FAB LAB: AN ALTERNATE MODEL OF ICT FOR DEVELOPMENT

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ABSTRACT
There is a growing sense that the Digital Divide and the role of Information and Communications Technology (ICT) in international development need to be fundamentally reconceptualized. This paper presents the composition and the rationale behind the creation of a network of fabrication laboratories, FAB LABs, whose mission is to provide concrete examples that would lay the foundation for a new framework for this reconceptualization. At the heart of this idea is the belief that the most sustainable way to bring the deepest results of the digital revolution to developing communities is to enable them to participate in creating their own technological tools for finding solutions to their own problems. Each FAB LAB consists of a collection of tools for design and modeling, prototyping and fabrication, instrumentation and testing and debugging, and documentation for a wide range of applications in formal and informal education, health and environmental monitoring, as well as economic and social development.

Keywords
ICT for Development, FAB LAB, Personal Fabrication, Design Tools, Documentation Tools, Rapid Prototyping.

INTRODUCTION
The next phase of the digital revolution will go beyond personal computation to personal fabrication. This expansion will have a far-reaching impact, and in order to recognize its full implications, we must think of fabrication in the broadest terms and in terms of its impact on the broadest range of audiences.

For an instructive analogy, consider the fields of "personal photography" and "personal movie-making." The word personal in "personal photography" is probably strange to most people today because they don't remember the days when photography was limited to professionals, much like computation was in the early days of mainframe computers. People today enjoy a much greater degree of control over

Figure 1: The FAB LAB site in Vigyan Ashram, a small educational community located just outside the village of Pabal in Maharashtra, India

the creation, manipulation, and processing of their still pictures and videos. Today a growing number of software tools allow everyone to experience being movie directors, producers, and cinematographers.

We believe that there will soon be a wide collection of affordable tools, which we call "personal fabrication machines," that will allow anyone to make his or her own physical artifacts and with embedded computation, communication, sensing, and actuation capabilities. Furthermore, in the not too distant future, everyone will be able to print active electronics – and even fully functioning computers – on a wide variety of substrates, including, for example, paper. [1]

It will be difficult to foresee the full impact of these technologies just as few in the 1970's imagined the scope of the impact of the personal computer. Though it is exciting to speculate about what will be possible in the future, this paper is premised on what is possible with the tools that are either available or can be readily developed today. Our driving assumption is that with careful attention to accessibility issues relating to the design, programming, and manufacturing tools, we can develop a new set of low-cost tools that will have a deep, positive, and sustainable impact on development and will help reconceptualize the current debate on the role of ICT in development.

More concretely, we believe that the most appropriate computational technologies for development are those that enable people to learn not only to design and manipulate their creations on computers, but also to use computer controlled manufacturing tools to build and realize their own creations.

In this paper, we will report on a new initiative, called FAB LABs, in which we are setting up a number of fabrication laboratories that are equipped with an initial selection of design and modeling, prototyping and fabrication, testing and monitoring, and documentation tools. [2] A remarkable group of our colleagues – community leaders, educators, and engineers working in different rural communities around the world – are using these tools to develop their own solutions to local problems.

It is important to emphasize that this project, though very active, is in its early stages of implementation, and we are not yet prepared to make any inferences in regards to the social impact of this project. We hope to be able to report on the social dimension of project in the near future. In this paper, we will describe the technical composition of the current instances of FAB LABs, our approach for introducing them to their current host communities, and our aspirations and initial impressions as to what the impact of the these tools are in the short and long run. One of the most concrete results of this paper is the discussion of the most challenging aspects of this type of initiative and our current research and development efforts to address them.

WHAT IS A FAB LAB?

Each FAB LAB is equipped with the tools for every aspect of the technology development process: design, fabrication, testing and debugging, monitoring and analysis, and documentation. Though we have begun with a common set of tools in every FAB LAB, it is quite natural for each FAB LAB to evolve to meet the unique needs of the communities that use the tools and resources within it. Over time, we anticipate that every site will find a different subset of the tools in the FAB LAB most critical to its needs, and may wish to extend the capabilities of these particular tools to meet their specific demands.

To this end, our ultimate goal is to make it possible for the users of each FAB LAB to use the tools in the FAB LAB itself to design and create the next generation of the tools that they need – and therefore, in parallel to documenting and assessing how the current FAB LABs are utilized, we are leading a research and development effort on designing new, low-cost versions of the FAB LAB tools so that they can be made entirely within the FAB LAB itself. A description of the tools in each FAB LAB as well as current and envisioned scenarios of use of FAB LABs will make these comments more concrete.

Design Tools

Each FAB LAB is equipped with a personal computer that is used in conjunction with almost every other tool in the lab. It is used for 2D and 3D mechanical design and modeling, simulations, data analysis, design of various electronic and computational devices, designing and laying out printed circuit boards, programming, interfacing with the fabrication tools, internet access for communication and information retrieval purposes, and documentation.

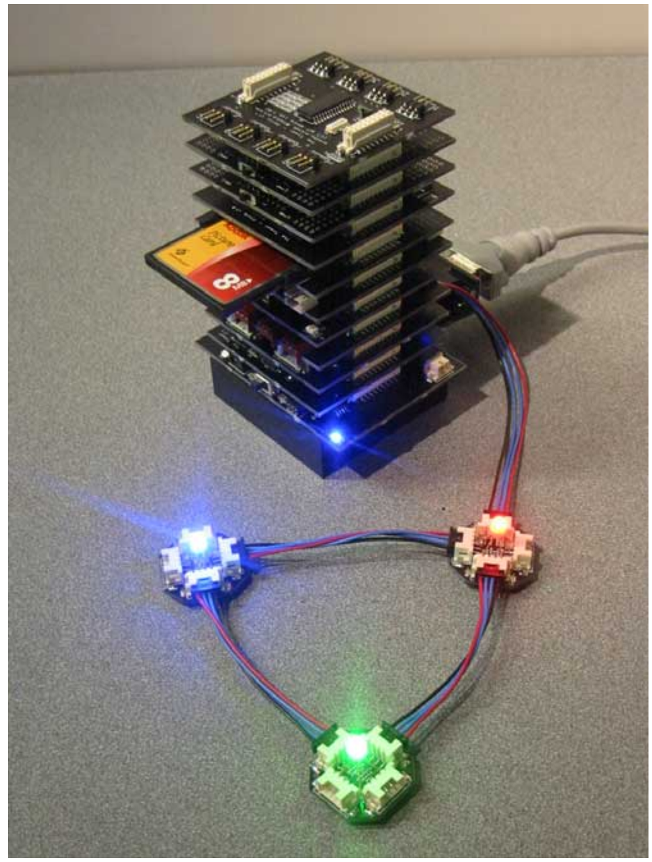

Figure 2: The Tower System: An Extensible Modular Computational Rapid Prototyping Toolkit

In addition to providing these prepackaged commercial tools to the FAB LAB user community, we are also supplying them with the Tower system – a fully extensible, modular computational construction kit to aid in the design and rapid prototyping of complex electronic systems, [3] which was developed by the Grassroots Invention Group at the MIT Media Lab. The Tower can be seen in Figure 2. Physically, the Tower is comprised of one of several different Foundation modules containing the core processor and other boards that stack on top of it, providing a wide range of functionality including sensing, actuation, data storage, communication, visual and audio output. In addition to the growing set of layers created by our research group, we have also provided the necessary prototyping tools to make it easy for anyone to add their own new layers to the system as specialized applications demand.

With the Tower, people can not only design and build their own experiments and activities, but they can even build their own tools, such as a simple low-cost oscilloscope, miniature personal computer, or even the control system for a table-top milling machine. By giving people the ability to build these tools, they will not only be able to easily extend the system by making new layers, but will also have all they need to actually recreate the system itself or design new, even more complex hardware systems. As the following discussion will illustrate, the Tower system is at the core of our aforementioned research and development efforts.

Fabrication Tools

Personal fabrication is at the heart of the FAB LAB concept. For our current FAB LABs, we have chosen two readily available commercial fabrication tools so that we could put them out in the field immediately and begin gathering information about their use. One of the tools is the Roland 3D milling and scanning machine and the other is the Roland vinyl cutter. We have also chosen to use the standard commercially available software for each of these tools while we are developing our own versions of many of these software applications.

The mill and vinyl cutter are useful for many two- or three-dimensional projects. The mill can be used to cut 2D parts out of a wide range of material, ranging from cardboard to metal. It can also be used to make functioning small-scale 3D mechanical parts that are designed with 3D modeling tools on the computer. In a different mode, the mill can act as an input device – it can be used to scan an existing 3D object and input its dimensions into the computer. With this information, one can create a 3D digital model of the original object, which in turn can be used for future modification and/or fabrication in the milling mode.

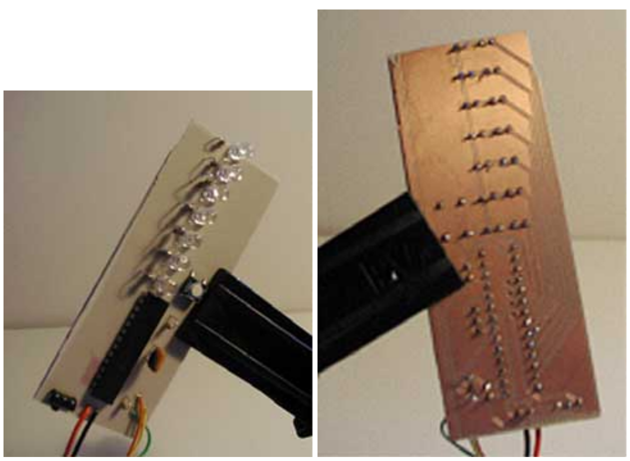

Figure 3: A PCB made with the milling machine

Furthermore, the mill can be used to make printed circuit boards, or PCBs for short. An example PCB made with the Modela is shown in Figure 3. The ability to design and fabricate PCBs with a FAB LAB is key to FAB LABs being able to reproduce themselves. It is also an important part of the users' ability to develop their own electronic and computational tools. We anticipate that one of the most common uses of the vinyl cutter in many FAB LABs will be to cut out circuit layouts or antennas from adhesive copper sheets and apply it to a variety of curved surfaces or plastic boards cut to size using the 3-D mill. We are currently refining the techniques required for using the vinyl cutter for these types of applications in our own labs at MIT. Figure 4 shows a circuit made with the vinyl cutter.

The reason we are excited about the ability to develop, make, and iterate through hardware designs is that we feel it is the natural step for many contexts – like India – where software development has experienced great success but has yet to experience the same development boom in hardware development. The FAB LABs capabilities for creating electronics can be viewed as a possible means to this end. However, we should make an important note that the electronics fabrication process is not without stumbling blocks as chips and other components will have to be ordered separately or salvaged from other parts. But the PCBs that these chips and components are soldered to can be made by a FAB LAB, eliminating the expensive and time-consuming use of PCB fabrication houses.

Figure 4: A printed circuit layout cut out of an adhesive copper sheet on the vinyl cutter and applied to a plastic board cut to size using the 3-D mill

In our research and development efforts, we are designing a milling and cutting machine as well as a 3D scanning machine that will use the Tower system as their control system. We anticipate to test our own machine at some FAB LAB sites within a year.[2]

Testing and Instrumentation Equipment

In order to debug and iterate on a PCB design, some basic electronic equipment was chosen to be included in every FAB LAB: [2]

- TEKTRONIX Oscilloscope
- WAVETEK Handheld Voltmeter
- B&K PRECISION function generator
- Microchip development tools for programming microcontrollers

These particular tools are the first that we will be replacing with Tower system components. We anticipate having the first prototype of each of these devices within the next six moths. A picture of a Tower-based oscilloscope is shown below in Figure 5.

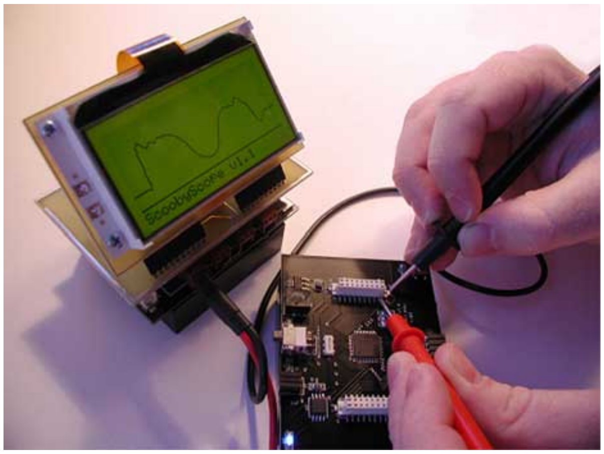

Figure 5: A first prototype of an oscilloscope made with the Tower System

The key to the instrumentation section of the FAB LAB is flexibility. Esa Masood, a researcher in Neil Gershenfeld's Physics and Media group at MIT, developed an inexpensive complex RF analyzer, which can be seen in Figure 6. In small quantities, the cost is about $1250. (The cost drops to $100 in large quantities.) The RF analyzer measures impedance from 10Hz to 300MHz. Relating measurements of dielectric constants of materials to properties of materials is an active research topic for us. Applications including milk fat analysis and postal mail analysis have been proposed and are currently being explored.[2,4] A low cost UV-VIS spectrometer that uses a commercial web cam in place of a more expensive instrument-specific imaging device is also incorporated. Chemical and biological analyses are the obvious applications of the spectrometer, but these can be extended to make use of the spectrometer's components. The web cam, acting as a light sensor in the spectrometer, can also be used in applications such as remote medical assistance and distance learning.[2,5]

Figure 6: The FAB LAB RF Network Analyzer

We have also included an Intel Play Microscope, which can be used for examination/verification of fabricated PCBs and some microbiological analysis applications as well as a number of hands-on educational activities.[2]

Tool	Purpose	Manufacturer	Cost
3D Mill and Scanner	Making PCBs and mechanical devices	ROLAND	$3,800 USD
Vinyl Cutter	Precision knife cutting	ROLAND	$2,100 USD
Oscilloscope	Electronic debugging	TEKTRONIX	$1,300 USD
Multimeter	Test and Measurement	WAVETEK	$125 USD
Function Generator	Test and Measurement	B&K Precision	$250 USD
RF Analyzer	Materials characterization	MIT	$1250 USD
UV-VIS spectrometer	Materials characterization	MIT	$200 USD
Tower Kit	Everything	MIT	$1,000 USD
Misc. supplies	Misc.	Various	$1,500 USD
PC	Computer	IBM	$1,500 USD
Microscope	Monitoring and debugging	INTEL	$50 USD
Digital Camera	Documentation and interaction	CANNON	$300 USD
Flatbed Scanner	Documentation	HP	$125 USD
		Total	$13,500 USD

Table 1: FabLab Cost Structure

Documentation

The development process is tracked by documentation. Think Cycle is facilitating the FAB LABs' documentation process. A camera and scanner are provided with the computer so that a FAB LAB users can place their designs and the subsequent iterations on Think cycle for other FAB LAB users to comment on.[2,6]

SCENARIOS OF USE

India

FAB LABs has the potential to have deep impact on two levels:

- *Personal Fabrication:* If a FAB LAB user needs a tool or an object, they design it to fit their needs and then fabricate it.

- *Grassroots Community Development:* The FAB LABs provide tools for communities to develop at their own rate and within their own cultures.

In India, two applications have arisen through collaboration with the FAB LAB site located in Vigyan Ashram [2] that provide examples for the above potential impacts of FAB LABs.

Vigyan Ashram is a small educational community located just outside the village of Pabal in Maharashtra, India, and is the site of the second international FAB LAB and the first site in India. It is a school that caters to those that, for one reason or another, did not fit into the traditional Indian school system and focuses on teaching practical skills that will allow these students to start their own businesses when they leave school. Since Vigyan Ashram is in a very rural area, where the use of fabrication houses is prohibitive due to cost and availability, the students and staff at the school found the FAB LAB capabilities for making PCBs easily very important.

One particular application that they conceived immediately was the development of boards to do more accurate timing of diesel engines. All of Vigyan Ashram's machines and even their back-up power system run on diesel engines which have very irregular timing characteristics, but they can not afford to buy commercial diesel engine timers. They are working on prototyping their own timing board with the Tower system and then making it on the FAB LAB milling machine. They look forward to fabricating their own diesel timers rather than have to look for outside sources that they really can't afford.

India's milk industry is one of the biggest and fastest growing in the nation. It employs a significant percentage of their population, the majority of these being the farmers that provide the milk. The question of milk quality therefore effects a large portion of India's population, not only on a health level but on an economic one as well. A quick look at the milk industry reveals three organizational levels: the farmers, the collection centers, and the processing plants. Losses that are incurred by the industry due to milk that has been contaminated, watered down, or simply gone bad are passed down this hierarchy until they reach the lowest tier, the farmers.

The contamination problem could be easily solved by implementing quality monitoring devices at the collection centers and then again at the processing plants. This is an easy solution to propose, but not to implement. The cost of a system of that magnitude is not the only daunting factor. A bigger obstacle than cost is the magnitude of the collection center system and the variety of people involved. A top-down approach from an outside source would not be likely to succeed in changing the system. The solution therefore must be bottom-up and use a reliable but low cost and low maintenance device for sensing milk quality that can be made inexpensively and easily within India, and if possible at a local level.

This is where the FAB LAB comes in. The FAB LAB model's grassroots approach would enable the jut-in-time design and manufacturing of the sensing tools needed at a local level and in desired quantities. The tools used would be made by those that are involved and in need of them, rather than handed down and told to them that it is useful.

Costa Rica

The Costa Rica Institute of Technology (also known, and hereafter referred to, as TEC) was selected as the first international FAB LAB site in the summer of 2002. The FAB LAB was introduced in the context of the Learning Independence Network (LIN) in Costa Rica, the first site for the Grassroots Invention Group's project that began in the summer of 2001.[2,7]

Developing nations typically settle for technologies that were designed elsewhere, with other purposes in mind. The Learning Independence Networks project was established to change that, working with networks of organizations in developing nations (including universities, foundations, companies, and NGOs) to help them build the capacity to develop their own technologies appropriate for their local needs. Bakhtiar Mikhak has been working most closely with universities, helping them to develop new courses, research programs, technological infrastructures, and strategies for collaborating with other members of the regional network on the design of new technologies.

The core team of LIN researchers, consisting of the faculty and students at TEC, local Scientific and Technical high schools, the Central American Institute of Business Administration (INCAE), and the school of education at the university of Costa Rica, and the Grassroots Invention Group at MIT Media Lab, have identified and begun work on a range of projects that are particularly relevant to low-income, rural communities in Cost Rica.

Inspired by early prototypes by Rich Fletcher from the Physics and Media group, they are making their own wireless environmental sensing modules with the Tower system for agricultural and educational applications. In collaboration with researchers at LINCOS, [8] a group of students at TEC are in the early stages of prototyping handheld and wearable devices for medical applications (in particular, the monitoring of a certain skin condition in a rural village). The students from the Scientific high school, with input from members of the network with extensive educational background, are making new tangible models to aid in learning about a number of concepts in chemistry and physics at the high school levels. The students from the Technical high school are developing a museum exhibit on buoyancy for the Children's museum in Costa Rica. And more and more applications are imagined everyday. Through regular interactions with the business students from INCAE, the group as whole debates the economic challenges and opportunities of developing technologies with high social impact. Careful accommodation of the expectations and priorities of the various participants' perspectives is one of the most challenging aspects of this project.

FUTURE DIRECTIONS

We have referred to our goal of equipping FAB LABs with the means to self-reproduce – with a human in the loop of course – a number of times in this article. This is one of the most active area of research in our groups right now and we would therefore like to elaborate on it in this closing section.

Over the next year, aside from the PC on which we run our applications for design, analysis, programming, and documentation, we would like to replace all the other machines with their less expensive counterparts which can be locally manufactured and are more appropriate for the needs of FAB LAB users. We will arrive at the detailed specification for the design of these tools based on a careful study of the most demanding projects undertaken in the various FAB LABs. An important part of this project will be the design of control systems for these machines based on possible extensions of the Tower system.

In addition to the mechanical designs, we also intended to develop design software applications that would not only be less expensive but also more accessible to those without an extensive technical background. An example of such a tool is a simple PCB layout and 2D design software application called ETCH that is currently under development in the Grassroots Invention Group. We have also built our own integrated development environment for programming of a wide variety microcontrollers and commercially available handheld devices like Palm Pilots and Pocket PCs both in an intuitive, cross-platform high-level programming language and in platform specific assembly languages. We have also integrated a data visualization tool for embedded applications that need it.

Given the relative ease with which the Tower system can be extended to implement new applications, once we have these Tower-driven testing and fabrication tools, we will be able to design, fabricate, test, and program a Tower with a Tower. (Within the next six months, we will have a version of the Tower that will be powerful enough to run our current Tower development environment.)

In order to have a fully integrated system, we will extend the Tower system with the needed modules so that current FAB LAB instrumentation tools (the UV-VIS Spectrometer and Network Analyzer that were discussed earlier) can be snapped together from the relevant Tower modules.

Therefore, to the extent that the 3-D mill makes it possible to create the casing of most parts, the vision of making a FAB LABs self-reproducible will be a reality in the not too distant future. And with this model of reproducible laboratory components, it is hoped that not only will FAB LAB users see fit to reproduce the lab and spread them, but also expand the toolset to fit their needs and pass these new tools and the associated know-how on with the rest of the FAB LAB. Together with a comprehensive approach to the important human dimensions of adoption and appropriate use of technologies (which are outside the scope of this paper at the current preliminary stage of this project), we hope that this grassroots approach will help us tackle the problem of introducing technology to communities in a self sustaining, self expanding, and self propagating fashion.

For this to be possible, materials must be available for fabrication. Most materials that we use in Boston are not readily available in other parts of the world. Rather than rely on an ill-conceived notion that the sites will somehow be able to supply themselves with materials that we have easy access to, we are looking to site users to experiment with materials that are native to their area. In Costa Rica, materials research has produced products made from banana leaves and water lilies, both of which are abundant in the area. Students at the TEC work with materials that they can get their hands on such as coke bottles and plexi-glass fragments; in Vigyan Ashram any material not already incorporated into a project soon finds a home in a new venture. The innovation, creativity, and spirit needed to drive this materials research process already exists in these places and many, many others, giving us good reason to believe that this approach to supplying FAB LAB with materials will have a good chance to work.

Having the FAB LABs provide materials for themselves at first appears to be leaving the FAB LAB sites to fend for themselves. However, they will not be alone. Support will be provided through collaboration between the FAB LABs via Think Cycle and the FAB LAB website. Through these communication and collaboration channels, problems and solutions can be exchanged, new tool designs can be shared, and the new materials and techniques with which different sites have experimented can be spread.

CHALLENGES

This summer, the first two international FAB LAB sites were set up in San Jose, Costa Rica and Vigyan Ashram, India – and we discovered many challenges in the process. Beyond the simple hassles of international equipment transfer, power incompatibilities and shortages, and the lack of materials and tools, there was the challenge of finding the most effective ways to give the new FAB LAB users the opportunity to gain the wide range of skills they would need to take full advantage of all the tools in the FAB LAB.

Education will continue to be an important and integral part of this project. Without the proper learning experiences, it is not unlikely that a FAB LAB site will go unused and will not only fail to fulfill its purpose but also might lead skeptics to believe that grassroots approaches will not work. It is therefore imperative that significant resources be committed to innovative approaches to learning and the development of tools that deeply recognizes the differences in human learning. This is why we feel that finding strong local partners is one of the most significant aspects of our work thus far. Dr. Kalbag, who runs the Vigyan Ashram school, and the core members of the Learning

Independence Network in Costa Rica are an critical asset to the success that we hope this project will enjoy.

In our FAB LAB installations thus far, we did not have as much time as we would have liked on-site to set up and introduce the tools in the FAB LABs. Despite our sincere efforts, it has been challenging to collaborate as closely as we would wish with our partners at these sites. Subsequent visits and constant contact has helped in filling this gap, but a lesson has been learned and a challenge identified: time, well chosen personnel, and an education plan are required to provide a thorough and lasting learning experience for FAB LAB users.

It is also important to note that education can take the FAB LAB users far, but the presence of someone who is familiar with the machines' idiosyncrasies and can serve as a resource for all users is incredibly important. The initial education that a new FAB LAB site will receive will not yield immediate gurus, but experts – local and from afar – will be necessary over the lifetime of a FAB LAB to field questions and solve quirky machine problems. We are actively looking for ways to reasonably supply an expert or access to an expert from the very time a new FAB LAB site is set up.

In short, continuity of the learning experience and a critical amount of intellectual, practical, and material contact with experts are critical to the success of FAB LABs. Though we feel that having more FAB LAB nodes might help in reaching a critical mass, we should be very careful to expand responsibly and thoughtfully. We are currently actively working on establishing a network of FAB LABs in Costa Rica, the lessons from which we hope will help in expanding this effort in other areas.

Another important challenge that we have partially begun to address is the use of commercial software that were primarily designed for very particular contexts in English-speaking countries. Though this has not been as much of a problem in the Boston FAB LABs, it is of serious concern in countries where English is not commonly spoken and the concepts that underlie "windows" and other western software are far from intuitive. In the creation of the user interfaces for our next generation of tools, we are paying close attention to these social, cultural and cognitive issues. One challenging approach we are exploring is to make it easy to customize the user interface to different cultures.

Lastly, good documentation practices are not only essential to sustainability and effective scalability of the FAB LAB initiative, but also unfortunately a time consuming and difficult task even for seasoned researchers. Though we have provided FAB LABs with some initial tools to make the documentation process easier, it remains to be seen how useful these tools will be. Our greatest research tool in answering this question will be the FAB LAB users themselves. We need to communicate with them regularly and incorporate – or better yet, make it possible for them to incorporate – their input into the functionality of the documentation tools and the next generation of fabrication tools.

An overarching challenge that FAB LAB sites face is achieving independence at some core level and develop a healthy interdependence on other FAB LAB sites.

CONCLUSIONS

We should emphasize that the FAB LAB initiative is an active ongoing research project. Even though we have very encouraging early results, our stated belief that this initiative will be effective and sustainable is still a hypothesis that remains to be tested. We are committed to report on what we learn with a healthy doze of realism and skepticism to make sure that we do not jump to conclusions based on transient effects that will not bear any truth on longer time scales.

Our confidence in our ability to make significant technical progress in term of the FAB LAB tools in the coming year should not be interpreted as though we believe technical success alone would necessarily lead to success in the social, political, and economic development of human condition. We consider it of great importance to pay close attention to the larger contextual questions that have a great bearing on all development projects so that we can at least interpret accurately the inevitable setbacks and the desired achievements of our project.

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