Fabbing for Africa's Informal Sector

Anna Waldman-Brown, George Yaw Obeng, Yaw Adu-Gyamfi, Sharon Langevin, Abdulai Adam

Anna Waldman-Brown, Technology Consultancy Centre, Kwame Nkrumah University of Science and Technology, Ghana

George Yaw Obeng, Technology Consultancy Centre, Kwame Nkrumah University of Science and Technology, Ghana

Yaw Adu-Gyamfi, Kumasi Centre for Lifelong Learning, Ghana

Sharon Langevin, College of Engineering, Brown University, USA

Abdulai Adam, Ghana Fab Lab, Ghana

Abstract

To manufacture anything in Sub-Saharan Africa (SSA) requires the same creative "maker" sensibility that is valued throughout the fab lab community. This presentation will draw upon research in one of Africa's largest informal industrial communities to explore the past and future of grassroots manufacturing, and examine how fab labs might be integrated into these communities. With over 80,000 technical artisans, auto-mechanics, and purveyors of related supplies, Ghana's Suame industrial cluster is a hotbed of West African manufacturing and creativity. Yet some of the local workshops are wooden shacks without electricity, and the entire community is on the path of decline unless local artisans can come up with competitive products and keep up-to-date with modern technology. The decline of Suame Magazine is typical of many such manufacturing and repair communities throughout SSA. In 1980, a group of engineers from Kwame Nkrumah University of Science and Technology (KNUST), Ghana founded an Intermediate Technology Transfer Unit (ITTU) in the heart of the Suame cluster. They introduced new tools and techniques for metal fabrication, welding, beekeeping, and other grassroots businesses. This presentation will discuss how the success of KNUST's technology-transfer program might be repeated today with digital manufacturing tools– how could a fab lab be tailored for use in SSA's informal manufacturing sector, where metalworking is more essential than carpentry or electronics? This paper will also compare the KNUST initiative to current programs in Ghana Fab Lab and Kenya's ARO Fab Lab. While both fab labs have benefitted their respective communities, neither one has worked with local informal industries in any significant capacity. If fab labs of the developing world wish to fulfill their stated goals of providing employment and fostering new industries, the authors firmly believe that these labs must become better integrated with the existing informal sector.

Keywords

Innovation, informal sector, metalworking, job creation, education, Africa

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ANNA WALDMAN-BROWN
Technology Consultancy Centre
Kwame Nkrumah University of Science and Technology, Ghana
annawab@fabfolk.com

GEORGE YAW OBENG
Technology Consultancy Centre
Kwame Nkrumah University of Science and Technology, Ghana
geo_yaw@yahoo.com

YAW ADU-GYAMFI
Kumasi Centre for Lifelong Learning, Ghana
yagyamfi@gmail.com

SHARON LANGEVIN
College of Engineering, Brown University, USA
sglangevin@gmail.com

ABDULAI ADAM
Ghana Fab Lab, Ghana
College of Engineering, Century College, USA
navropio@gmail.com

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Introduction

The “informal” sector—as defined by the lack of registered businesses and ties to established industries, as well as the small scale of operations— comprises an estimated 72 per cent of employment in Sub-Saharan Africa, 65 per cent in Asia, and 51 per cent in Latin America (ILO, 2002). Yet this sector occupies a relatively minor percentage of most countries' GDP, and remains largely derided by governments and industries.

Globally, the predominant approach to modernization has been a focus on centralized industrialization and manufacturing. As many developing countries still lack the infrastructure, organization, and start-up capital to formalize their industries, the majority of local manufacturing and repair firms has remained in the informal sector. Today’s informal technology-related firms play a significant role in processing agricultural products, supplying furniture, and maintaining imported technology (including computers, factory equipment, and public/private vehicles). The informal industrial sector is characterized by clusters of semi-permanent shacks of wood or found materials, where often-undereducated artisans can subcontract jobs to their neighbors in specialized workshops.

Despite many failed attempts by governments to formalize this sector, informal industries have continued to proliferate throughout most of the developed world. In Kenya, the informal sector contributes over 90 per cent of new jobs annually (Daniels, 2010), and Ghana’s largest informal industrial cluster could employ up to 10 per cent of the nation’s junior high school dropouts (SMIDO, 2012). The local union organization in this Ghanaian cluster declares its informal industries to be “the center of indigenous African creativity.”

This paper discusses a 1980s initiative to upgrade informal manufacturing capabilities in Ghana; we will compare this initiative to current programs in Ghana Fab Lab and Kenya’s ARO Fab Lab. While both fab labs have benefitted their respective communities, neither one has worked with local informal industries in any significant capacity. If fab labs of the developing world wish to fulfill their stated goals of providing employment and fostering new industries, the authors firmly believe that these labs must become better integrated with the existing informal sector. We conclude with a comparison between fab labs and informal sector workshops, and propose a model for successful collaboration. This paper aims to facilitate further cooperation between the informal manufacturing sector and modern technological workshops such as fab labs, hackerspaces/makerspaces, and other centers for innovation.

Historical Background and Literature Review

During India’s battle for independence in the 1940s, Mahatma Gandhi was one of the first political figures to critique the idea of centralized industrialization as a replacement to local manufacturing. As India modernized, rural businesses moved into urban areas to increase efficiency and access to resources. Gandhi feared that rural populations would migrate into cities at an unsustainable rate, leading to a decreased quality of life as well as high rates of poverty and unemployment. Most Indian officials dismissed Gandhi’s endorsement of self-sufficient rural villages as backwards and counter-productive to development, and India pursued a more typical and centralized model of industrialization. However, Indian officials did recognize the necessity

of supporting local industry instead of allowing immediate competition with industrialized nations.

Many Sub-Saharan African (SSA) nations also gained independence throughout the 1950s-1960s, and a number of these governments also feared the destruction of local manufacturing as they entered the global market. Ghana and Kenya, among others, made efforts to support small-scale manufacturing by pursuing protectionist trade measures to bar imports and foster indigenous innovation. With the scarcity of imported goods, Ghanaian auto-mechanics strengthened their ties to foreign, formal-sector motor agencies and created an effective monopoly on auto-parts. Instead of replacing expensive components, Ghanaians then turned to the informal sector—which soon employed tens of thousands of auto-mechanics to undertake more intensive repairs. Repair services included building truck beds, unwinding and cleaning the wire coils inside motors, and grinding down engine shafts to fit in a different brand of automobile (Powell, 1995).

In the 1970s, the International Monetary Fund persuaded a number of developing nations to relax import tariffs and open their doors to international trade. Although the impact of these measures varied, many countries suffered a decline of national industry and a sudden collapse of their informal sectors. Local, small-scale industries could not compete with the flood of cheap foreign goods; American and European hand-me-downs destroyed Kenya's burgeoning clothing industry, while low-cost vehicles and lightly-used spare parts in Ghana diminished the need for repairs and put many industrious auto-mechanics out of business.

This decline led to a renewed backlash against modernization, spearheaded by Oxford economist EF Schumacher who built upon Gandhi's ideas to advocate for "human-centered" rather than purely profit-driven businesses. In his 1973 manifesto *Small is Beautiful,* Schumacher proposed the concept of "intermediate" or "appropriate" technology to bridge the gap between modern and indigenous workplaces:

> If we define the level of technology in terms of "equipment cost per workplace," we can call the indigenous technology of a typical developing country—symbolically speaking—a £1-technology, while that of the developed countries could be called a £1000-technology. The gap between these two technologies is so enormous that a transition from the one to the other is simply impossible, destroying traditional workplaces much faster than modern workplaces can be created, and thus leaves the poor in a more desperate and helpless position than ever before. If effective help is to be brought to those who need it most, a technology is required which would range in some intermediate position between the £1-technology and the £1000-technology. Let us call it—again symbolically speaking—a £100-technology (Schumacher, 1973).

Schumacher's ideas inspired the appropriate technology movement in Ghana, which created roughly hundreds of thousands of new jobs and introduced hundreds of new industries across the informal sector (Powell, 1995). The program will be discussed in more detail in the Case Studies section. Yet due to the nature of small-scale manufacturing, these new workplaces had a limited effect upon Ghana's GDP and never gained the national or international support required for continued modernization.

Another approach to industrialization championed by Prahalad (2004) and Polak (2009) is the Bottom of the Pyramid approach, which supports the importation of foreign-made, labor-saving devices—such as mobile phones and drip irrigation— to increase production capacity of the

informal sector. This approach argues that formal-sector businesses have a financial incentive to develop low-cost technologies to improve the lives of the poor. As it caters to established manufacturers (primarily in the developed world), this approach provides little support for informal manufacturing as a replacement to centralized industry. Aside from the widespread penetration of low-cost communication devices, Bottom of the Pyramid theories have largely served higher income, urban residents of the developing world (Daniels, 2010).

Today, the idea of New Industrialization proposes a renewal of efforts toward upgrading the informal sector, with a focus on more urban areas. Mary Kinyanjui of the University of Nairobi proposes, "Informal production systems could be upgraded into import substitution status [through] relief on import duties on raw materials, tax concessions for jobs created, [and] improved infrastructure and factory premises" (Kinyanjui quoted in Daniels, 2010). Other engineers and academics call for stronger linkages between the informal sector, formal industries, and global educational institutions (Daniels, 2010). Industrial development specialist Keijiro Otsuka states, "Sub-Saharan Africa will never succeed in industrialization if it focuses on the development of inappropriate industries. It is better to begin with simple labor-intensive industries" (Otsuka quoted in SMIDO, 2012).

The fab lab movement has always advocated local manufacturing; founder Neil Gershenfeld states that a future involving universally accessible fab labs "represents a return to our industrial roots, before art was separated from artisans, when production was done for individuals rather than the masses" (Gershenfeld, 2005). Today, the rural-centric Appropriate Technology approach is often discussed among fab lab proponents in developing countries. In Pune, India, the founder of Vigyan Ashram—which hosts a community fab lab—states, "my vision is that every village will have the equipment and the skills that are the basis of all modern industry" (Kalbag, 2003).

Table 1: Approaches to SSA Industrialization (Daniels, 2010)

Movement	Technology	Labor	Materials	Design	Poor as	Center
Traditional Industrialization	Complex	Low	Imported	External	Producer/ Consumer	Urban
Appropriate Technology	Simple	High	Local	External with testing	Producer/ Consumer	Rural
Bottom of the Pyramid	Complex	Low	Imported	External	Consumer	Urban
The New Industrialization	Simple	High	Local	Co-creation	Producer/ Consumer	Urban

Notes: As Daniels explains, it is important to evaluate these different approaches in consideration of a nation's development objectives. Also, the Ghanaian appropriate technology project discussed in this paper adopted a "Co-creation" approach to design— unlike the majority of appropriate technology initiatives.

One key challenge across the informal sector—including retail, agriculture, auto-mechanics, machinery production, shoe-making, etc.— is the fact that very few firms succeed in growing their businesses, so informal workers remain at or below the poverty line.

Based on their research among informal businesses in developing countries, Banerjee and Duflo (2011) provide the following qualitative graph (red circle has been added for emphasis):

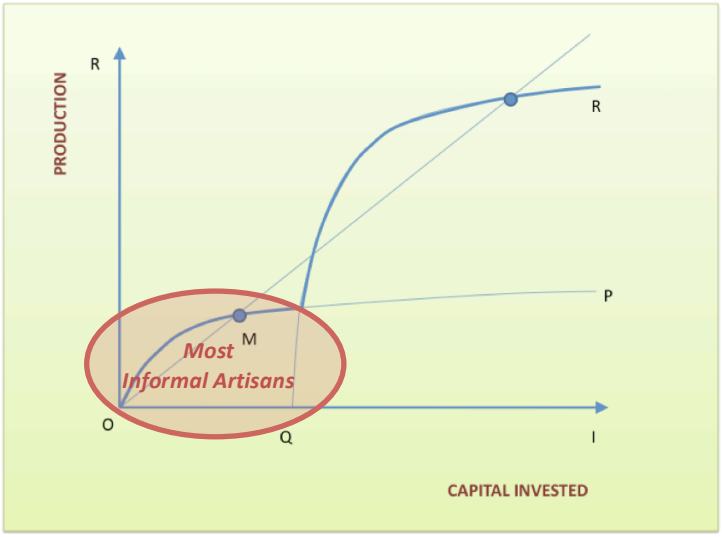

Figure 1: Investment vs. Returns for informal firms (Banerjee and Duflo, 2011). R = Returns; M = Majority of small firms; I = Investment. Curve OP = representative of low investment; curve QR = representative of high investment.

As shown in Figure 1, most forms of growth require a substantial capital investment that is beyond the means of many small firms. Firms become stuck around the point M where incremental investments do not yield significant returns; if a firm cannot obtain the capital required (Q) to jump from curve OP to curve QR, there remains no incentive for attempted innovation. This results in highly conservative businesses that lack the means for upgrading their facilities. Innovation becomes even more risky and resource-intensive, since the purchase of new equipment or materials can be counterproductive and cause a firm to spend years in debt.

Among agricultural and artisanal firms, the lack of growth can often be attributed to the difficulty of obtaining modern technology that is locally appropriate (Powell, 1995). Schmitz (2004) stresses that the upgrading of technical capabilities requires *continuous* investment by local firms in people, organization and equipment. Since artisans in the developing world lack the resources and working capital required for this investment, the impetus may need to come from outside the cluster.

In their assessment of industrial innovation in developing countries, Morrison et al. (2006) state, "Technology and knowledge transmission– and their effectiveness—often appear *as exogenous to the local firms involved*. That is, they would be either determined by the leader strategy (i.e. Global Value Chain governance) or by other forces like for example clusters' external economies and collective efficiency." For innovation to occur in such a cluster, any knowledge that is introduced must be tailored to local needs; artisans must understand new concepts and machinery well enough to fully appropriate these and develop their own technologies.

All these studies imply that informal businesses would greatly benefit from external initiatives designed to upgrade local production capabilities.

As the informal sector is often highly dependent upon imported goods, manufacturing firms tend to be more resilient to market forces than those businesses involved solely in retail or repair; manufacturing businesses have the flexibility to change their wares to fit demand or compete

with foreign products. In addition, the local manufacture of tools allows for a cascade effect of new businesses that can rely upon those tools and introduce new products to the market.

During Ghana's economic downturn of the 1980's-90's, both Dawson (1988) and Powell (1995) report that many of the informal sector firms that survived in Kumasi's Suame industrial cluster were engaged in some aspect of manufacturing. Imports in Suame have continued to proliferate in recent years and replace the demand for local labor. Iddrisu et al. (2009) found that Suame's manufacturing workshops experienced a mean growth of 2% from 2000 to 2004, compared to a mean decline of 5% among auto-mechanic businesses over the same period. Despite a steady linear growth in the population of the Suame cluster since the 1970s, the onslaught of unfamiliar computerized vehicles has been detrimental to local businesses; up to 40% of commercial drivers in the Kumasi metropolis used to be employed as auto-mechanics (SMIDO, 2012).

As discussed by Powell (1995) and Buatsi (2011), any exogenous endeavor to support informal manufacturing industries must involve two components:

1. Upgrading of knowledge (human capital)
    a. Apprenticeships to master craftsmen
    b. Occupational experience in larger firms
    c. Formal education (vocational institutions or university)
    d. Short-term training workshops (free or tuition-based)
2. Upgrading of machinery and tools (technological capital)
    a. Technology provided at a central location for use/rental on an as-needed basis
    b. Technology purchased by firms (directly or through a microfinance scheme)
    c. Technology donated by aid organizations

Throughout the developing world, most informal clusters utilize basic personal fabrication tools, many of which are manufactured abroad and brought into the cluster as used goods. There have been several attempts to work with the informal sector in order to upgrade manufacturing capabilities, and the authors believe that studying prior successes will inform those developing fab labs in similar areas.

Methods

We used exploratory and case study research methods to assess the impact of the Ghanaian Intermediate Technology Transfer Unit (ITTU) initiative on the manufacturers and auto-mechanics of the Suame Magazine industrial cluster (named for its location in an old British armory). Over the 80 years of this cluster's existence, outside influences have played a crucial role in upgrading the artisans' technological capabilities and promoting innovation. While this paper mainly relies upon secondary sources in discussing the ITTU, its co-authors have about two decades of combined experience working in Suame Magazine. Our data sets included recent surveys from the Suame Magazine Industrial Development Organization (SMIDO), as well as research done by the World Bank, the Kwame Nkrumah University of Science and Technology (KNUST), and other academic institutions.

The authors utilized a grounded theory approach in discussing their personal experiences with the Ghana Fab Lab and the Kenya's ARO Fab Lab. Originally put forth by Glaser and Strauss

(1967), grounded theory is the discovery of theory from data systematically obtained from social research. Grounded theory is meant to be contextualized and suited to its particular use, as opposed to taking an existing theory and trying to force it to fit into a new situation. Because fab labs constitute an emerging initiative, no theory has been generated to understand their impact on communities. Author Adam has several years of experience as a Ghana Fab Lab assistant, and author Langevin spent three weeks interviewing community members in the ARO Fab Lab.

Case Studies

Personal Manufacturing in Suame Magazine

With over 80,000 technical artisans, auto-mechanics, and purveyors of related supplies, Ghana's Suame informal industrial cluster is a hotbed of West African manufacturing and creativity. Yet most of the local workshops are wooden shacks without electricity, and the entire community is on the path of decline—unless local artisans can come up with viable and competitive products, and learn how to repair computerized vehicles to keep up-to-date with modern technology. The Suame cluster is one of Africa's largest informal industrial communities, and its dynamics are typical of many such manufacturing and repair communities throughout SSA.

Due to the lack of reported business transactions and registered firms, all statistics about the Suame cluster are estimates based on surveys of artisans (Azongo, 2007; Obeng, 2002; Alexander et al., 2010; Adeya, 2008):

- Over 12,000 workshops within roughly 0.5 square kilometers (discounting food sellers)
    - Permanent building/workshop structures: 40%
    - Registered businesses: 20%
    - Firms that keep business records: 20%
- 70-90% of artisans learned trade through apprenticeships
- 50-70% of artisans have at most a primary education
    - By most accounts, majority of artisans are illiterate
- Average firm size: 5 people
    - Most firms employ 3-10 people
- Artisans interested in computerized technology training: 87%
- Daily income range: US$3-15

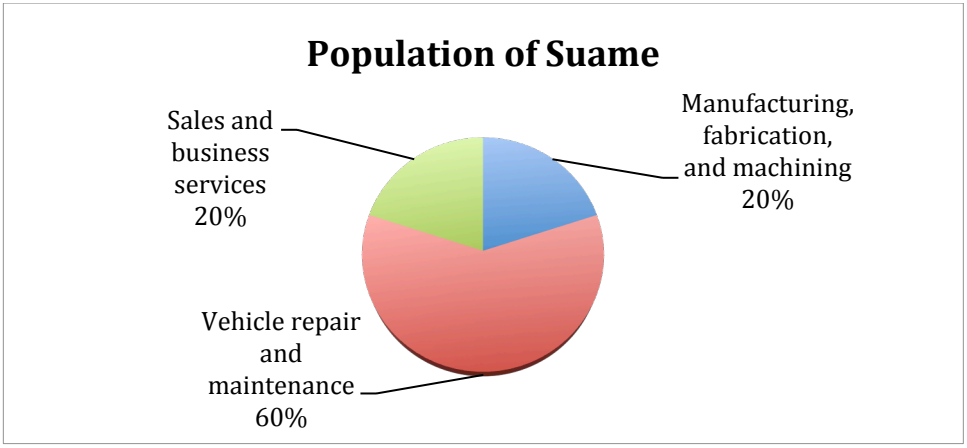

Figure 2: Services performed in Ghana's Suame cluster (SMIDO, 2012 and Obeng, 2002)

As Ghana's informal sector declined in the 1970s following the relaxation of trade barriers, a team of engineering professors from the Kwame Nkrumah University of Science and Technology (KNUST) initiated a program to support manufacturing in Suame Magazine. With government support, these professors worked with KNUST to capacitate auto-mechanics in manufacturing rather than mere repair-work—and bring a more reliable source of revenue to the community. In 1980, KNUST established the Intermediate Technology Transfer Unit (ITTU) in the heart of the cluster, with the goal of providing engineering support to the auto-mechanics and encouraging a shift to manufacturing. The ITTU is a concrete three-story building, with a large front lawn and a well-equipped shop for carpentry and metalworking. Through training programs, targeted academic research, and the provision of tools and equipment, the ITTU facilitated the growth of Suame Magazine's manufacturing sector by transferring technologies and innovating with local artisans.

After a decade of ITTU operations, the Ministry of Trade and Industry concluded that the program had provided such benefit to Ghana that KNUST should establish a similar workshop and training facility in each of the country's nine additional regions. Today, the ITTU network is known as the Ghana Regional Appropriate Technology Industrial Service; it was highly active in research and training for the informal sector throughout the 1990s, but has since lost most of its focus on developing new informal industries. (Reasons for this change include organizational corruption, staff turnover, shifts in donor interest, and a failure to keep up with modern technology.)

There is no research on the exact number of enterprises that exist because of the Suame ITTU; from 1980-1995, we estimate ITTU activities led to hundreds of new businesses in the region. Today, at least thousands of individuals throughout the region have indirectly benefitted from the Suame ITTU and offshoot businesses. We estimate the countrywide appropriate technology program has indirectly initiated jobs for *tens of thousands* of Ghanaians in beekeeping, auto-mechanics, agricultural processing, textiles, metalworking, and similar small-scale industries.

Personal Manufacturing in Ghana Fab Lab and ARO Fab Lab, Kenya

In this paper, we discuss two Sub-Saharan fab labs with which the authors have personal experience: Ghana Fab Lab at the Takoradi Technical Institute along the west coast of Ghana, and ARO Fab Lab in Majiwa, rural western Kenya. Very little critical research has been done on fab labs in the developing world (Langevin, 2011), so we cannot draw upon prior studies.

Unlike the ITTU, neither fab lab lists job creation as one of its primary goals. Nonetheless, this is an objective in most of the related fab lab and media publicity.

While fab labs have many and varied intended purposes, the mission statements of both these labs make explicit reference to "solving local problems." As discussed, the lack of technological advancement in Ghana and Kenya's informal industrial sectors have contributed to numerous local problems; this paper will focus on how effectively these two labs have promoted the establishment of new enterprises and supported existing small-scale manufacturing firms. The staff of these fab labs has the technical knowledge required to provide this support, as well as

access to the required technical capabilities. Both fab labs are located within walking distance of informal industrial workshops, and equipped with a standard suite of fab lab machines except the Ghana lab is missing a ShopBot.

Ghana Fab Lab was the first developing world fab lab. MIT's Center for Bits and Atoms expressed a desire to explore the implications of personal digital fabrication technology in nontraditional communities: "the hope is that students and other learners will eventually acquire the competencies in designing and fabricating the basic to complex tools needed to solve community problems" (Azasoo, 2012). The lab was established in June 2004 by MIT's Center for Bits and Atoms on the campus of the Takoradi Technical Institute (TTI), the region's foremost vocational institute for several thousand secondary school students. It was born out of a strong collaboration between the Sekondi Takoradi Metropolitan Assembly and Boston, Massachusetts; TTI has numerous international ties, and has also received donations of state-of-the-art machining tools, new computers, and other classroom facilities from the Austrian and German governments. TTI offers secondary schooling for students who wish to attend university, as well as vocational certificates in auto-mechanics, sewing, cooking/catering, electrical wiring, computer skills, and welding and fabrication. There is little emphasis on design and invention in the TTI curriculum, and most student projects follow prescribed instructions; however, the administration has expressed interest in integrating additional "fab lab skills" into classrooms (Azasoo, 2012). TTI students apprentice themselves to formal-sector firms in their final year, and top students attend the Takoradi Polytechnic in order to pursue careers in industry. Many alumni eventually establish their own informal sector firms, as running a small business often proves more lucrative than working in a formal-sector factory.

Potential users of the Ghana Fab Lab number in the tens of thousands, as TTI is conveniently located in an urban area and accessible by inexpensive public transport from central Takoradi. Although the lab is located within the gates of TTI, community members are welcome to enter the school campus and utilize the fab lab during working hours and over the weekend. Nearly all of the current Ghana Fab Lab users, however, are current students at TTI, Takoradi Polytechnic, and local primary schools.

ARO Fab Lab officially opened in October 2009, though planning had begun as early as 2006. The idea to build the lab came from the Norwegian funders of ARO Centre, who believed that bringing the Fab Lab would enable community members to create their own solutions to problems that affected them daily. The lab manager was hired externally, and currently works with the support of another ARO Staff member who has been employed there since before the lab was built. The Fab Lab was built largely through the influence of the donor organization, with little input from the local community. There was no participation from the community in selecting the site for the lab, developing guidelines for how it should be used, or creating a plan to help sustain the lab through selling products and continuing to maintain and expand the user base. Although the idea for building the Fab Lab did not come from the community, the lab manager and other staff members and lab users do see ways that having the lab helps the local community. Some community members reported having gained skills and seen positive changes since the lab opened (Langevin, 2011).

In Majiwa, Kenya, nearly every family participates in subsistence farming as a primary source of food and income, with many performing casual labor or running small shops as a supplement. The ARO Centre houses the Fab Lab as well as several other community programs, including a health clinic that provides care to the local community. Within the area around ARO Centre are about 3000 people, all of who live within about 5 km (walking distance) of the center; these are the primary potential users of the ARO Fab Lab (Langevin, 2011).

The exact number of new enterprises that began as a direct result of these two fab labs is unknown. Although a handful of businesses have been supported by the fab lab facilities, we estimate *fewer than 5-10* new businesses were initiated over a combined thirteen years of fab lab operation. Unlike the ITTU program, these two fab labs have not led directly to the establishment of additional fab labs in the region. (There are many more SSA fab labs today, but none of these trace their origins to the Ghana or ARO lab.)

Results and Discussion

Evaluation of Suame Magazine Intermediate Technology Transfer Unit

Waldman-Brown, Obeng, and Adu-Gyamfi (2012) identify three stages of technology in Suame Magazine, as explained below.

1. Basic tools stage: solely vehicle-repair

From its inception, Suame Magazine has relied upon both knowledge and physical technologies from outside the cluster. In the early 1930's, British colonists sent a few Ghanaians to Europe to study vehicle repair out of frustration with the lack of trained auto-mechanics in SSA. Upon their return, these mechanics set up workshops in Kumasi and proceeded to train some of their sons and other male relatives in their trade. Despite the steady growth of the Suame cluster after Ghana's independence—as Ghanaians began to acquire personal cars from abroad—the site remained a modest collection of workshops until the mid-1970's, when a series of political failures forced Ghana's formal sector economy into decline and vehicle owners were forced to employ local artisans for repairs. Given the lack of Ghanaian knowledge, many auto-mechanics who came to Suame during this period had trained in the European-dominated formal sector of Ghana (Powell, 1986).

While the formal sector factories and auto-mechanic workshops shut their doors, vehicle-owners relied increasingly upon informal artisans to keep their cars on the road and the population of Suame Magazine exploded. From 1979 to 1984, membership in the Suame Mechanicals Association grew from 27,000 to 40,000 (Powell, 1986). In 1980, the government launched a major initiative to repair all state-owned vehicles and Suame Magazine took on the bulk of this project. Artisans designed and built wooden beds for cocoa-bean transport trucks, and hammered out new bodies for official cars and buses. Dozens of auto-mechanic communities sprouted up across the country as the trade became more profitable.

2. Machining tools stage: introduction of manufacturing

From 1971 to 1979, 42% of apprentices in Suame Magazine went on to self-employment, and another 21% remained in their masters' workshops as professional craftsmen. Yet between 1985 and 1990, only one apprentice in 400 (0.25%) succeeded in becoming self-employed due to Ghana's financial restructuring (Powell, 1994). Before Ghana relaxed its international trade barriers, most of the Suame firms were engaged in vehicle repair and minor alterations. Following financial restricting, local, small-scale industries could not compete with the flood of cheap foreign goods. Around the same time, a number of artisans who had relied upon vehicle owners in the Kumasi lumber business lost their jobs when Kumasi ran out of trees to harvest.

In 1980, KNUST erected the ITTU to provide both technology-based and knowledge-based support and encourage a shift toward manufacturing.

Today, the ITTU is best known among Suame artisans for selling some of the first electric machining tools to artisans on hire-purchase terms, and for training apprentices and leading workshops to introduce new methods and technologies. The ITTU introduced a machining tool called the capstan lathe, which was ten times faster and more reliable than the centre lathes that were currently in operation. In the 1980s, the Canadian-based volunteer agency Cuso International sent an automobile technician to the ITTU to train artisans in modern auto-repair techniques. The ITTU continues to host an exchange programme for KNUST engineering students to gain practical experience by apprenticing themselves to Suame artisans for several months. The ITTU facilitated the growth of Suame Magazine's innovation capabilities by introducing new technologies, as discussed in Table 2.

Table 2: Impact of machining tools upon Suame artisans

Tools Introduced	**Knowledge Introduced**	**Volume Introduced**	**Impact**
Metal fabrication tools (lathe, drill-press, milling machine, etc)	Manufacture of agricultural processing tools, engine re-boring, customized gears...	Over 100 machining tools	Customized manufacturing and precision work
Small-scale iron foundries and aluminium-spinning	Making of nuts/bolts, tools, millstones...	Currently over 100 small-scale foundries in Kumasi, trained through workshops	Customized manufacturing, improved compatibility of repair tools, introduced scrap-metal collection for iron recycling
Record-keeping	Basic accounting skills, literacy	Dozens of workshops for interested artisans	Improved customer relations, advertising, business transactions (primarily big businesses)

Due in large part to the efforts of the ITTU, the stock of machine tools in Suame Magazine grew from 6 in 1971 to more than 150 in 1986 (Powell, 1986). By working with the government and establishing a precedent for the importation of used equipment, the ITTU also helped pave the way for unaffiliated artisans within Suame to import their own machining tools.

While the direct effects of ITTU have been limited to a small group of firms within Suame, the introduction of new manufacturing technologies provided many of Suame's vehicle-repairers with specialized equipment that would not have otherwise been available (McCormick, 1998). The local production of steel bolts and nuts, as well as gear and chain sprocket wheels, ushered in a new era of vehicle repair (Obeng, 2002). With their new machining technology, the ITTU

designed and demonstrated manufacturing processes for products such as palm-oil extractors, soap boiling tanks, corn-mills, carpenters' benches, donkey-carts, and agricultural tools—and Suame artisans quickly appropriated many of these ideas (Powell, 1990). By introducing equipment that could be used for the local manufacturing and processing of raw materials, the ITTU's activities helped stimulate the nation's economy and produced a cascade effect of new manufacturing industries (Powell, 1990). For example, the introduction of small-scale foundry technology provided new jobs for foundry-workers, dealers in scrap iron (to be melted down in the furnace), and manufacturers of corn-mills who can buy large volumes of locally made iron grinding mills instead of costly imported versions. The introduction of beekeeping provides another example of this effect; although Ghanaians had historically harvested honey and wax from wild bees, the ITTU's collaboration with beekeepers in Kenya brought the first domestic beehives into Ghana. While honey was rare and of inferior quality prior to the ITTU's intervention introduction, it is widely available throughout the country today.

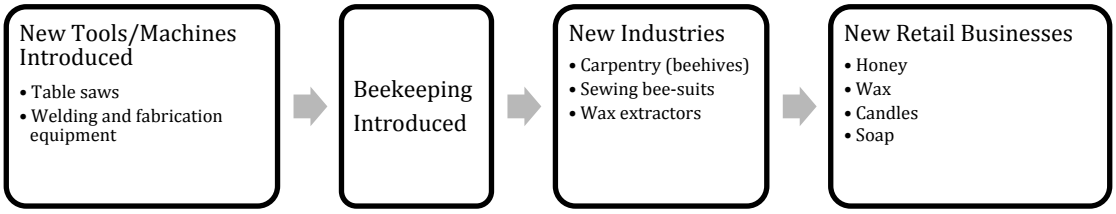

Figure 3: Cascade effect of new industries, as enabled by the introduction of new technology

3. Computerized technology stage: potential for advanced manufacturing and repair

As computer technology becomes increasingly pervasive worldwide, Suame Magazine is falling behind in terms of standard business practices, manufacturing capabilities, and the repair of computerised vehicles (Alexander et al., 2010). The government of Ghana places a national tax on the importation of any vehicle older than 10 years, so Suame artisans are now forced to repair computerised vehicles from the 1990's and work with modern electronic components. Yet to the artisans of Suame Magazine, modern vehicles represent a quantum leap from their current technological capabilities.

As inexpensive, foreign goods continue to flood the market, and Ghana introduces new safety regulations for both vehicles and food processing, Suame artisans are discovering that their level of technology is no longer competitive. Many Suame artisans also aspire to compete on a global market, which would require a much higher degree of technological capabilities (Obeng 2002). Just as the introduction of lathes, drill-presses, and other machinery into Suame increased both process efficiency and product quality, the introduction of computerised technology and digital manufacturing have the potential to radically upgrade artisans' capabilities.

Today's tools enable an unprecedented level of precision for small-scale manufacturing and repair-work, and can also facilitate global communication and information collection. Suame artisans identify their lack of knowledge about modern technology to be the primary challenge to their livelihood today (SMIDO, 2012). As late as 2007, only 2% of the master craftsmen interviewed had email addresses (Azongo, 2007). In Adeya's (2003) survey, 87% of Suame artisans surveyed were interested in receiving computer training, and 81% were willing to pay an unspecified amount. Table 3 demonstrates the potential for modern technology.

Table 3: Expected Impact of Computerised Technologies on Suame Magazine

Technology	Knowledge required	Volume required	Impact
Basic Computers (for use in design, manufacture, or business practices)	Literacy, numeracy, computer skills	High (ideally one per workshop)	Enable use of computerised technology, access to information, facilitate recordkeeping, advertising, and information-sharing
Computerised Vehicle Diagnostic Tools (to troubleshoot modern vehicles)	Literacy, computer skills, familiarity with programs	Low (a few workshops can provide diagnostics for all mechanics)	Enable safe and comprehensive repair of modern vehicles, simplify troubleshooting of vehicles
CNC Tools (upgrade known technology: lathes, routers, etc)	Literacy, numeracy, computer skills, engineering background	Moderate (replace existing antiquated machines)	Facilitate improved manufacturing, increase precision and efficiency of products and safety of vehicle repair
Digital Fabrication Tools (new technology: 3-D printers, circuit-board makers, etc)	Literacy, numeracy, computer skills, engineering background, advanced software	Very low (few workshops can produce wide variety of customized devices)	Facilitate new level of manufacturing and product-creation, attract educated engineers, enable customized molds for casting and other rapid-prototyping

Basic computers and vehicle diagnostic tools have been introduced to a handful of Suame artisans, although more computers and additional training will be necessary before these interventions have a demonstrable impact. There is very little modern fabrication equipment in use; most machining tools in Suame are several decades old and have no digital components, and very few artisans have experience with computers or modern circuitry.

The cost of digital fabrication is dropping rapidly, allowing individuals access to precision manufacturing tools that were hitherto only available to full-scale factories. A Suame artisan could use a 3D printer to quickly create precise objects of various sizes from melted plastic, for customizing molds in metal casting or designing prototypes for new inventions. A corn-mill with an inexpensive electronic sensor built on a locally-manufactured circuit board could alert the user of problems such as overloading or the wearing-out of machinery. Soldering and electronics also require a higher skill level, but soldering stations are easy to procure and operate and circuit-board manufacturing can take place at some central workshop.

One capable craftsman with a modern CNC machine or a 3D printer can provide improved manufacturing services and specialized components for hundreds of artisans; similarly, a technically literate artisan with a computer and an auto-diagnostic tool can assist hundreds of Suame mechanics. (The computer in a modern vehicle is a small box, which can be easily removed and carried to another workshop for diagnosis.)

In 1996, the ITTU offered a computer course to Suame artisans at KNUST; they taught computer-aided drawing and followed-up with more general computer training. In 1997, the ITTU and later the KNUST School of Engineering attempted to bring a full-scale CNC machine into Suame Magazine for demonstration and training purposes, but this project has not yet been completed. The Suame Magazine Industrial Development Organization (SMIDO) has trained

dozens of artisans in basic computer skills, but interest waned when artisans were unable to afford their own computers after graduating from SMIDO's courses.

The Suame ITTU has not been able to modernize its own workshop due to its present lack of funding and the difficulty of forming linkages between KNUST's own mechanical, electrical, and automotive engineering departments. The authors have found an unfortunate trend among potential funders (primarily aid organizations and governments) to support the development of computer skills in developing countries while ignoring the importance of upgrading mechanical capabilities; conversely, the few programs that do support mechanical technologies have made little effort to integrate computerization.

Figure 4 shows KNUST's Suame ITTU in the 1980s; today's workshop is identical to this photo, plus the addition of several computers.

Figure 4: Suame ITTU in the 1980s (Buatsi, 2011).

Waldman-Brown, Obeng, and Adu-Gyamfi (2012) propose a simplified qualitative graph to demonstrate the discontinuity of innovation within the Suame cluster, and the necessity of exogenous interventions.

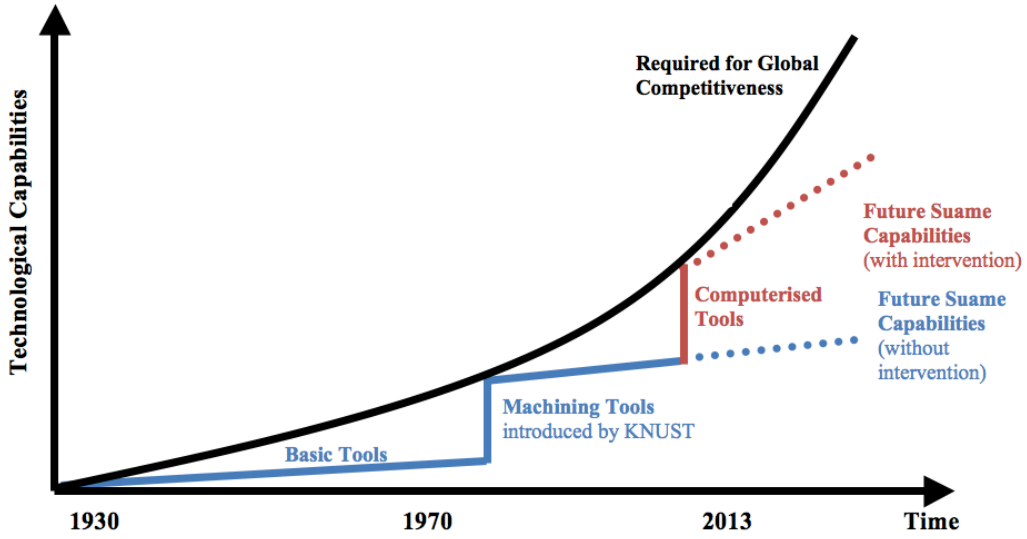

Figure 5: The discontinuity of innovation in Suame, and necessity for continued intervention. Innovation is represented here as the change in technological capabilities per time.

Technological progress is path-dependent, so any discontinuity in innovation capabilities leads to a much greater discontinuity in technological capability. Waldman-Brown et al (2012) estimate that innovation in formal sector firms follows an exponential trend, based on the cumulative improvement of technological capabilities combined with new discoveries. Within the informal sector, artisans have less incentive for innovation, minimal working capital, and an education based upon practical skills rather than knowledge; thus, innovation becomes a more linear function of continuous, incremental improvement upon established practices.

Theoretically, dynamic exogenous interventions would enable Suame artisans to maintain an exponential increase in technological capabilities, and thus remain globally competitive. This ideal outcome would require continuous collaboration between knowledgeable researchers (in either academia or industry) and informal artisans in order to identify and prototype promising new technologies.

In summary, our research indicates that current efforts to introduce computerized tools have been insufficient; additional exogenous interventions will be necessary if Suame artisans are to innovate and regain their former competitiveness. As Suame is a typical SSA cluster, these findings can be extrapolated to similar informal industries throughout the sub-continent.

Evaluation of Ghana and ARO Fab Labs

We present a table of metrics (Table 4) to evaluate the community involvement of the two labs discussed above (Langevin, 2011 and Azasoo, 2012).

Table 4: Metrics for community involvement of two SSA fab labs, with a focus on the creation and support of small-scale industries

	Ghana Fab Lab	**ARO Fab Lab Kenya West**
Regular users	Roughly 30: ~ 50% solely use computers ~30% work on school projects ~15% do repair services ~5% work on independent projects	Roughly 20: ~ 75% solely use computers
Daily users	5-25 from TTI 0-10 from Takoradi Polytechnic 0-3 adults from local communities	5-20 from local community
Level of education	Most high school, some college	Most high school, some college
Primary equipment used (purpose of use) **Note: listed in order of popularity**	Computers (internet use and CAD) Epilog Laser Cutter (customized 2D engraving) Soldering stations (student projects and electronic repair) Modela Router (making circuits) Vinyl cutter (screen printing and stickers)	Computers (internet use) Electricity (charging appliances) Vinyl cutter (screen printing and stickers) Epilog Laser Cutter (customized 2D engraving)
Sampling of completed projects not for sale	Prototype circuits, prototype signal lighting systems, solar PV systems, artistic chandeliers, mobile phone repair services, toy robotics, variety of student projects	FabFi wireless internet, prototype circuits, toy robotics
Sampling of completed projects made for sale	Prototype water pump, 2D laser-engraved acrylic (trophies, key chains, nameplates), customized T-shirts	Customized T-shirts, jewelry, prototype solar-powered lamps
Long-term formal sector ties	Facilitation of student projects at TTI and Takoradi Polytechnic, CAD/CAM training for local industries (mostly oil/gas sector)	Weekly computer classes with ARO Centre
Long-term informal sector ties	1 speaker-manufacturing businesses equipped/trained with CNC cutter	Computer classes for anyone interested, 1 jewelry maker
Funding sources	Fab Lab (some materials costs) TTI (limited support) MIT Fab Foundation (replenish materials every 1-2 years)	NORAD MIT Fab Lab Norway ARC-Kenya and ARC-Aid
Marketable skills taught	CAD/CAM and computer-aided design, soldering and circuitry, limited prototyping/engineering	Basic computer literacy, soldering and circuitry (upon request)

Our research has not found these two fab labs to be successful in initiating or supporting small manufacturing enterprises, despite their capabilities for advanced fabrication. However, both labs have succeeded in educating students and those in the formal sector, and have provided (primarily well-educated) users with a unique opportunity to experiment with digital manufacturing. Additional long-term, data-driven studies are needed before the overall success of these fab labs can be evaluated. As the focus of this research is the creation of new enterprises and the introduction of new technologies, the evaluation of these labs' educational programs is outside our scope.

While the introduction of a technology such as beekeeping creates a chain of downstream enterprises as mentioned above, the final products of SSA fab labs (such as trophies and solar panels in Ghana, or solar lamps at ARO Kenya) tend to go straight to market rather than support additional manufacturing capabilities. That is, every step of manufacturing takes place at the fab lab rather than being spread across a variety of different industries.

Unlike the ITTU, most fab labs in the global network do not have strong ties to research or outreach programs that support involvement with the informal sector. Still, there is evidence that fab labs can develop new, viable businesses. At Vigyan Ashram in India, students at the fab lab sold over 5000 units of homemade LED lights, and one entrepreneur started a company to manufacture and sell a pedal-powered charger designed at the fab lab (Kulkarni, 2013). Yet these projects, like the businesses supported by the Ghana and ARO fab labs, are all endeavors to be pursued by entrepreneurs rather than products that can be manufactured/repaired locally in hundreds of different informal workshops.

Our research also identifies a mutual mistrust between the formal and informal sectors, which is supported by the findings of Daniels (2010) in Kenya and Powell (1995), Obeng (2002) and Alexander et al. (2010) in Ghana. While informal artisans are understandably focused on immediate functionality and their own potential for future employment, those in the fab lab are often more concerned with industrial projects or furthering the education of students by focusing on interesting rather than practical problems. In an academic setting, once an engineering problem is solved, it may be more educational to move onto a new endeavor rather than spend time turning the completed solution into a new business.

Langevin (2009) found that undereducated community members (who constitute the majority of potential fab lab users) are disinclined to visit ARO Fab Lab because they would feel useless in a facility based on computer skills. Since most informal artisans in SSA are computer-illiterate if not entirely illiterate, local fab labs would need to make a particular effort to make these artisans feel welcomed in their workshops. Informal artisans often work for long hours at or below the poverty line, so they have little leisure time in which to leave their workshops and attend classes; if they do not see any immediate benefit in using fab lab facilities, they will not take time to visit.

Table 5 lays out several predominant distinctions between fab labs and manufacturing workshops in the informal sector.

Table 5: primary differences between fab labs and informal sector manufacturers

Fab Labs	**Informal Sector Manufacturing Workshops**
Predominant materials: plastics, circuitry, wood, fabric	Predominant materials: metals, wood, fabric, used car parts and vehicle engines
Most products involve electronics, art/handicrafts, prototyping of small machines	Most products involve moderate-to-large-scale agricultural machinery or cooking equipment
Perceived audience of upper-class academics and hobbyists: well-educated but impractical	Perceived audience of lower-class informal artisans: uneducated, crude, and dangerous
Low level of technical handiwork, moderate level of background knowledge required	High level of technical handiwork, low level of background knowledge required
Most users trained through formal education and fab lab seminars	Most users trained through long-term apprenticeships to master craftspeople
Emphasis on collaboration and open-source	Fear of IP theft, intense competition with neighbors
Centralized organization: often sponsored by academic institution or industry	Grassroots organization: income generated by clients and resources obtained from multiple sources
High value placed on design, aesthetics, and precision	High value placed on practicality, durability, and potential for employment
Often located in a community center or school/university: safe environment and low rate of theft	Often located in industrial slums on outskirts of urban areas: unsafe environment and high rate of theft

Unlike most current SSA fab lab managers, the ITTU directors had a clear mission to promote job-creation; as a result, their initiative involved an unprecedented amount of collaboration, co-creation, and skills training. Throughout the 1980s, when the ITTU was most rapidly researching and promoting new industries, the majority of ideas came from informal artisans who approached academics at the ITTU with their own engineering problems. When an idea derived from an ITTU academic, such as the beekeeping initiative, it always had its roots in the informal sector: everyone knew that Ghanaians had always enjoyed honey and utilized beeswax, but no one in Ghana had any experience with beekeeping. In developing and prototyping potential business opportunities, the ITTU worked collaboratively with artisans who would ultimately run those businesses.

Throughout Ghana, regional ITTU directors found that, unless informal artisans can identify the potential for profit, they will not appropriate new technologies or methods (Powell, 1995). One of the Suame ITTU's first projects was the local manufacture of high-quality nuts and bolts of different sizes (previously, these were imported and of variable and inconsistent sizes). If nut-and-bolt manufacture became a thriving business, Suame ITTU staff hypothesized that the existence of a reliable source of nuts and bolts would allow for the proliferation of new manufacturing industries. Yet few artisans were genuinely invested because no one expected to make any profit from such a small-scale enterprise. The project did not take off until one Kumasi trader discovered a ready market in a fishing boat-building enterprise: the wooden boards of

these fishing boats were held together with hundreds of large steel bolts, which had been nearly impossible to source locally in large volumes. With support from KNUST researchers, this trader purchased a lathe and established his own bolt-manufacturing workshop (Powell, 1995).

In the two fab labs, however, we did not find evidence of any specific program to promote new informal jobs. As a result, the occasional identification of potential business opportunities often comes from an academic setting (such as a student project) or a donor agency without community ties. The projects themselves are carried out almost exclusively within the fab lab, without direct collaboration with potential business owners. While potentially useful, these projects thus remain academic and fail to garner any significant interest from the informal sector.

Figure 6 proposes a general model for cooperation and business-generation across sectors; the informal sector must be involved throughout the process of creation, and all successful business opportunities must be rooted in the realities of communities such as Suame Magazine.

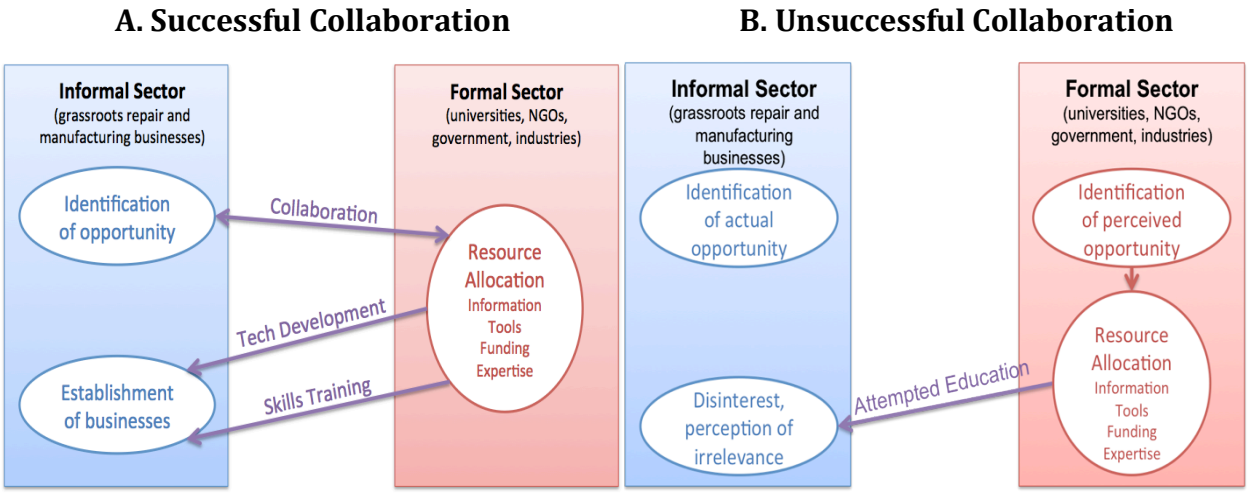

Figure 6: Diagram depicting information flows in two types of cross-sector collaborations. Our research indicates that the informal sector is well aware of business opportunities but may not recognize their full potential.

It is important to recognize that few directors and managers in any technological workshop overseen by a formal-sector institution (such as a fab lab) have direct experience working in the informal sector.

Conclusion and Recommendations

We believe fab labs can play a role in upgrading the informal industrial sector across Sub-Saharan Africa, and research indicates that the artisans of clusters such as Suame Magazine require continued external support to facilitate innovation. Given the success of the ITTU's program to upgrade machining capabilities, we hypothesize that a similar strategy could work to introduce digital manufacturing technologies. A successful strategy will require a multilateral approach: informal artisans must cooperate with the private sector, the government, development organizations, and academia. SSA fab labs must make an effort to involve local artisans, to facilitate the importation of digital technologies, and to pursue projects that are rooted in the realities of informal manufacturing. These fab labs must acquire additional resources and funding in order to make their equipment available and attractable to informal artisans, who

would otherwise dismiss the workshops as purely academic. The number of imported digital manufacturing tools need not be very large in order to have a substantial impact on the community, since machines are often shared across workshops.

The success of the Suame ITTU throughout the 1980s provides several valuable lessons for future endeavors. In particular, continual collaboration across sectors is critical for the creation and proliferation of new, technology-based industries. Centralized organizational structures, such as those present in most of developing world fab labs, may be detrimental for gathering grassroots support from the informal sector. As both schools and governments pay little attention to small-scale manufacturing, it may be useful to follow the model of the Suame ITTU and place new fab labs in the middle of informal clusters. If SSA artisans deem fab labs to be useful, local workers' unions could initiate their own fab labs in a manner similar to the emergence of makerspaces/hackerspaces across the developed world. In the case of exogenous fab labs, local unions and influential artisans from the informal sector must take part in determining workshop activities and organizing new classes.

Despite the myriad opportunities for professional engineers to work within the informal sector, those with formal education tend to look down upon informal artisans. Also, many formally educated engineers have very little experience with practical engineering. We recommend promoting increased education about the informal sector, as well as expanding exchange programs to bring academics into industrial clusters and vice versa. Creative informal artisans could be provided with fellowship/apprenticeship opportunities to spend time in workshops such as fab labs.

The ITTU example demonstrates that, in order to create a workshop that will support and empower informal artisans to utilize fab labs for local manufacturing, potential users must recognize the relevance of fab lab technologies. That is, new technologies and methods must not seem too difficult to learn, and must demonstrate some potential for increasing the profit or livelihood of informal artisans. Fab labs can provide the equipment for this type of innovation, but the two SSA labs in our study did not offer enough support for undereducated users from the informal sector.

The authors also advise developing world fab labs to adapt their technical capabilities to the local environment; the majority of manufacturing businesses in the informal sector utilize large-scale industrial tools and resources rather than the precise, small-scale prototyping equipment available at fab labs. For example, microprocessors could be useful for incorporating sensors into agricultural processing equipment—yet if fab lab staff is unfamiliar with industrial machinery, the lab may have difficulty making its product robust enough to satisfy customers.

Ultimately, the impetus for improving collaboration with informal artisans must come from the formal sector. The two SSA fab labs examined in this paper have not, to date, made any significant effort towards this end. Workshops and institutions across the formal sector have access to extensive resources that can aid in the development and promotion of small-scale manufacturing; yet, if any new technology is to benefit the informal sector, increased collaboration with the end-users is required.

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