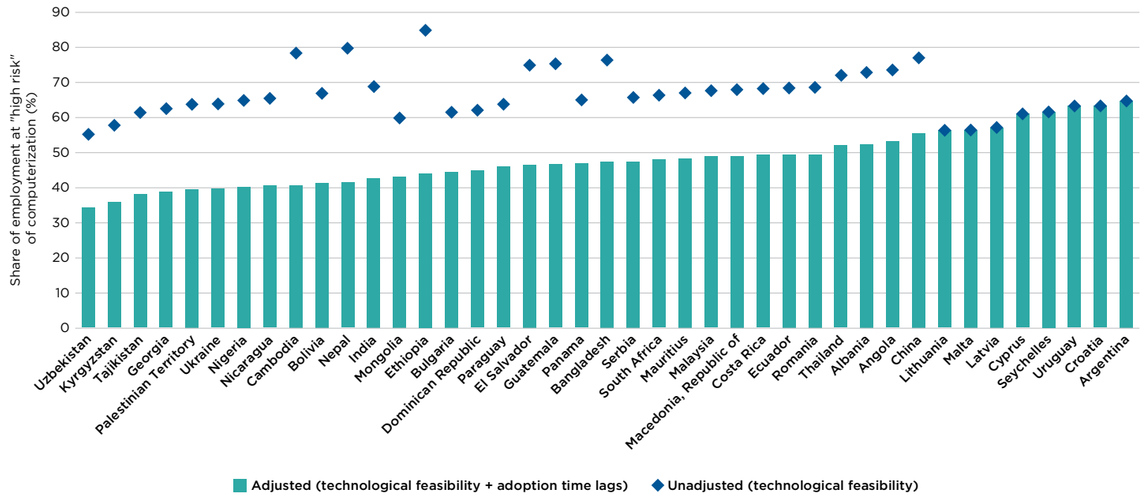
9 Raluca Besliu, "Want to Build a 3D Printer? Look No Further Than Your Electronic Junkyard," *YaleGlobal Online*, January 18, 2018, https://yaleglobal.yale.edu/content/want-build-3d-printer-look-no-further-your-electronic-junkyard.

10 Jaime Bonnín Roca et al., "Getting Past the Hype About 3-D Printing," *MIT Sloan Management Review*, 2017, http://ilp.mit.edu/media/news_articles/smr/2017/58323.pdf.

11 Sean Monahan et al., *3D Printing: Disrupting the $12 Trillion Manufacturing Sector*, ATKearney, 2017, https://www.atkearney.com/documents/20152/891756/2017+OPT+-+3D+Printing+Disrupting+the+12+Trillion+Manufacturing+Sector+-+Final.pdf/21088bd6-7346-d666-8d65-f795d00c11aa.

12 Wendy Mok, *China 3D Printing Market Forecast 2017–2021*, International Data Corporation, October 2017, https://www.idc.com/getdoc.jsp?containerId=AP41344416.

Figure 1. Jobs Susceptible to Automation in the Developing World



World Bank, *World Development Report 2016: Digital Dividends*, 2016, Washington, DC: World Bank, doi:10.1596/978-1-4648-0671-1.

Beijing expects its 3D printing industry to reach annual sales revenues of more than $3 billion by 2020, with an average annual growth rate of 30 percent or higher.[13] This is part of China's overarching shift toward automation, as it aims to move its companies up the manufacturing value chain to remain competitive.

As China and other developed economies retool their factories with the latest technologies, Africa's core competitive advantage—its large and inexpensive labor force—risks being eroded. Not that long ago, African countries were encouraged to integrate into global value chains (GVCs) as corporations turned to offshoring to boost efficiency. Integration into GVCs—first as a source of primary inputs and later as potential production hubs—was seen as a means of improving African countries' industrial capabilities, employment, and social structures.[14] In Ethiopia, Chinese footwear, pharmaceutical, and other light manufacturing factories employ thousands of Ethiopian workers engaged primarily in product assembly. But labor-saving technologies like 3D printing are making these low-wage, labor-intensive manufacturing roles increasingly redundant, leaving African countries with fewer entry points into GVCs. 3D printing is also likely to repatriate some production activities that were earlier offshored.[15] 3D printing has few production stages, and the flexibility to build products at the point of consumption reduces global transportation costs and vulnerability to risk factors like political unrest and natural disasters common to some African countries. It can also improve time-to-market responsiveness and hasten responses to changes in demand. According to the Oxford Martin School at the University of Oxford, 85 percent of Ethiopian jobs are at risk of being replaced by 3D printing and automation, 67 percent in South Africa, and 65 percent in

13 Priyankar Bhunia, "China Formulates Action Plan for the Development of 3D Printing Industry," *OpenGovAsia*, December 14, 2017, https://www.opengovasia.com/articles/china-formulates-action-plan-for-the-development-of-3d-printing-industry.

14 "Global Value Chains and Africa's Industrialisation," African Economic Outlook, last updated 2014, http://www.africaneconomicoutlook.org/en/theme/global-value-chains-and-africa-s-industrialisation.

15 Luciano Fratocchi, "Is 3D Printing an Enabling Technology for Manufacturing Reshoring?" in *Reshoring of Manufacturing: Drivers, Opportunities, and Challenges*, ed. Alessandra Vecchi, (Cham: Springer, 2017), 99–124.

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"Many governments are aware that 3D printing will affect industries unevenly and are pursuing Industry 4.0 strategies that build on their competitive advantages, with some possible lessons for African leaders and industries."

Nigeria.[16] Such massive job loss may undermine industrialization and may increase the likelihood of social unrest as Africa's young population—an estimated 830 million individuals by 2050[17]—enters the job market with limited opportunity.

3D Printing in Comparative Perspective

African economies are not the only ones facing this challenge. In Vietnam, globalization has allowed for the creation of some 250,000 hardware manufacturing jobs.[18] By inserting itself into downstream activities in GVCs, Bangladesh was similarly able to generate millions of jobs in the textile and garment sectors. However, 86 percent of jobs in Vietnam[19] and more than 70 percent of jobs in Bangladesh[20] are at risk of being replaced by 3D printing and other disruptive technologies.

Governments and private-sector entities in potentially affected economies are working to soften the effects. Upgrading skills and retraining staff are obvious initiatives. The United Arab Emirates has established a "Fourth Industrial Revolution Council," creating a knowledge-sharing system of think tanks for new technologies. In 2016, the Singaporean government launched two statutory boards—SkillsFuture Singapore and Workforce Singapore—which, together with its educational institutions, are working to strengthen adult training in technology. It is essential for countries to have an educated and skilled workforce to be able to actively participate in an increasingly digitized global economy and to meet what will likely be changed quality and productivity benchmarks. On its own, however, a skilled workforce is not enough. Many governments are aware that 3D printing will affect industries unevenly and are pursuing Industry 4.0 strategies that build on their competitive advantages, with some possible lessons for African leaders and industries.

India

India risks losing nearly 69 percent of jobs because of 3D printing and automation.[21] At particular risk are the food and beverage, pharmaceutical, and automotive industries; today, robot makers in India mostly supply the country's automotive sector, with more than 2,100 industrial robots being sold in 2014.[22] Additionally, most of the 3D printers are sold to the automotive and aerospace industries. The trend threatens to undermine the government's "Make in India" initiative, which was intended to attract investment and boost employment in labor-intensive manufacturing sectors. India suffers from an overhang of more than 17 million unemployed workers.[23]

The government is taking steps to prepare its industries, and it has identified IoT as one of the most important

16 Carl Benedikt Frey et al., *Technology at Work v2.0: The Future Is Not What It Used to Be*, Citi GPS, January 2016, https://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf.
There is great variance in data around the automation of work, due in part to competing methodologies and inconsistencies between reported statistics. These figures reflect the unadjusted numbers referenced in Figure 1.

17 Siddharth Chatterjee, "Promise or Peril? Africa's 830 Million Young People by 2050," UNDP Africa, August 12, 2017, http://www.africa.undp.org/content/rba/en/home/blog/2017/8/12/Promise-Or-Peril-Africa-s-830-Million-Young-People-By-2050.html.

18 M. Rokonuzzaman, "New Industrialisation Strategy of Leapfrogging," *The Financial Express*, December 9, 2017, http://thefinancialexpress.com.bd/public/views/views/new-industrialisation-strategy-of-leapfrogging-1512833520.

19 "Southeast Asia: Automation Could See Labour Unrest," *Oxford Analytica Daily Brief Service*, September 19, 2016.

20 Frey et al., *Technology at Work v2.0*.

21 Ibid.

22 James Crabtree, "Spectre of Automation Hangs over Indian Manufacturing," *Financial Times*, October 20, 2015, https://www.ft.com/content/d40d0de2-7702-11e5-a95a-27d368e1ddf7.

23 "Unemployment in India to Increase Marginally in 2017-18: UN Report," *The Times of India*, January 13, 2017, https://timesofindia.indiatimes.com/india/unemployment-in-india-to-increase-marginally-in-2017-18-un-report/articleshow/56512962.cms.

disruptive technologies for the country. IoT—a network in which smart devices communicate with each other to send and receive data—relies on information technology (IT) capabilities and allows India to capitalize on its 3.9-million strong and skilled IT workforce to innovate around the edges of 3D printing. 3D printers can be integrated with IoT technologies to optimize manufacturing supply chains and reduce costs. In "smart factories," for example, the integration of 3D printing and IoT capabilities allows production and logistics systems to organize themselves without human intervention. India's first smart factory is being developed in Bangalore. Set up at the Indian Institute of Science's Center for Product Design and Manufacturing, with seed funding from the Boeing Company, it allows data to be continuously collected and monitored to provide real-time insights into every movement and process taking place on the factory floor. The data generated are fed back into a responsive, network-enabled framework that allows the factory to function truly autonomously.[24] Indian companies Mahindra & Mahindra, Tata, Godrej, and Welspun are adopting smart-factory principles. The Indian state of Andhra Pradesh aims to be an IoT hub by 2020.[25]

IoT is expected to eliminate nearly 94,000 low-skilled IT jobs in India.[26] In the long term, however, it is also expected to create more than 100,000 medium-skilled jobs that complement other disruptive technologies, such as data security, data science, communications, technology support, and technology services.[27] Global demand for traded goods and services has diverged in recent years. As technology reshapes manufacturing processes, demand for GVC trade in services is likely to remain high and is likely to benefit populous, low-skilled, English-speaking economies like India.[28] Indian companies DhruvSoft, OnGraph, and Altiux have already entered the IoT services space. Others, like 75F, are developing IoT platforms for building automation and other applications that also rely on 3D printing.

"Internet of Air" Building Solutions

Founded in the United States, India's 75F[1] creates solutions that predict building needs and proactively manage them, making buildings more energy-efficient, automated, and "smart." Leveraging IoT design, the 75F system deploys cloud-based algorithms to predict the behavior of a building. Internet-connected devices sense, analyze, and control building behavior to achieve consistent temperature, airflow, and lighting. As India's 3D printing industry progresses, 75F will be able to manufacture and improve its systems and system components in closer proximity to end-users.

1 "Our Story," 75F, last updated 2018, https://www.75f.io/our-story-sustainable-buildings.

Cambodia

One of the fallacies surrounding 3D printing is that monumental change is imminent. In reality, 3D printing is still underdeveloped. It currently does not scale well; even as the range of printable materials is expanding, it remains limited. Generally, 3D printers do a poor job of handling soft, flexible materials, for instance, which is why the automotive and aerospace industries that use hard materials are among its earliest adopters. For a country like Cambodia, where garment and footwear manufacturing contributes 16 percent to the total gross domestic product and accounts for more than 80 percent of all exports,[29] this may be good news—for now.

Third after Ethiopia and Nepal, Cambodia is among the countries most susceptible to the effects of automation.[30] Nearly 90 percent of garment workers are at risk of being replaced by what the International Labour Association calls "sewbots."[31] These sewbots are unlikely to appear in Cambodian factories, but they are being installed in Europe and the United States, where Cambodian exports are heavily concentrated.[32] The footwear manufacturer Adidas already uses 3D printing at its "Speedfactory" in Ansbach, Germany, and at its US location in Atlanta, Georgia. The factory pairs a small human workforce of around 160 people with 3D printing, robotic arms, and computerized knitting to produce 500,000 pairs of shoes per year for the European market.[33] This is a modest figure compared with the nearly 300 million pairs of shoes that it sources annually,[34] suggesting that mass production of 3D-printed footwear may be on the way, but it is not fast approaching.

Similarly, 3D-printed garments are not yet within reach. Because 3D printers build objects by depositing layers of material one on top of the other, the layers fuse together in a way that is wholly unlike how fibers become fabric. 3D-printed clothing so far is rigid and unwearable.[35] Even when this problem is solved, it is likely that 3D-printed garments will have to undergo finishing processes to improve their aesthetics. Detailed or even whole pieces for higher-end fashion labels will likely still have to be sewn by hand.[36]

Cambodia has begun to diversify away from garment and footwear manufacturing and from US and European markets. While garment manufacturing continues to dominate, Cambodian exports have expanded to include primary commodities like rice and rubber, as well as light manufactured goods, including automobiles and electronic components.[37] Cambodia's proximity to Thailand is one of the factors driving this diversification, as the country is a major producer of trucks, cars, and electronic components; Cambodian exports to Thailand surged 46 percent in 2016.[38] In Thailand and in neighboring Association of Southeastern Asian Nations (ASEAN) markets, low-quality, low-priced goods are still in demand, even as technological advancement facilitates more sophisticated production. This mirrors the experiences of China and India, where highly traded manufacturing sectors segmented the markets. This holds notable promise in Africa; many local manufacturing industries have seen increases in their intra-African trade shares over the last decade.[39]

> "Manufacturing is not monolithic in terms of the extent of 3D printing. The adoption varies across subsectors, with some industries more affected than others."

3D Printing in Africa: South Africa Leads the Way

Manufacturing is not monolithic in terms of the extent of 3D printing. The adoption varies across subsectors, with some industries more affected than others. Those less affected are likely to continue to facilitate potential entry points into GVCs for less industrialized economies. Along with the services sector, this includes a range of commodity-based manufacturers, such as wood and paper products and food processing, which

24 Probodh Chiplunkar, "Making Connected Factories a Reality in India," *Forbes India*, May 5, 2017, http://www.forbesindia.com/blog/technology/making-connected-factories-a-reality-in-india/.

25 Information Technology, Electronics & Communications Department, *Andhra Pradesh Internet of Things (IoT) Policy 2016–2020*, Government of Andhra Pradesh, March 16, 2016, http://www.aponline.gov.in/apportal/Downloads/2016ITC_MS3.pdf.

26 Ananya Bhattacharya, "The Internet of Things Could Be the Light at the End of the Tunnel for Indian IT," *Quartz India*, August 9, 2017, https://qz.com/1048800/the-internet-of-things-could-be-the-light-at-the-end-of-the-tunnel-for-indian-it/.

27 Phil Fersht and Jamie Snowdon, *Impact of Automation and AI on Services Jobs, 2016–2022*, HfS Research, September 4, 2017, https://www.hfsresearch.com/market-analyses/impact-of-automation-and-ai-on-services-jobs-2016-2022.

28 Frey et al., *Technology at Work v2.0*.

29 *Cambodia: Diversifying Beyond Garments and Tourism*, Asian Development Bank, November 2014, https://www.adb.org/sites/default/files/publication/149852/cambodia-diversifying-country-diagnostic-study.pdf.

30 Frey et al., *Technology at Work v2.0*.

31 Jae-Hee Chang, Gary Rynhart, and Phu Huynh, *ASEAN in Transformation: The Future of Jobs at Risk of Automation*, International Labour Organization, July 1, 2016, http://www.ilo.org/actemp/publications/WCMS_579554/lang--en/index.htm.

32 More than 80 percent of Cambodia's exports go to Canada, the European Union, and the United States.

33 Anna Wiener, "Inside Adidas' Robot-Powered, On-Demand Sneaker Factory," *Wired*, November 29, 2017, https://www.wired.com/story/inside-speedfactory-adidas-robot-powered-sneaker-factory/.

34 Tansy Hoskins, "Robot Factories Could Threaten the Jobs of Millions of Garment Workers," *The Guardian*, July 16, 2016, https://www.theguardian.com/sustainable-business/2016/jul/16/robot-factories-threaten-jobs-millions-garment-workers-south-east-asia-women.

35 Roni Jacobson, "The Shattering Truth of 3D-Printed Clothing," *Wired*, May 12, 2017, https://www.wired.com/2017/05/the-shattering-truth-of-3d-printed-clothing/.

36 Y.L. Yap and W.Y. Yeong, "Additive Manufacture of Fashion and Jewellery Products: A Mini Review," *Virtual and Physical Prototyping* 3 (2014):195–201, accessed March 22, 2018, https://www.tandfonline.com/doi/abs/10.1080/17452759.2014.938993.

37 *Cambodia: Diversifying Beyond Garments and Tourism*.

38 Cheng Sokhorng, "Exports Driving Shift in Thai Trade," *The Phnom Penh Post*, March 1, 2017, http://www.phnompenhpost.com/business/exports-driving-shift-thai-trade.

39 Mary Hallward-Driemeier and Gaurav Nayyar, *Trouble in the Making? The Future of Manufacturing-Led Development*, World Bank Group, September 20, 2017, www.worldbank.org/futureofmanufacturing.

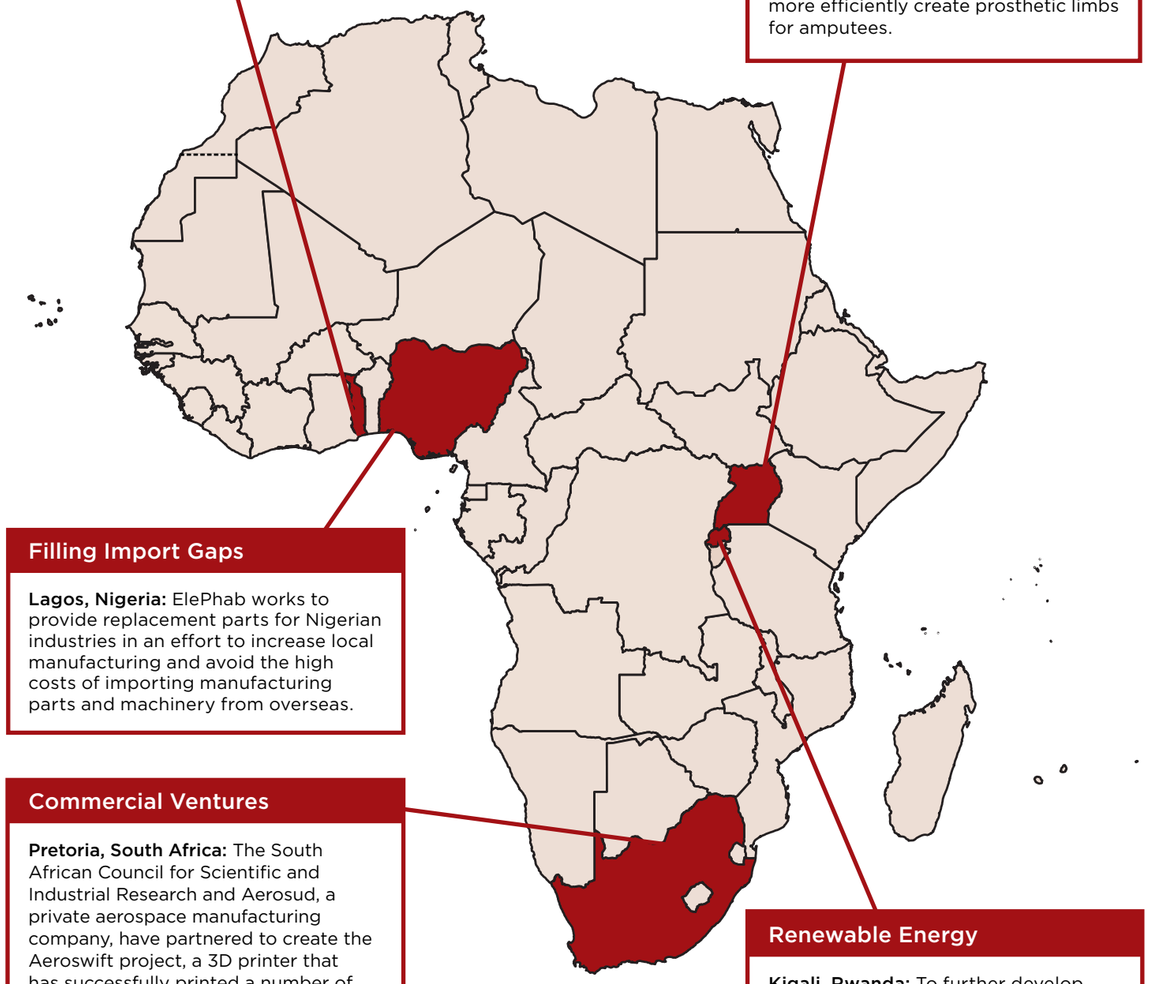
3D Printing Ventures in Africa

Local Entrepreneurship

Lomé, Togo: A 3D printer made from electronic waste has been used to build product prototypes for local entrepreneurs, including anti-theft products for motorcycles.

Medical Supplies

Kisubi, Uganda: In partnership with a consortium of Canadian organizations, the Comprehensive Rehabilitation Services hospital uses 3D printing to more efficiently create prosthetic limbs for amputees.



Filling Import Gaps

Lagos, Nigeria: ElePhab works to provide replacement parts for Nigerian industries in an effort to increase local manufacturing and avoid the high costs of importing manufacturing parts and machinery from overseas.

Commercial Ventures

Pretoria, South Africa: The South African Council for Scientific and Industrial Research and Aerosud, a private aerospace manufacturing company, have partnered to create the Aeroswift project, a 3D printer that has successfully printed a number of titanium aircraft parts from powder. The printer is able to produce parts ten times faster than other commercially available laser melting machines.

Renewable Energy

Kigali, Rwanda: To further develop Rwanda's solar energy sector, Great Lakes Energy 3D prints packaging and storage solutions for its solar products.

Map credit: FreeVectorMaps.com

are traded less and are therefore less susceptible to international competition. Additionally, countries that feed GVCs with raw materials may assume more powerful roles as 3D printing is more widely adopted; more players will need to be supplied with small batches of input materials for printing.[40]

With an abundance of mineral reserves—including titanium, which is of special interest for the aerospace and defense industries because of advantages it has in weight and chemical resistance—South Africa is positioning itself as a global supplier of metal inputs and metal 3D-printed parts for the medical and aerospace markets. It currently leads the continent in 3D printing. In the long term, the government aims to export more than fifty tons of 3D-printed titanium parts per year.[41] In 2017, the Aeroswift project, a South African-built titanium powder 3D printer, successfully produced aircraft parts, including a throttle lever, a condition lever grip, and a fuel tank pylon bracket, with the first commercial applications expected in 2019. The project is a collaboration between Aerosud, South Africa's largest private aerospace manufacturing company, and the South African Council for Scientific and Industrial Research. Among its likely clients are Airbus and Boeing.[42]

South Africa benefits from established educational institutes that have advanced research and design capabilities, as well as vibrant innovation hubs. Examples of the former include Vaal University of Technology's (VUT) Southern Gauteng Science and Technology Park and the Centre for Rapid Prototyping and Manufacturing at the Central University of Technology, which provides services in 3D printing for medical, prototyping, and rapid tooling purposes. "Makerspaces" additionally help entrepreneurs realize their product ideations for which 3D printing is a key tool. The global "maker movement," a technology-based extension of the "do-it-yourself" culture, has given rise to a number of makerspaces, or "fab labs," around the world. There are more than one hundred such makerspaces in Africa today.[43] In 2011, VUT launched the "Idea 2 Product" lab series with twenty personal 3D printers. Since then, the labs have expanded to multiple South African universities, science centers, and schools, including township schools,[44] and globally to New Zealand, Sweden, and the United States. Labs are typically furnished with 3D printers, laser cutters, and even sewing machines. They allow entrepreneurs to experiment, collaborate, and learn the skills necessary to remain relevant in the coming era of manufacturing.

> "The trend toward 3D printing narrows the path for less-developed economies to industrialize."

Preparing Africa for the 3D Printing Revolution

The trend toward 3D printing narrows the path for less-developed economies to industrialize. In Africa, the expected inward migration of labor-intensive manufacturing activities—especially from China—may not happen. Countries outside of Africa also face the prospect of "premature deindustrialization,"[45] with governments and private-sector players scrambling to mitigate the risk. The experiences of India, Cambodia, and South Africa offer possible lessons learned and ways forward for African economies.

40 André Laplume, Bent Petersen, and Joshua M. Pearce, "Global Value Chains from a 3D Printing Perspective," *Journal of International Business Studies* 47 (2016): 595–609, accessed March 22, 2018, https://link.springer.com/article/10.1057/jibs.2015.47.

41 Deon de Beer et al., *A South African Additive Manufacturing Strategy*, Department of Science and Technology, Republic of South Africa, April 2016, http://www.rapdasa.org/wp-content/uploads/2017/02/South-African-Additive-Manufacturing-Strategy.pdf.
For more on South Africa's growing investment sectors and opportunities for engagement with the United States, see Anthony Carroll, "Forging a New Era in US-South African Relations," *Atlantic Council*, November 2017, http://www.atlanticcouncil.org/images/Forging_a_New_Era_in_US-South_African_Relations_1128_web.pdf.

42 Wendell Roelf, "South Africa in Talks with Airbus, Boeing to Print 3D Parts," *Reuters*, March 2, 2017, https://www.reuters.com/article/us-safrica-aircraft-printing/south-africa-in-talks-with-airbus-boeing-to-print-3d-parts-idUSKBN1691YW.

43 Ndubuisi Ekekwe, "Africa's Maker Movement Offers Opportunity for Growth," *Harvard Business Review*, May 29, 2015, https://hbr.org/2015/05/africas-maker-movement-offers-opportunity-for-growth.

44 Selina Rapulane, "Idea to Product Labs Spring Up in Township Schools," *Vaal University of Technology*, http://www.vut.ac.za/idea-to-product-labs-spring-up-in-township-schools/.

45 Dani Rodrik, *Premature Deindustrialization*, National Bureau of Economic Research, February 2015, http://www.nber.org/papers/w20935.

Focus on GVCs in the Services Sector

India's strategy to leverage its IT capabilities and innovate around the edges of 3D printing—particularly in services—reflects broader patterns in global trade. Mostly, countries trade in manufactured products. However, when manufacturing GVCs are broken down, services play a significant role and now account for nearly one-half of world trade.[46] This trend reflects the importance of software in smart finished products (such as connected cars using 3D printing and IoT), as well as the growing role of services in managing supply chains.

Many African economies have opened up to trade and investment in manufacturing, but they have not done so in services. This is a futile approach. Poorer African economies with lower labor costs risk losing entry points into GVCs for manufactured goods, and they are unlikely to develop sufficiently advanced 3D printing and robotics capabilities to compete with their more developed counterparts. Specializing in upstream activities, such as research and development and design, and in downstream activities like marketing, finance, communications, and distribution of finished goods, can facilitate new entry points. Many African economies are already competitive in these areas and can become even more competitive over time. Kenya, Rwanda, Senegal, and South Africa have vibrant information and communications technology (ICT)-based services sectors. Nigeria has sophisticated capabilities in banking services; Ghana has capabilities in transportation, storage, and public administration. As GVCs become more digitized, financial technology (fintech) services are also likely to elevate countries like Kenya with advanced fintech capabilities.

All of these services require careful regulation, and if properly managed, they could be effective means for integrating African economies into GVCs as 3D printing and automation advance.

Capture 3D Material Segments

The availability of materials and material science know-how will be one of the key enablers for the widespread adoption of 3D printing. The players at the front of the value chain who supply materials for 3D printing will hold significant influence, as they will likely define the properties and production costs of the components. South Africa is taking advantage of its significant titanium reserves to position itself as a supplier of metal inputs and metal 3D-printed parts across industries. While plastics have garnered the most attention as a 3D printing material, it is metals that have been the fastest growing 3D printing category since 2012.[47] The range of printable materials is further expanding to include ceramics, cement, and glass.[48]

For African countries rich in natural resources, a significant opportunity may lie in supplying and producing metals for metal 3D printing systems. Common metals used include stainless steels, aluminum, nickel, cobalt-chrome, and titanium, which are usually applied in powder form.[49] Mineral-rich countries, such as Tanzania, Mozambique, and the Democratic Republic of the Congo, can differentiate themselves by dominating particular material segments. This may position them to exert influence over the market and the value chain. If not part of a wider economic strategy, however, this approach risks further entrenching African dependence on commodity exports. Resource-rich countries should leverage their competitive advantage in 3D printing materials in tandem with a policy of market and industry diversification and a focus on skills training.

Strengthen Intra-African Trade

Over time, 3D printing is likely to curb trade in manufactured goods to developed economies. Some manufacturing segments will be reshored, and goods will be produced domestically and for domestic markets. Like Adidas, for example, the footwear manufacturer Nike is embracing 3D printing to move production closer to its key consumer markets.[50] According to the Dutch banking company, ING, 3D printing could eliminate one-quarter of world trade by 2060, leaving export-oriented countries with severe trade deficits.[51]

In anticipation of such shifts, Cambodia has started to reorient its trade to neighboring ASEAN countries, as well as to its domestic market. For less industrialized countries, low-quality, low-priced goods produced and consumed domestically or regionally are likely to remain in demand. As China's economy developed, for example, it consisted of a small upper segment served by foreign companies and a large, low-end segment served by local firms offering low-quality, low-priced products at the bottom.[52] The Indian textile manufacturer Arvind Mills was able to take an ostensibly global product—blue jeans—and fashion it to suit local needs. In Africa, regional markets for such goods hold considerable promise. Intraregional trade has the potential to expand production, generate jobs, and reduce dependence on developed markets for exports.

In March 2018, leaders of forty-four African nations signed the Continental Free Trade Agreement (CFTA), establishing the largest single market for goods and services since the World Trade Organization.[53] The CFTA will go into effect once twenty-two countries have ratified it in their national parliaments; as more states ratify the agreement, its implementation will proceed automatically in those countries. The hope is that the agreement will trigger a cycle of more intra-African trade, which will in turn drive the structural transformation of their economies. Currently, only 16 percent of Africa's trade is intraregional, owing to high trade costs in the region.[54] The CFTA has the potential to increase this by an estimated 52 percent by 2022, providing all countries complete negotiations and ratify in a timely fashion.[55]

> "Many African manufacturing industries have seen significant increases in their intra-African trade shares between 2000 and 2014."

African countries already trade more value-added products among themselves, unlike their exports to the rest of the world, which are mainly commodities. For example, many African manufacturing industries have seen significant increases in their intra-African trade shares between 2000 and 2014.[56] In 2014, manufactured goods accounted for 41.9 percent of intra-African exports compared with a 14.8 percent share of exports

Fab Labs

"Fab labs" are open spaces where entrepreneurs can access digital manufacturing tools, training, and propose projects. The first fab lab was established in 2001 at the Massachusetts Institute of Technology's Center for Bits and Atoms; there are now more than 450 centers worldwide. The labs generally use the same digital tools and are usually virtually connected, which allows them to share designs, code, and instructions for manufacturing. African fab labs can, for example, connect with the more than forty labs in Latin America[1] to exchange ideas and transfer knowledge.

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46 Global Value Chain Development Report 2017: *Measuring and Analyzing the Impact of GVCs on Economic Development*, World Trade Organization, 2017, https://www.wto.org/english/res_e/publications_e/gvcd_report_17_e.htm.

47 Avetik Chalabyan et al., "How 3-D Printing Will Transform the Metals Industry," *McKinsey & Company*, August 2017, https://www.mckinsey.com/industries/metals-and-mining/our-insights/how-3d-printing-will-transform-the-metals-industry.

48 Richard D'Aveni, "The 3-D Printing Revolution," *Harvard Business Review*, May 2015, https://hbr.org/2015/05/the-3-d-printing-revolution.

49 "Metal Powders – The Raw Materials," Metal AM, http://www.metal-am.com/introduction-to-metal-additive-manufacturing-and-3d-printing/metal-powders-the-raw-materials/.

50 Jennifer Bissell-Linsk, "Nike's Focus on Robotics Threatens Asia's Low-Cost Workforce," *Financial Times*, October 22, 2017, https://www.ft.com/content/585866fc-a841-11e7-ab55-27219df83c97.

51 Leering, *3D Printing*.

52 Orit Gadiesh, Philip Leung, and Till Vestring, "The Battle for China's Good-Enough Market," *Harvard Business Review*, September 2007, https://hbr.org/2007/09/the-battle-for-chinas-good-enough-market.

53 Justina Crabtree, "Africa is on the Verge of Forming the Largest Free Trade Area since the World Trade Organization," *CNBC*, March 20, 2018, https://www.cnbc.com/2018/03/20/africa-leaders-to-form-largest-free-trade-area-since-the-wto.html.

54 Arabile Gumede, "Africa Set to Agree $3 Trillion Trade Bloc, Without Key Economy," *Bloomberg Markets*, March 21, 2018, https://www.bloomberg.com/news/articles/2018-03-21/africa-set-to-agree-3-trillion-trade-bloc-without-key-economy.

55 David Luke and Babajide Sodipo, "Launch of the Continental Free Trade Area: New Prospects for African Trade?" *International Centre for Trade and Sustainable Development*, June 23, 2015, https://www.ictsd.org/bridges-news/bridges-africa/news/launch-of-the-continental-free-trade-area-new-prospects-for-african.

56 Hallward-Driemeier and Nayyar, *Trouble in the Making?*

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outside of the continent.[57] For members of the East African Community (EAC), a regional organization of six countries, bilateral trade is highest among neighboring states. In 2011, EAC-member bilateral trade was 213 percent higher than before the common market was established in 2010.[58] Commodities are among the most commonly traded goods, followed by manufactured goods such as cement, textiles, sugar, beer, and salt.

Intraregional trade provides a unique opportunity for African countries to build on their competitive advantages and develop more robust trade platforms. Combined with appropriate domestic industrial policies, as well as improvements in logistics and infrastructure, intraregional trade may significantly offset some of the losses likely to be caused by 3D printing.

Continue to Foster Technology Innovation Hubs

Intra-African trade may hold promise for 3D printing across the continent. In the absence of an adequately trained workforce, African countries are unlikely to be globally competitive in 3D-printed products and parts, with few exceptions. However, less sophisticated production may meet local demand. In Nigeria, the start-up ElePhab produces 3D-printed replacement parts for the Nigerian market. In Rwanda, the solar energy provider Great Lakes Energy uses 3D printing to develop packaging and storage solutions for its solar products.[59]

Technology ecosystems like fab labs and makerspaces are vital to such ventures, as they allow entrepreneurs to develop skills, collaborate, and innovate around local challenges and solutions. Today, there are more than one hundred such hubs in Africa spurred by government, academic, or private-sector support, or some combination of the three. For example kLab (knowledge Lab), a Kigali-based co-working space for IT entrepreneurs housed within the government-sponsored "ICT Park," attracts young software developers, offering them a place to gain practical experience and training in digital design and production. The Rwandan government heavily supported kLab's ecosystem as part of its National ICT Plan.[60] kLab also maintains ties with the Kigali Institute of Technology and the National University of Rwanda, through which it gains access to potential clientele.

> "Intraregional trade provides a unique opportunity for African countries to build on their competitive advantages and develop more robust trade platforms."

Other models also exist. The Nigerian incubator program, 400.NG, for example, has partnered with the venture capital firm L5Lab in Lagos, as well as local tech hubs in an effort to bridge the gap between talent-picking and skills development.[61] Nairobi's well-known technology hub, iHub, prides itself on having emerged in spite of, rather than because of, government support. Johannesburg's Braamfontein neighborhood houses technology firms, including Impact Hub, Black Girls Code, TechinBraam, and the Branson Centre for Entrepreneurship. Like kLab, its success points to the important role that multiple stakeholders have played in supporting Africa's technology ecosystems and to the likely and varied local applications of 3D printing.

Leverage Global Partnerships

Fab labs and similar technology innovation hubs are good examples of how partnerships with international

57 Lily Sommer et al., *Smart Industrialisation Through Trade in the Context of Africa's Transformation*, Overseas Development Institute, August 2017, https://www.odi.org/sites/odi.org.uk/files/resource-documents/11678.pdf.

58 "Trade in East Africa: Worth Celebrating," *The Economist*, June 9, 2016, https://www.economist.com/news/middle-east-and-africa/21700398-regional-co-operation-has-been-good-least-part-continent-worth.

59 Elizabeth Dearborn Hughes, "Why Africa Should Embrace 3D Printing," *Medium*, April 5, 2016, https://medium.com/@elizabethdearbornhughes/why-africa-should-embrace-3d-printing-d2e2384f183d.

60 Jonathan Kalan, "kLab: A Space for Innovation in Rwanda," *How We Made It In Africa*, August 1, 2012, https://www.howwemadeitinafrica.com/klab-a-space-for-innovation-in-rwanda/18942/.

61 Tim Kelly and Rachel Firestone, *How Tech Hubs are Helping to Drive Economic Growth in Africa*, World Bank Group, 2016, http://documents.worldbank.org/curated/en/626981468195850883/How-tech-hubs-are-helping-to-drive-economic-growth-in-Africa.

Young entrepreneurs brainstorm together on "Open Data Day" at iHub, an innovation and hacker space for the technology community in Nairobi, Kenya. iHub is one of many technology ecosystems seeking to facilitate skill development, collaboration, and innovation around local challenges and solutions. *Photo credit:* iHub/Flickr.

stakeholders can help African countries hone their competitive advantages in the coming era of manufacturing. Virtual connections to labs worldwide can facilitate knowledge exchange. Partnerships with global venture capital funds and other sources of start-up funding are also important. A significant portion of the $560 million in venture capital funding to Africa's tech hubs comes from US and European investors.[62]

Leveraging the know-how of international partners is pivotal for the development of 3D printing in Africa and in regions currently lacking such knowledge. For example, a 2017 pilot project between Siemens, the Emirati aerospace manufacturer Strata, and Etihad Airways successfully designed, certified, and manufactured the first aircraft interior part to be created with 3D printing technology in the Middle East.[63] As a leader in the industry, Siemens consulted on the selection of materials, testing, and the development of the manufacturing processes; Etihad was responsible for the design and certification of the part for use in aviation; and Strata 3D-printed the part with support from local collaborators. The project is an example of 3D printing's potential when the right global and local expertise is leveraged. Similar collaborations could benefit African airline companies, including the continent's biggest airline, Ethiopian Airlines, to diversify their op-

62 Yomi Kazeem, "Startup Venture Funding Jumped More Than 50% in Africa Last Year to a Record High," *Quartz*, February 21, 2018, https://qz.com/1211233/how-much-did-african-startups-raise-in-2017-partech-disrupt-africa/.

63 "Strata, Etihad Airways Engineering and Siemens Reveal the MENA's First 3D-Printed Aircraft Interior Part," *Siemens*, 2017, http://www.middleeast.siemens.com/me/en/news_events/news/news_2017/strata-etihad-airways-engineering-and-siemens-reveal-the-menas-first-3d-printed-aircraft-interior-part.htm.

erations. In 2016 Ethiopian Airlines signed a memorandum of understanding with South Africa's Aerosud to explore the potential of 3D manufactured aircraft parts in Ethiopia.[64]

At its core, 3D printing is just another manufacturing process. Yet, over time it will significantly reshape how and where things are made, with far-reaching consequences for economies that rely on low-wage, labor-intensive manufacturing. In this, African countries are not alone; observing how other countries anticipate and prepare for the coming changes may provide valuable lessons. Smart governments are supporting skills training and innovation, developing complementary competencies, and diversifying their industries and markets. They are now making the decisions that will later determine their role in a world of 3D printing and automation. In the near term, Africa does not have much to gain from 3D printing, but if its governments do not start to make such decisions now, the continent will have even more to lose.

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64 Samuel Getachew, "From Service to Manufacturing: Ethiopian Airlines Verging Towards 3D Printing," *Reporter*, August 13, 2016, https://www.thereporterethiopia.com/content/service-manufacturing-ethiopian-airlines-verging-towards-3d-printing.

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