Fab Labs Overview

Fabien Eychenne

INTRODUCTION ///

Although the original concept is fairly old in the US (conceived and developed at the Massachusetts Institute of Technology in 2000) Fab labs have literally invaded the Netherlands (there are 1 or 2 Fab labs in each major city) and have cropped up in Norway, England, Spain, and finally in France in 2011. Fab labs are literally driving a democratisation of "digital fabrication" by providing access to industrial-grade machinery capable of producing individual pieces and prototypes fairly easily. Despite their relatively low profile, a growing number of D.I.Yers, designers, engineers, hackers, electronic engineers, and amateur robotics specialists are increasingly utilising these spaces to build individual objects and prototypes that they would not be able to build at home or at work.

The basic Fab lab concept has evolved in response to the demands of various locales where new Fab labs have emerged.

This is not a step-by-step manual that describes how to set up and operate a Fab lab. The goal of the present research was to move beyond mundane, project-related discourse toward establishing a more complete typology: we went into the field to meet Fab lab operators, and spoke directly with Fab lab users. The present document is an introduction to the Fab lab concept that intends to document and analyse this growing phenomenon, including an attempt to provide an accurate description of the stakes involved in Fab lab operation.

The primary objectives are to document Fab labs' day-to-day functioning, observe real-world uses, practices, and projects, and understand emerging business models through interviews with users, management teams and Fab lab project owners.

The first section examines Fab labs as a whole, and includes a description of their unique ecosystem and a discussion of their common aims. Next, we attempt a general outline of the various types of Fab lab that have emerged in response to specific local demands or geographic requirements. Finally, we describe several other kinds of spaces distinct from Fab labs, which are equally dedicated to the democratisation of personal digital fabrication.

This study relies heavily on research that was conducted in collaboration with students from *Centrale Paris*, in 2011. Fact-finding missions were carried out in the Netherlands, Spain, and on the West Coast of the US. Gabriella Polisel, Matthieu Bonneric, Arnaud Clavreul, Nicolas Parisot, and Armand Michaud were able to explore some of these spaces dedicated to digital fabrication, and they interviewed dozens of others via email and telephone.

Travel diaries and fact sheets describing the Fab lab people, sites, and local colour we encountered can be found on the Fing website (http://www.fing.org).

"How to Make (Almost) Anything"

This is the title of a very popular course at MIT (the Massachusetts Institute of Technology) taught by Neil Gershenfeld[1]. The course was initially offered in 2000

---

[1] http://en.wikipedia.org/wiki/Neil_Gershenfeld

to provide students with an opportunity to master the various pieces of digitally controlled hardware being used in the Center of Bits and Atoms lab. This module prompted Gershenfeld to create the first Fab lab, which facilitated wider student access to the digital hardware. Initially open only to students on campus, the course is now available online at http://fab.cba.mit.edu/classes/MIT/863.08/. It forms the foundation of the Fab Lab Academy distributed learning program, whose tutorials are completed at Fab labs scattered across the globe.

WHAT IS A FAB LAB? ///

A Fab lab (abbreviation of Fabrication laboratory) is a rapid prototyping facility that enables users to create physical objects that can be "intelligent" or not. It's use is reserved for individuals and entrepreneurs who wish to move more quickly from an idea or concept to a physical object or prototype, or for artists and students who want to experiment with and enhance their practical knowledge of electronics, CADCAM, design, 21st century D.I.Y…A Fab lab is part of a worldwide network of 100, stretching from the US to Afghanistan, from Norway to Ghana, from Costa Rica to the Netherlands.

A Fab lab hosts several pieces of professional-grade yet basic and relatively inexpensive numerically-controlled machinery, including a laser cutter that can produce 2D and 3D parts; a vinyl cutter capable of producing antennas and flexible circuits; an extremely high-definition milling machine to make flexible circuit boards and 3D moulds, and a larger milling machine for more voluminous parts. Basic electronic components and materials are also available, in addition to programming tools associated with inexpensive yet powerful embedded open source processors. The entire range of hardware is controlled using customised computer-aided design and fabrication software.

More sophisticated machinery, like 3D printers, may also be found at certain Fab labs.

History

The first Fab lab emerged inside MIT as part of the CBA (Center for Bits and Atoms), an interdisciplinary laboratory founded in 2001 by the National Science Foundation. The ambitious CBA research lab is driven by what comes after the digital revolution, specifically as this relates to the evolution of digital fabrication, where advances may eventually produce tools that can assemble matter at an atomic level. To the CBA, Fab labs are a kind of educational learning grounds that raise awareness about digital and personal fabrication. They democratise technologies and techniques instead of simply promoting their consumption.

For Neil Gershenfeld[2], Fab labs are an extension of the Internet. Similar to the way web "2.0" platforms democratised the tools we use to create, edit, and share information, allowing millions of users to become "prosumers", personal digital fabrication will make it possible for many to become "inventors" of their own technology.

According to Gershenfeld[3], Fab labs should fulfil certain criteria. These are:

- to be a vector of empowerment and skills development, so that users become part of the development process instead of just consumers;
- to help users make "doing" central to their technological learning process,

---

[2] Neil Gershenfeld TED Talk: http://www.youtube.com/watch?v=5n-APFrlXDs
[3] Neil Gershenfeld Fab6 conference: http://fab6.nl/

by supporting the gradual, step-by-step construction of individual prototypes, allowing space and time for mistakes, and prioritising cross-disciplinary and collaborative approaches;

- to provide internationally networked solutions to local problems, specifically in countries located in the Southern hemisphere;
- to valorise and practice bottom-up innovation; and
- to contribute to high-tech startup incubation by facilitating prototype fabrication.

A global movement

The Fab lab concept (originally conceived at MIT and partially financed by the NSF) is currently being developed on an international scale independent of MIT. Gershenfeld[4] claims that the number of Fab labs doubles each year. Today the "official" MIT list includes over 80 international locations (http://fab.cba.mit.edu/about/labs/). The interactive map "Fab labs on Earth" lists over 100.

Geolocational map of Fab labs in the world: http://maps.google.com/maps/ms?ie=UTF&msa=0&msid=100531702172447774282.00044fdbd79d493ad9600

[4] Neil Gershenfeld interview Futur en Seine Festival 2011 Paris : http://nod-a.com/2011/09/present-et-futur-du-projet-fablab/

The Fab lab: cornerstone of the digital fabrication democracy?

Digital fabrication integrates the manufacturing process from conception to production into one single chain. The chain begins with the use of CAD (Computer Assisted Design) and CAM (Computer Assisted Manufacture) software; resulting designs are constructed with the use of numerically controlled hardware. This is by no means a recent development; Gershenfeld[5] reminds us that computers were being hooked up to machines at MIT in the 1950s. Heavy industry has been using this process on assembly lines for years, while mechatronics centres where small businesses can build rapid prototypes exist worldwide.

Fab labs have altered the landscape of innovation by providing the general public with an opportunity to appropriate the digital fabrication process: to make things "personally". At a Fab lab, anyone can use CADCAM software to move swiftly from an idea to a prototype**.**

Many users told us that Fab labs have allowed them to "slim down" their projects and better estimate their feasibility, and have made it possible for them to go directly to potential investors with working prototypes. The prototypes can then be further refined at mechatronics centres, for example.

Fab labs come into play before an object moves into the chain of production. They enable rapid prototyping but are not suited to production on a larger scale (a limited number of identical pieces can be made if the hardware is not overused), nor are they suited to distribution, repair, or recycling. Their flexibility and their mimimal fees make them hubs of innovative activity, greatly lowering the traditional barriers to innovation.

Fab lab = D.I.Y. coach?

The hi-tech connotation of the term "D.I.Y." ("do-it-yourself", borrowed from the home improvement sector) was popularised by Internet guru and tech media giant Tim O'Reilly–originator of the web 2.0 concept–in his magazine *Make*. Behind his use of the term lies an important idea: individual creativity should be encouraged because it drives social consciousness and **(social)** responsibility. In the US, the highly popular D.I.Y. concept is the foundation for the classic "garage hobbyist" innovation model made famous by Steve Jobs and Steve Wosniak, who developed their first computer in Job's garage.

These D.I.Y. "makers" are also into crafting, sewing, furniture building, toy making, music production, robots, drones and car customisation. According to Dale Dougherty, Editor in Chief of *Make* magazine, these practices are nothing new, but their scale has increased exponentially thanks to collaborative discussions between makers made possible by the Internet. People no longer do things "themselves", but rather "with others" ("DIWO"). Numerous forums, wikis, and discussion lists provide thousands of aficionados with discussion boards where they can discuss and exchange ideas, share or publish their plans, offer and request advice, and display final creations. These online exchanges take

[5] Idem

place in real time, several times a year, in the US, Europe and Africa: the Makerfaire. (http://en.wikipedia.org/wiki/Maker_Faire).

The practices of makers are but the tip of the iceberg. They are actually part of a larger trend dubbed "user innovation" by economist Eric Von Hippel[6]: bottom-up innovation carried out by "pro-am" ("professional amateur") users themselves. In a report [7] commissioned by NESTA (the British not-for-profit research organisation dedicated to innovation), Von Hippel[8] found that there is 2-3 times more innovation originating from the consumer sector than from industry. The lack of users in emerging markets provides little incentive to industry/greater incentive to users to innovate. For example, white-water kayakers are responsible for more than 73% of materials innovations and 100% of their infrastructure (cartography).

Von Hippel[9] underscores the fact that not only are users innovating, they are (for the most part) openly sharing their innovations. Their designs then spark the interest of other users, and communities are born.

The Internet facilitates open, decentralised user innovation: it has lowered the barriers to individual innovation significantly, allowing scores of people to create, invent, and share.

The majority of online innovation originates with small-scale or one-person "independent" inventors: members of a larger ecosystem who have appropriated the Internet as their development platform. Today, Gershenfeld[10] insists that the practices of open innovation inherited from the Internet are making their way into the physical world. The enormous success of websites marketing D.I.Y. products, and big name financing or co-opting of collaborative spaces dedicated to makers demonstrates that the influence of user innovation is penetrating an increasing number of business sectors.

Fab labs support user innovation by generalising the use of personal fabrication tools and expertise; like the Internet, they are platforms that facilitate bottom-up, open innovation. The important difference is that these are physical spaces.

What impact would an increasing number of Fab labs have on the landscape of innovative practices? Are they harbingers of a "new industrial age"? Are they the cornerstone of open, "horizontal" innovative models for industrial production, urban services, distribution, cities, life…? Will they become ubiquitous? And what if certain so-called "amateur" practices supported by Fab labs become more professionalised, as has recently been the case in multimedia content, software and online service development?

These questions indicate compelling directions for future research: although worthy of reflection, they are only at the embryonic stage in their development; this report will not attempt to answer them.

---

[6] http://en.wikipedia.org/wiki/Eric_von_Hippel
[7] Measuring User Innovation in the UK, Von Hippel, 2010, http://www.nesta.org.uk/publications/reports/assets/features/measuring_user_ innovation_in_the_uk
[8] Idem
[9] Idem
[10] Neil Gershenfeld Ted Talk

A CLOSER LOOK AT A FAB LAB ///

The majority of the places we visited fulfil the charter laid out by MIT (see annex). Adopting the charter provides labs with a framework that enables them to provide digital fabrication tools and techniques to anyone. Of course, a large number of studios, R&D centres, open spaces, and rapid prototyping centres with digitally controlled machines for hire have existed for years, but their access has been restricted to professionals only. For this project, we decided to concentrate on spaces that were open to entrepreneurs, businesses, designers, students, artists, and the general public equally. For us, open access was the decisive factor contributing to the successful development and generalisation of digital fabrication practices. Open, low-cost access creates the perfect climate for innovation.

Although they share a common charter, each Fab lab has adapted itself to the needs of sponsors, managers, lab teams and volunteers, the public, and to the goals outlined by project owners.

Physical space configuration

Although MIT does not stipulate a required surface area or endorse a particular floor plan, nevertheless Fab labs across the globe share similar spatial configurations. A typical site plan includes:

- surface area ranging from 100 to 200 square metres,
- at least one completely closed off section for the router (see the hardware list below),
- and a large central space, sometimes partitioned, where less noisy, dangerous and/or messy machinery is located,
- in addition to computer terminals, workbenches, desks large enough to double as conference tables or carry several laptops, and a break area with coffee machine, snacks, refrigerator, couches, etc.

The configuration of these spaces varies widely from site to site. For example, the Amsterdam Fab lab is squeezed into a building constructed in 1690 (80m2), while the lab in Utrecht (250m2) has an enormous workspace and a very well-equipped break area. Some labs included some kind of facility for completed project presentations and a storage space for small electronics and smaller tools.

Spaces are situated in a variety of locales:

- in universities or schools: Fablab@school Stanford, Fab lab Boston (CBA), Fab lab Groningen, Fab lab San Diego, Fab lab Barcelona, Fab lab Costa Rica, Fab lab Nairobi, etc.
- within sites specifically dedicated to innovation: Fab lab Reykjavìk, Amsterdam Fablab, Fab lab Boston (South End Technology Center), Fab lab Manchester, Fab lab Utrecht, Fab lab Ahmedabad, etc.
- at purpose-built Fab labs: Fab lab Cape Town, Fab lab Toulouse, Fab lab the Hague, etc.

- in museums: Fab lab Chicago (Chicago Museum of Science and Industry), Fab lab Florida (G.WIZ Museum of Science)
- in mobile Fab labs: Fab lab South Bronx (in a truck that criss-crosses the US), Fab lab Amersfoort.

We saw that not only does each space have its own local 'colour', they also notably differ in terms of services provided, technical expertise available and business model.

Tools and machines

Fab labs are specifically equipped with numerically controlled machines. Computers running CADCAM (computer aided design/computer aided manufacture) software operate the tools, translating plans into spatial coordinates that the machines replicate.

MIT specifies the hardware required for a space to carry the "Fab lab label" (see below).

Laser cutter	• Cuts a wide variety of materials (wood, paper, cardboard, PMMA, leather, etc.) • Marking (metal, aluminium, stone, etc.) • Engraving (engraving is deeper than marking)	€15,000-€30,000 depending on laser strength and workspace size
CNC milling machine	• Mills (removing/cutting away of material according to a specific design) a variety of materials (wood, foam, light metals, etc.) • Creates moulds • Printed circuit board (PCB) milling (epoxy coated with adhesive copper film) • Some function as 3D "scanners" by replacing the mill with a sensor	€3,000-€5,000
3 Axis router/spindle	• Woodworking mill (solid wood) • Large-volume mould creation • Applications similar to the CNC milling machine but with added security	€14,000-€20,000
Vinyl cutter	• Cuts various materials including vinyl, certain papers, heat transfer films, decals, and certain fabrics • Cuts adhesive copper film for PCB manufacture	€1,500-€2,500
3D Printer	• 3D Object "printing" on demand • Meld creation • Prototyping	€2,000-€50,000

(The complete list of machinery and hardware recommended by MIT can be found at http://fab.cba.mit. edu/about/fab/inv.html)

To equip a Fab lab properly, these five digitally controlled machines are recommended by MIT. See annex for more detailed descriptions and guidelines for their use, maintenance and disposition.

It is important to note that although 3D printers are relatively popular at Fab labs, up until the beginning of 2011 the official MIT list of machines did not include them. Expensive, commercial-grade printers (the Dimension 1200 starts at €25,000) are too slow and materials too expensive to justify their "collective" use. Despite spectacular results, models can take up to 15 hours to produce. Professional printers such as these are primarily used at Fab labs to produce moulds for future piece reproduction.

Supplemental hardware

Depending on the particular Fab lab or team, there might be other machines on hand. In Amsterdam, several sewing machines are available, while in Groningen there are PCB (printed circuit board) fabricators. These tools are not included on the MIT inventory list (see annex for more information on supplemental hardware).

Small electronics

Fab labs also provide an array of small electronics to control various actuators, buttons, switches, chips, sensors, controllers, etc. Electronic prototyping platforms like Arduino and others of its ilk are highly prevalent. Arduino is an open-source printed circuit containing a microcontroller that can be programmed to analyse and produce electric signals that execute a diverse range of tasks: it can manage the chips and sensors that direct a robot or regulate a lighting system, for example.

Soldering irons, oscilloscopes, LEDs, microcontrollers and various chips and other components are also available at Fab labs.

Typical weekly schedule at a Fab lab and conditions for entry

	Monday	Tuesday	Wednes-day	Thursday	Friday	Saturday
Fab lab Amsterdam	Work-shops / classes / presenta-tions	Open Lab	By appoint-ment	Open Lab	Machine rental	Closed
Fab lab Utrecht	By appoint-ment	Open Lab	Open Lab / by appoint-ment	Work-shops / classes / Presen-tations	Work-shops / by ap-pointment	Closed
Fab lab Iceland	Open Lab	Open Lab	Open Lab	Open Lab	Open Lab	Open Lab
Fab lab LCCC (USA)	Closed	Open Lab	Work-shops	Open Lab	Open Lab	Open Lab
Fab lab Manchester	Closed	By appoint-ment	By appoint-ment	By appoint-ment	Open Lab	Open Lab

Fab labs are generally open 5-6 days a week, with a pre-defined yearly program: see below for a more detailed description of weekly schedules.

"Open Lab" days are typically free of charge and open to anyone. Certain labs stipulate that users must publish their project plans on the lab's website under an open license in exchange for using the facilities on these "free" days. Others ask that users pay a (usually small) yearly membership fee to take advantage of open access days. Other days are "semi-public", intended for workshops and training sessions, while machines are available only to those who have made a booking, and pay a fee.

Services, pricing

Fab labs are open access spaces. They make the digitally controlled machinery described above available to the general public. Of course, depending on public demand, finance model, and team skillset, each Fab lab might also offer specific services.

Nevertheless, four major services emerge:

The "Open Lab"
On "Open Lab" days, anyone can use the machines without a booking. These

times are ideal for future users to gain a better understanding of how a Fab lab operates, learn how and when to use the machines and meet the staff. Public access to the space and the machines (for testing) is free, and operates on a first-come first-served basis. Staff request that machines are not used for more than a few minutes at a time. In certain Fab labs, those who use "open lab" days to build prototypes are required to document and publish their project plans openly.

Workshops, training
Even if the machines are relatively easy to use, Fab labs provide courses and workshops that provide instruction in CADCAM design, specific machine usage, Arduino-type material usage, introduction to electronics, etc. (See examples below.)

"Advanced" courses providing machine skills, expertise and uses for a variety of situations are also available at certain Fab labs.

Rental by appointment
Rental appointments are often booked after Open Lab days. Usually, users will book a machine for an hour; the machine is at the disposal of that user for his or her project without restriction during the time requested. The Fab lab team is on hand to help if needed. This type of utilisation does not require users to document their projects.

Workshops, training
Several of the Fab labs we visited make their entire space available for rent for a full day or half day. The lab is closed to the public during these times. The business, school or individual who has reserved the space has access to all the machines, the Fab lab team (who might also sign NDC agreements, if required) and all Fab lab resources. Several of the Fab labs provide customised or tailor-made services devised for business, designers or schools. Fab lab teams rely on the skills of their managers and their supporters. For example, the Barcelona Fab lab run by the Architecture Institute offers architechturally-oriented businesses an opportunity to work on projects that focus on digital fabrication technologies, sensor interactivity or ambient intelligence; while the Amsterdam Fablab, run by the Waag Society (a foundation that promotes innovation), organises rapid prototyping sessions for businesses and designers over several days, and team building sessions that revolve around prototype-building games.

Again, prices vary from lab to lab. The table below features a sample range of pricing for booking an entire space, booking specific machines or hiring the services of a tutor.

Fab lab	Use	Price	Notes
Fab lab Manchester (UK)	Space rental	• Full day €2,345 • Half day €1,173	• Small groups receive a 50% price discount • Two Fab Managers on hand • 12-person buffet provided • Materials included
Fab lab Amsterdam (NL)	Space rental	• Specialist machine training €200/2h • Half day €800 • Full day €1,400	• Fab manager support is not included: €120/h • Price of materials not included
Fab lab Utrecht (NL)	Machine rental	• €50/h • Free during open labs, (however public documentation of project and sources is compulsory)	• Half price for students, small businesses, non-profit groups • Price of materials not included
NextFab (private) (USA)	Training, consulting	• Private tutor $100/h	• Price reductions available to members

Two levels of training are usually available:

Level 1 courses introduce the basics of the machines and tools available with the goal of promoting user autonomy: rapid prototyping, how to use a specific machine, or the basics of CADCAM tools.

Fab lab	Topic	Details	Price
San Diego (USA)	Mastering the vinyl cutter: 1/2 day	• Drawing with dedicated software • Machine prep • Piece production	(not listed)
Manchester (UK)	Intro to Arduino: full day	• Connecting the Arduino to a computer • Building a simple circuit • Arduino programming	£150, lunch included
Groningen (NL)	Google/Trimble Sketchup: open source software training course	• Installing Google Sketchup • Models • Materials costing	€70/2h

Level 2 courses offer practical training across the range of resources available at a Fab lab. Offered several times a year, these courses rely on the expertise of the team and management. Courses are designed for different audiences, e.g.:

children, architects, designers, startups, etc.

Fab lab	Course	Aims	Price
San Diego (USA)	"Create wearable electronics": 5 day course for students grade K-12 offered in conjunction with the University of San Diego	• Using the Arduino platform • Programming controllers, sensors, switches, networks • Ambient technology basics • Project-based	(not listed)
Manchester (UK)	"Robolab": interactive, UK curriculum-based one day activity for 11-16 year olds	• Learn teamwork • Learn the latest prototyping techniques • Learn to make presentations and sales pitches	£300/group £15/pupil
Protospace, Utrecht (NL)	"CNC D.I.Y. Workshop": Building a remote controlled machine (3 days)	• Introduction to several machines, RepRap (3D printer), Mantis (milling machine) • Intro to basics of mechanics • Managing settings	(not listed)

Emerging business models

The subject of Fab lab business models often arises. They are the focus of numerous workshops during Fab lab network forums (see below), although these do not often generate any concrete solutions. Discussions with various Fab lab team members indicated that as of today, none of them could survive without public/private funding. There exists no single business model, but a host of services that make the labs eligible for financing. Managers insist on maintaining open access (on certain days) at zero or minimum cost to the public; this defining element of a Fab lab is what renders it financially unprofitable, or at the very least unable to operate without some kind of (public or private) funding.

At the last Fab7 conference in Lima, six "business model archetypes" were identified.

- Space privatisation, machine hire, and production on demand
- Training, workshops, seminars
- Project incubation, proofs of concept, prototyping
- Small business incubation (marketing, legal, communications, etc.)
- Fab lab network and skills mobilisation to respond to RFPs from national and international project owners
- "Gurus for hire": utilise Fab lab members as consultants to provide expertise or directly use their skills

The majority of Fab labs create a hybrid of these various sources of revenue. Public (state, local, European, university, etc.) as well as private financing (sponsors, collaborations, etc.) supplement Fab lab coffers.

Generally, two of the above models were combined in the Fab labs we visited:

- Service provider, including space and/or machines for hire with the dedicated support of one of the Fab managers to define and produce a functional prototype. The Manchester Fab lab specifically uses this model to target small businesses and startups by advertising its capacity to help them innovate, and
- Training provider, including Fab lab basics (machines, software, small electronics) plus specialised training drawing on community skillsets.

The Fab lab team

Position	Responsibilities	Comments
Director	• Imparts overall Fab lab strategy • Fundraising • Partner relations	At several of the labs, the director often held the dual role of lab and management direction. This is the case in Amsterdam: Klaas Hernamdt is both "Managing Director" of the Waag Society and Director of the Fab lab.
Fab Manager	• Day to day lab management • Greets and informs the public • Available for project support • Machine repair and maintenance • Workshop/training organization • Responsible for smooth operations	The "handyperson" of the Fab lab. This "emerging" role is still to be defined: since the tasks are so widely varied, Fab managers are extremely multi-faceted. Several conversations revealed the need to implement specialised training in Fab lab operations management. (See the section entitled "The Fab Manager")
Intern	• Helps the Fab manager with on-going tasks • Greets the public • Workshop instructor according to skillset	The majority of Fab managers receive support from interns. Their presence is regulated either by some kind of official (school-related) internship agreement, or (as is the case in Amsterdam) by tacit agreement with the Fab manager, in exchange for unlimited free access to lab resources.

At times, resources borrowed from supporters/sponsors supplement the core team. At the Amsterdam Fab lab, one employee spends ¼ of total weekly hours doing administrative tasks for the Fab lab and the rest of the time works for the Waag Society. The Utrecht Protospace employs two Fab managers: one who works 30 hours per week and the other who works 20.
At university Fab labs, lab techs and part-time professors maintain the machines and take on some organizational tasks. The LCCC (Lorain County Community College) Fab lab is entirely volunteer-run. The Fab manager is an ex-professor

who gets help from student volunteers.

The Fab manager

The Fab manager is the incredibly competent, multitasking 'handyman/woman' at a Fab lab. The manager greets and directs the public; manages, maintains and repairs the machines; and organises workshops and user support for software, hardware and Fab lab processes.

Many of the people we spoke with explained the "on the ground" evolution of this position. The first Fab labs relied heavily on the skills of MIT student designers, engineers, etc., but with Fab labs cropping up around the world, the position has become more specialised, requiring managers to dramatically develop and enhance their significant arsenal of multi-tasking skills. Independent learning is compulsory: machine maintenance, repair, and process administration are achieved through painstaking trial and error.

Aware of the demands placed on Fab managers who had not been trained at MIT, Gershenfeld developed an online "How to Make Almost Anything" course. This distributed learning facility helps managers develop the skills that are integral to the operation of a Fab lab.

Ecosystem and network

Learning by doing and sharing

For Neil Gershenfeld[11], the Fab lab concept goes beyond that of a simple prototyping shop: it is a place of creativity and idea sharing. People do not go to Fab labs to learn things, they go to make things. The Fab lab model makes a case for a new kind of apprenticeship. The devaluation of manual labour and the methodical suppression of hands-on activities in school curriculums documented by Mathew Crawford in his "Shopclass as Soulcraft" are ideas that resonate strongly with the stakes outlined by Gershenfeld.

The "maker" culture is weak, if not inexistent, in the French school system. Thankfully there are small-scale, after school initiatives like the "Petits Débrouillards" (Can-do Kids) here. Yet the movement is still in its infancy… At its root is a profound rethinking of the current French educational system and the ways we learn, in keeping with the ideas Kevin Kelly described in a recent article (http://bit.ly/axy7Bu) wholly dedicating themselves to the process, to the act of "doing/making", Fab lab "makers" remind us of the crucial importance of "doing" in the learning process.

In the Amsterdam Fab lab, many of the machines feature stickers bearing the phrase "Failure is always an option", often attributed to Adam Savage and the *Mythbusters* TV program (US). Taking things step by step and making mistakes are both actively encouraged. When an employee is asked to verify an idea for a concept, the same response is offered time and time again: "Try it and see!"

(Re)gaining confidence

At a majority of the labs we visited, the employees and volunteers spoke often

[11] Neil Gershenfeld interview Futur en Seine festival: http://nod-a.com/2011/09/present-et-futur-du-projet-fablab/

about users who lack confidence in their creative abilities. One of the primary methods used to address this issue is to create and maintain the "climate of confidence" which has an integral role in the Fab lab framework. Not everyone is going to become a designer or an electrical engineer – and this is not the vocation of these spaces. The goal at most labs is to provide training for an assortment of techniques in a supportive environment that fosters creative risk-taking.

For newcomers and long-term project holders alike, participation in community life is another significant aspect contributing to increased self-confidence and individual creativity. Teamwork is a natural by-product at a Fab lab because each individual has his or her own special area of expertise (electronics, woodcutting, sewing, or the simple desire to learn and participate). Peer learning is a common approach at Fab labs. Intra- and inter-Fab lab exchanges are common, with co-operative projects drawing on the skills and expertise of users from different labs.

Sharing and documenting

Sharing is another hallmark of Fab labs. "Open Lab" days are only free to users if they share their projects openly. Project plans and materials lists are documented and published under an open license allowing others the opportunity to re-use or modify them, or use them as a point of departure for a different project. The person using the plans must also republish their project openly. According to those interviewed, a project has more chances of achieving success if it is shared with more people because the concept is enriched and improved through contact with others. Open source software development and online community collaboration practices borrowed from the Internet have been replicated at Fab labs in physical form, in an effort to promote knowledge and expertise locally, and to create sustainable innovative practices.

Fab(X), an international yearly symposium

Network members convene each year at one of the MIT-affiliated Fab labs for a weeklong series of meetings to exchange uses and techniques, compare business models, present practices and projects, and generally forge the community spirit. Days are organised so as to allow time and space for spontaneous talk and exchange. Workshops allow members to practice novel techniques employed at other Fab labs. The most innovative, pertinent, or locally minded projects are the subject of presentations that facilitate their re-appropriation by other members. An entire day is dedicated to prospection, including use development, emerging techniques, the political impact of the re-appropriation of personal production tools, or an examination of the tensions that this kind of space may provoke (copyright infringement, security, competition, etc.). The Fab(X) meeting is the ideal time to meet a majority of Fab lab associates, participate in valuable discussions, and establish international project collaboration.

Fabfolk, innovative globetrotters

The Fabfolk began as a loosely organised group of advanced users, students, and Fab lab interns who made their knowledge and skills freely available to international local communities for several years. Fabfolk became officially established as a (MIT-recognised and encouraged) non-profit organization in 2011.Network connections and similar machinery permit the Fabfolk to further their aims whether in Boston, Barcelona or Nairobi.

Fabfolk projects are exclusively educational or charitable; they provide instruction and training in technique appropriation and Fab lab process to enable individuals and support local communities. Research data, project plans and knowledge developed with the support of the Fabfolk must be openly documented so as to be beneficial to all. This not-for-profit organisation aims to facilitate access to the tools, materials and technologies that support the cultivation of sustainable innovating practices.

Visit the Fabfolk website at: http://www.fabfolk.com/

The Fab Academy

The Fab Academy is a series of online distributed learning modules (complemented with hands-on training at a Fab lab) intended to help users master the mechanisms, applications, and implications of digital fabrication. The Fab Academy was created for students/users worldwide who do not have access to training in advanced digital production techniques. Students are linked via videoconference and team projects. It is not distance learning, but *distributed* learning, as everyone has access to the same tools. The Fab Academy awards MIT-recognised certification for various fabrication techniques and rapid prototyping practices. Obtaining all the certificates is the equivalent of completing the entire MIT "How to Make (Almost) Anything" course. Coursework is evaluated in terms of projects completed and skills acquired, rather than awarding meaningless grades. Training takes place over six months, from January to June.

Fab Academy website: http://fabacademy.org/

Fab Manager training and self-directed study

Although many Fab Managers can easily teach themselves the basics of Fab lab operation (CADCAM software, public-technology interfacing, machine maintenance and repair, etc.), they also have the arduous task of supporting the constant flux of incoming users, whether seasoned veterans or inexperienced newcomers. On "Open Lab" days, people with varying degrees of skill converge on the Fab lab, and the Fab manager is called upon to provide time-consuming assistance and training in software and hardware use. At several labs we noticed that Fab managers would grant free access to the space to students they had already trained, in exchange for the students' help with user orientation and instruction on busy Open Lab days. When we visited the Amsterdam Fab lab, three "interns" were on hand to greet the public. In exchange, they were granted "virtually unlimited" access to the lab.

"FABJECTS" ///

Typology

Through our on-site and dedicated website explorations, we were able to assemble a typology of Fab lab projects. The following general typology attests to the diversity of Fab lab usage (although not all projects are possible at every lab).

Type	Aim
Prototyping, proof of concept, "v.1"	• Try out an idea, a first concept • Demonstrate feasibility • Produce a first functional version
Limited edition	• Make a series of prototypes • Test a local market with a few pieces
Group projects requiring "inter-Fab lab" cooperation	• Utilise the collective know-how of the Fab lab network • Pool knowledge • Share knowledge on a large scale
"Individual" project	• Art project • Fine-arts or design student project, etc.
Niche-market project	• Create a limited number of pieces for specific markets • Object customisation

Prototypes, proofs of concept

One of the primary uses of a Fab lab is to move rapidly from an idea to a prototype. A project is conceptualised using CADCAM software and constructed using digitally controlled machines. If the prototype meets expectations, perhaps it might subsequently be mass-produced using a more classic production model.

Scottie

In conjunction with its partners, the Waag Society uses the Fab lab to build certain internally developed prototypes, including their "Scottie" project.

http://fablab.waag.org/scottie

This project arose out of reflections on communicative objects that might be used during extended hospital stays. It was developed under a “creative commons” license at the Amsterdam lab; the entire project, including concept plans, designs, digital files and computer coding can all be found on the Amsterdam Fab lab website. The project can be replicated freely at any Fab lab in the world.

Flatpack Walker
As a practice exercise, Edwin Dertien, a robotics student at the University of Delft, has been working on a simple robot for several months.

http://wiki.edwindertien.nl/doku.php?id=a4designs:flatpackwalker:start

He is independently developing a robot capable of changing course in response to obstruction. The first version, constructed in his garage, was a laborious, time-consuming affair with many iterations. At the Fab lab he was able to create a second version with community help. His “fabject” project now has investors and is in the first stages of commercial production.

Niche projects

Fab labs feature numerous projects that traditional industrial practices are not able to address. These can be very specific designs or objects that have been designed for very small markets.

Wheelchair accessibility
Eric has been using a wheelchair for many years. Even though many public places provide wheelchair access, others still remain (literally) hard to reach.

http://fablab.waag.org/project/doorstep-climber

With this in mind, Eric began working on systems that would provide him with more wheelchair autonomy. What began as an individual project has now become a collaboration with the Waag society. The project is documented online, with the author conducting an "under the hood" narration of his experiences, disappointments and successes.

Universal-fit mudguard

Olaf Wit is a trained industrial designer; he uses the Fab lab to build cycling prototypes.

http://www.witindustries.nl/index.php?/products/fen-dor-bendor/

He is an ardent 'fixie' (fixed-gear bike) fan, with several at home and a group of like-minded friends. Fixies are usually "made", and compatible parts are notoriously hard to locate. Wit designed a universal mudguard (called the "Fendor Bendor") that is compatible with fixed-gear bikes; he used the Fab lab to produce 100, which are currently on sale at specialised retail outlets.

Art projects, individual projects

Artists, users, entrepreneurs, designers and other individuals can be found building their solo projects at Fab labs. Some of these fabjects may be produced in a limited number, each with a subtle variation.

Electric candle

The innovative company readiymate, a specialist in the Internet of things, took advantage of a temporary Fab lab (part of the *Futur en Seine* exhibition in Paris) to build some "electric candles".

http://readiymate.com/

Each candle uses a slightly different mould, making each piece unique.

D.I.Y. MIDI Sequencer
Another user at Futur en Seine came to the Fab lab to build a MIDI sequencer. Plans can be found on the Instructables website.

http://www.instructables.com/id/Arcade-Button-MIDI-Controller/

The user modified the basic plan to create a one of a kind piece for personal use. In this case the fab lab user had no plans to produce a line of products, he simply wanted a sequencer for himself. The modified plans attributed credit to the original project author.

Group projects requiring "inter-Fab lab" cooperation

Several projects employ the Fab lab network to complete large-scale projects that draw on local know-how. Multidisciplinary teams, financial partners, and Fab lab-associated techniques are all brought together for a common purpose.

Two flagship projects have paved the way toward large-scale North to South inter-Fab lab collaboration.

FabFi wireless network
FabFi is a large scale distributed wireless network system. The project was conceived in 2009 at the Jalalabad Fab lab, and is the result of collaboration

between several Northern and Southern hemisphere Fab labs.

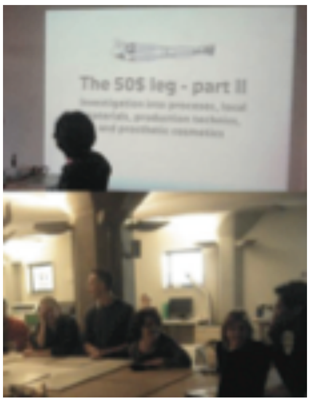
http://code.google.com/p/fabfi/wiki/WikiHome

The goal was to link a remote village with the local hospital and various charitable organisations via high-speed fibre optics. The project is based on an existing sheep "tracking" project developed in Norway, and calls for low-cost, easily sourced, local materials. The system can be easily extended to other villages and has been designed to resist damage from local weather conditions. Technicians are trained in node maintenance at the Fab labs.

FabFi was subsequently tested and launched in Kenya, once again utilising local materials to keep costs down. It is currently under development in Washington, D.C.

Low cost prosthesis

The low cost prosthesis project is a collaboration between Fablab Amsterdam, the Netaji Subhas Institute of Technology (New Delhi, India), the arctic Fab lab Norway, MIT Biomechatronics Group in Boston and HONF (House of Natural Fibre) Indonesia.



http://waag.org/en/node/644

The goal of the project is determine how a developing country (Indonesia) can become self-reliant in building a ($50) lower leg prosthesis. The project has inspired the creation of dedicated tools such as a homemade 3D scanner that is capable of aligning the patient's leg with the prosthesis. The scanner is on par with a professional-grade scanner, and is easily produced in developing countries.

Project documentation and publishing

With the considerable number of projects being developed at Fab labs across the globe, one of the major stakes contributing to spreading up to date knowledge and instruction is fairly detailed documentation. Many projects are documented, with details regarding processes, pitfalls, aspects that could be improved, etc. Some do include materials sourcing information to make the project easier to reproduce. But as we have mentioned, there is no formal obligation for users to share their projects or publish their source information.

Dutch Fab labs make local "Fab moments" (the Dutch name for project documents) available online (http://fablab.waag.org/fabmoments, http://www.protospace.nl/fabmoments), while the collaborative wiki portal on the Icelandic Fab lab site hosts a sizeable number of projects originating from the Fab lab worldwide network (http://www.fablab.is/w/index.php/Fab_Lab_Portal).

Several Fab managers expressed the difficulties they had experienced motivating Fab lab users to document and publish, despite the number of available tools. A plan to address this problem, shared by all Fab labs, is currently under construction (http://blogs.fabfolk.com/anu/2011/07/anatomy-of-a-fabmoment/).

Project documentation is central to Fab lab functioning, more specifically on "Open Lab" days. Free access is granted in exchange for project documentation and publication. This aspect should not be neglected and will continue to require sustained effort on the part of Fab lab staff.

TYPOLOGY ///

The previous two sections analysing Fab lab operations and projects have provided us with the means to describe the wide variety present among these spaces dedicated to open digital fabrication. Despite sharing the same charter, the same machine inventory and membership in a worldwide network of similar spaces, each Fab lab is unique in terms of its overall management, financing mode and core team skills.

Structure and organisation

In the vast majority of cases, a single organisation, collective, foundation, university or government project sponsors or supports the creation of a Fab lab. This organisation then plays a pivotal role in the orientation of Fab lab efforts and imparts the general "colour" of the lab. Legal models vary widely from country to country. The organisation or organisations that finance a Fab lab also play a role in defining the lab (user target, business model...). It is for this reason that it is possible to discern three categories of Fab lab:

- Fab labs supported by a school or university (e.g.: Stanford, Barcelona). These "educational" labs host mostly student projects, and a limited number of projects from external sources (13% in Barcelona). They organise regular workshops (twice monthly in Barcelona) that remain relatively low profile. Students pay a small fee to gain access to the machines (€6/hr. for the laser cutter in Barcelona). The Fab lab is largely financially dependent on the university, coffers are typically supplemented with local grants and sometimes a few private sponsors. The number of users who come in off the street wanting to rent machines is marginal.

- Rapid prototyping "private business" Fab labs, targeting small businesses, startups or individual entrepreneurs. To acquire and "employ" the MIT Fab lab label, they maintain at least one "Open lab" day. The other days are reserved for individual machine bookings, private space hire, and professional workshops. Despite initial government assistance, these spaces are actively working toward financial autonomy.

- Fab labs supported by governments, R&D organisations (cf. the Innovation Center Iceland) and local authorities, targeting "pro-ams" and the general public. These labs lean toward the vocation of educating the general populace. Workshops and instruction sessions are organised to permit access to the widest number of people. Despite being open to anyone, the majority of users are "pro-ams", designers and artists who are at ease with digital technology. Public funding makes a greater number of free-entry "Open Lab" days possible (the Reykjavik Fab lab schedule is made up entirely of Open Lab days). There are usually two or three Open Lab days per week, treating 5-10 projects per day. Other days are dedicated to rapid prototyping; users book individual machines or the entire space.

The “educational” Fab lab

Aims

- Linked with universities, institutions of higher learning and sometimes national agencies for innovation.
- Foster learning by doing, allow students to produce prototypes, open a trans disciplinary space that is open to the wider public

Example:

- Fab lab Barcelona, sponsored by the IAAC (Institute of Advanced Architecture)
- Fab lab LCCC Lorain County Community College (USA)
- Fab lab Iceland, sponsored by the Icelandic Innovation Centre
- Fab lab Stanford (see below)

Support structure

- Supported by the associated university, in combination with public grants provided by local and national entities

Example:

- The Barcelona Fab lab receives funding from the Catalan Regional Government and the City of Barcelona
- LCCC is financed by the university who provides the machines and manpower, in the form of university technicians and engineers

Traffic volume

- An average of 10 users per day
- On schooldays this number might be larger, or smaller on days reserved for businesses
- The majority of users are students who attend classes in the morning and work in the Fab lab in the afternoon
- Traffic increases significantly as finals approach and final projects are due

User profile

- Students make up the majority of users, together with faculty
- The Fab lab maintains an open door to the public, notably to local innovators

Example:

- The Stanford Fab lab organises workshops and courses that are open to the public during school holiday periods
- LCCC collaborates with local organisations on projects that benefit the local community

Services

- Students have free access
- Specific program to increase access to the science and techniques involved, and help to generalise their practices
- Instruction and training in digitally controlled machinery, rapid prototyping platforms like Arduino, concepting software, etc.
- Prototyping services are sometimes offered to local startups for a very modest sum

Project types

- Highly associated with the learning facility
- Engineering, design and architecture
- Supplements coursework; class project assignments

Example:

- The Fab lab House (http://www.fablabhouse.com/) project is shared between several Fab labs and relies on the skills of the Fab lab Barcelona team

Weekly program

- Several free "Open Lab" days
- Other days reserved for students or companies wishing to build prototypes
- Machine hire is available to the non-student population

Example:

- Fab lab Reykjavìk provides "Open Lab" facilities every day
- Prices tend to be quite affordable: in Barcelona the laser cutter can be booked for €5/hr., while one hour with the ShopBot will cost €30.

Initial investment

Investment levels vary greatly, depending on management investment; the Barcelona Fab lab initially used the machines available at the architectural school, while LCCC received machines handed down from the university

Personnel

- The university or management provides technical staff (machine maintenance, repair, upgrade)
- Students quickly become autonomous and able to assume responsibility for numerous tasks (newcomer training, opening the space, etc.)
- Staff members include graduate students and interns
- In general, the Fab Manager is supported by several student helpers.

Example:

- LCCC exclusively employs volunteers, retired professors and student volunteers. No salaries are paid.
- Barcelona employs only one school alumnus Fab Manager, all other staff are student interns and seconded technicians

Business model
Typically support two free "Open Lab"-style days, while other days are reserved for (paid) prototyping services directed at students and small businesses. Membership is not usually required: payment is per hour and per machine.

In this kind of Fab lab, university/sponsors usually cover overhead expenses, including salaries, machine acquisition and rent.

Location
Close proximity to university or learning facility.

Fablab@school, promoting science and technology learning at school

Stanford professor Paulo Blikstein has an innovative use for the Fab lab. Fewer and fewer high school students are interested in studying science, so Blikstein now offers a series of workshops for high school students to put the "fun" back into science. The objective is to allow students and teachers to use the Fab lab as an educational tool: program participants work on experiments, prototype/product development and robotics that deal with current issues in the scientific field. The first Fablab@school experiments began in Russia in 2011.

http://stanfordmakersclub.ning.com/page/fablabschool-1

"Private business" Fab lab

Aims
- Laboratory providing rapid prototyping facilities, machines for hire, consulting services, instruction and training, and customised services

Example:

- Fab lab Manchester
- Cab Fab the Hague (ex-Fab lab converted to privately-held company)
- Next Fab Philadelphia (http://nextfabstudio.com/)
- TechShop, a privately-held fab lab with no public funding (see below)
- Fab lab Utrecht, to a lesser degree

Support structure
- Self-supported using private funds (possible initial support from public grants)
- Business partnering/sponsorship

Traffic volume
- The TechShop has 50 customers per day
- The CabFab has an average of 10 daily customers, due to its small size
- Evening use is more frequent

User profile
- Businesses seeking rapid prototyping facilities
- Entrepreneurs developing their products
- "pro-ams"

Services
- Everything required to bring a project from conception to realisation
- Advice, support, and professional assistance provided by staff on-site
- Entire space for hire
- Projects can be built by lab team
- Machine booking/hire by appointment, priced per hour
- Marketing, communications, and project development consulting services, assistance finding industrial or private investment

Project types
- Most projects have a commercial application
- Test market rapid prototyping
- Limited editions for niche market penetration

Example:

- The DODOCase accessory (http://www.dodocase.com/) developed at TechShop, produced in a limited number and subsequently mass produced
- « It's Unique », laser-cut greeting card prototyped at Fab Manchester (http://www.fablabmanchester.org/p103/Case-Studies.html)
- Cataract surgical instrument prototype

(http://www.fablabmanchester.org/p103/Case-Studies.html)

Weekly program
- One or two free access "Open Lab" days (in line with the MIT Fab lab charter), or no open days (e.g.: NextFab, TechShop, which do not carry the "MIT" label)
- The remainder of the week is reserved for appointments (machine hire, instruction sessions) or the space is made entirely available for private hire

Example:

- Fab lab Manchester: 1.5 "Open Lab" days, the remainder by reservation
- TechShop, NextFab: introductory appointments are available, access is private for the remainder of the week

Initial investment
- MIT-labelled Fab lab "businesses" have the same inventory as a regular Fab lab (€50-€70k) including one or two professional-grade 3D printers (€25-€50k)
- The TechShop provides access to a wide variety of machinery and equipment requiring a $750k initial investment (according to the website)
- The NextFab has several copies of the same machines at a Fab lab (3 laser cutters, several routers, etc.)

Personnel
- At these spaces, staff is generally highly qualified and salaried.

Example:

- At the Manchester Fab lab: 3 full-time employees, one administrator and two engineers
- At Fab lab Utrecht: 1 administrator, 1 secretary, 3 part-time Fab Managers, 2 of which are designers, the other an engineer
- The TechShop employs 10 "dream coaches" with a variety of specialised skillsets

Business model
- Machine hire
- Services provided on-demand
- Space available for private rental
- Workshop organisation
- Project realisation.

Although "rapid prototyping" spaces may receive some initial public funding, costs in the long term are to be financed through the services provided.

Example:

- TechShops: membership ($125/month, $75/month for student), renting

spaces for businesses, specialized services, etc.
- Manchester: 58€/hours to use the machines

Location
Industrial park/City centre

MIT-Fablab Norway: separating the "public" and "private"

During his presentation at the Lift conference in 2010, Haakon Karlsen Jr, president of Fab lab Norway (located inside the Arctic circle) attempted to explain the unexpected success the lab had experienced. Closely tied to MIT, the Norway Fab lab is open every day and every day is "Open Lab". This model of freely provided open access was turned upside down by a project that would eventually instigate a formal evolution. Karlson recounted the story of a single user who wanted to build a prototype for a new kind of candy box. Happy with his prototype, he built a limited edition of 10 pieces. The next week he was back to produce 100, then 1,000. His project was consuming entire days of Fab lab machine time. This "commercial" usage highlighted the real difficulty the lab would have if it wanted to remain open to everyone.

In response to the demands of smaller entities who wished to "mass-produce" items as limited editions, the creators of Fablab Norway opened an identical private space alongside the MIT-Fablab. The new space does not carry the MIT "label", nevertheless it responds to a very real demand.

The "pro-am", general public Fab lab

Aims

- Open to all with the aim of providing access to the tools, practices and culture of digital fabrication

Example:

- The majority of Southern hemisphere Fab labs (Fab lab Afghanistan, Kenya, Ghana, etc.)
- Certain Fab labs in the Northern hemisphere that present a hybridization of the first two categories of Fab lab described previously (Fab lab Amsterdam, Norway, the Dhub in Barcelona, etc.)

Support structure

- Supported financially by local and national governments, Europe, organisations that further innovative practices, sometimes receive private backing

Example:

- Dhub in Barcelona, a museum equipped with a Fab lab created in conjunction with the IaaC Fab lab, financed by the Spanish Foundation for Science and Innovation, the Minister of the Economy, and the Catalan regional authority
- Fab lab Amsterdam, financed by the Waag Society (Foundation for Innovation) and MediaGuild, a startup support organisation
- Fab lab Afghanistan is entirely financed by the NSF (National Science Foundation)
- The Fab labs in South Africa are financed by the government and supported by public entities (university, innovation agency, etc.)

Traffic volume

- Fab lab traffic depends on supported advertising and communication
- Southern hemisphere Fab labs generally see 15 people per day
- At Fab lab Amsterdam, traffic often depends on student assignments and final project deadlines

User profile

- Public first-timers coming to the lab to complete small projects (cutting, fabric printing, etc.)
- In the Southern hemisphere, the public is encouraged to come and discover the available technology, receive instruction and training, and collaborate on current projects
- Design, fine arts, and architectural students who do not have access to digital fabrication tools at their schools
- Pro-ams who want to develop their concepts
- Some companies and startups during "private", all-day sessions

Services

- Services revolve around education and training that to promote the mastery of the tools and techniques used for rapid prototyping, including the ability to operate the machines independently
- Machines available with or without the help of onsite staff
- Kids' programs (Fab lab Kids)
- The Fab Academy, MIT online course

Project types

- In the Southern hemisphere, projects are based on local demand and foster local skills and expertise development • In the Northern hemisphere, pro-am and independent designer projects

Example:

- See the "Fab Moments" page on the Fab lab Amsterdam website: http://fablab. waag.org/fabmoments?page=1

Weekly program

- A majority of free access "Open Lab" days
- One or two "private" days, when reservations are available for individuals or businesses and professionals

Initial investment

- This type of Fab lab matches the MIT inventory list item for item, for a total cost from €60-70k. (View the MIT inventory list here: http://fab.cba.mit.edu/about/fab/inv.html)

Personnel

- One or two part-time Fab Managers supported by (often student) interns, and in the Southern hemisphere, Fabfolk interns
- Administration and communications activities are handled by lab sponsors and supporters

Business model

- Machines for hire
- Space for hire
- Workshops and instruction sessions
- Fab lab network collaboration to respond to national and international RFPs

Overhead costs are financed in a hybridised manner. Supporters provide partial financing, revenue for services covers another portion, while "sponsorship" and public funding make up the difference.

Location

Close to university/learning institution

OTHER OPEN ACESS SPACES DEDICATED TO DIGITAL FABRICATION ///

During their fact-finding missions, the students visited two other types of spaces that offer digital fabrication facilities. With a dedicated business development model, the TechShop is widely known as a workspace providing access to powerful materials and machinery, and offering a string of services, while a hackerspace is much more protean.

TechShop

TechShops are vast spaces (1400 m2) founded on the principle of low-cost access to a wide variety of machines, tools, and equipment dedicated to personal digital fabrication. They target inventors, D.I.Yers, entrepreneurs, artists, designers, etc. that do not have access to workshops, materials, or perhaps do not have the expertise needed to complete their projects.

Some of the machines and tools available at a TechShop: milling machines, lathes, soldering stations, drill presses, industrial-grade sewing machines, digitally controlled machines that treat wood and plastic, laser cutters, metal folding machines, 3D printers…plus sheet metal, various basic materials and supplies, etc.

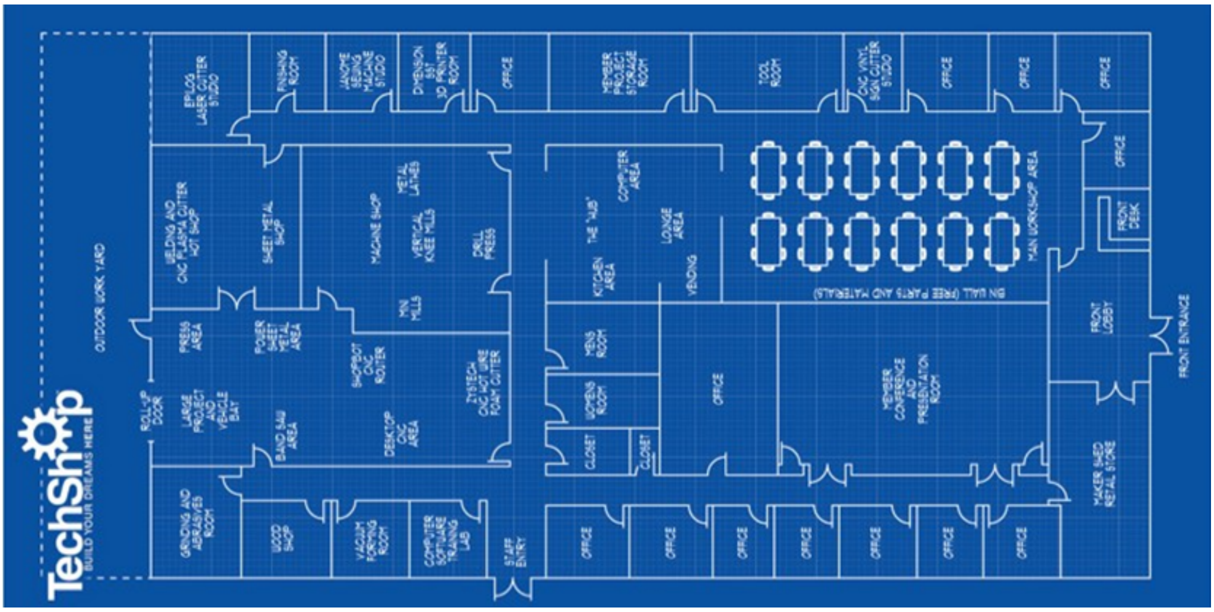
Jim Newton opened the first TechShop in 2006 in Menlo Park, California. As a former university professor of robotics and scientific advisor on the Discovery channel program *Mythbusters* (program hosts attempt to confirm or debunk urban legends), Newton was accustomed to having unlimited access to a wide variety of materials, tools and electronic components. When his contracts expired, he wanted to pursue what had become more than a hobby. Together with a few friends he opened the TechShop to provide inventors, hobbyists, D.I.Yers etc. with access to the wide variety of professional-grade machinery, tools and materials he had enjoyed for so long.

Access to the TechShop is regulated by a monthly or yearly membership fee, although daily rates are also available. Membership grants access to all the machines as well as the tools available (oscilloscopes, soldering irons, drills, etc.). The Menlo Park TechShop has 500 members; it is open 7 days a week from 9am to midnight. The TechShop also provides a wide range of services, including advice on project development or instructional courses on machine operation, in addition to professional completion of individual projects.

Several sources indicated that apart from machine use, their TechShop also served as a meeting place where users network with other members.

Physical space, configuration, location

TechShops are much bigger than Fab labs, yet tend to organise the space in a similar fashion. There is a large workshop with workbenches, and smaller workshop rooms, each dedicated to a specific type of material (wood, metal, etc.). TechShops also provide space for storage, private workshop space, and a large presentation room. A TechShop is like a cross between a coworking space (like *La Cantine* in Paris, http://lacantine.org) and a Fab lab with its professional-grade equipment.



TechShop floor plan (URL: http://www.TechShop.ws/Floor_Plan.html)

Machines

TechShops have more machines than Fab labs, and they also have more sophisticated machines. For example, the Menlo Park TechShop has four laser cutters. TechShops provide access to 'analog' machinery like ribbon saws, band saws, hydraulic presses, drills of all kinds and professional soldering devices as well.

One of the users interviewed at the TechShop we visited described the space as "the extension of a typical American garage like the one where Steve Jobs and Steve Wozniak built the first Apple."

Initial investment figures are considerably higher than those for a Fab lab. The machine budget alone is $750,000, compared to $80,000 for a Fab lab. A complete inventory (organised by workshop) can be found here: http://www.TechShop.ws/tools_and_equipment.html

Access/special offers/services

As opposed to Fab labs, TechShops are privately run. Access is granted to monthly and yearly membership holders.

	Monthly membership	Yearly membership
Individual	$125	$1200
Student	$75	$700

In addition to providing free access to the machinery (members must make bookings like at a Fab lab), TechShops provide five paid services:

Service	Description	Price
Personal training	• Security training • Training in basic machine usage	$95/hr.
Personal consulting	• Help with machines • Concept development support • Materials selection consulting • Etc.	$95/hr., 2-hour minimum
Prototyping consulting	• A TechShop instructor actively supports the user • Prototypes built by request	$95/hr.
3D Printing	• TechShops are equipped with professional-grade printing materials; processing and printing costs are in addition to membership fees	Priced according to material used
Courses and instruction	• There are numerous training courses available at TechShops (see below)	$30-90

More than 100 training courses are offered at TechShops. Each course takes place once a week, and is run by a TechShop staff member. Courses are open to non-members. There may be several levels of the same course, with certain levels sanctioning a user to use certain dangerous machines independently.

TechShop class listings: http://www.TechShop.ws/take_classes.html?storeId=1

Projects
TechShops do not publish their projects. Anyone can publish their work on their personal website, but TechShops do not focus as heavily on sharing as Fab labs do. A photo gallery is available on the main TechShop site (http://www.TechShop.ws/gallery.html).

At a TechShop, anyone can come and execute plans for an object, and even produce a limited number, as shown by the young San Francisco designers of the DODOcase (http://www.dodocase.com/). The young firm specialises in protective cases for the iPad inspired by Moleskine notebooks (http://www.moleskine.com/) using traditional binding methods. Company members spent their first few weeks at the TechShop in Menlo Park designing and building a prototype, followed by a limited edition consisting of a few pieces. After two months, they had so many orders that the DODOcase was shifted into mass production. TechShops do not provide specific advice regarding manufacturing or bringing a product to market–they are nothing more than spaces with machines and machine-related services for hire–but they ask for no commission if a business venture initiated on the premises happens to succeed.

A first in its field, the TechShop in Menlo Park had a hard time finding investors due to the originality of its concept. Planners finally found backing from several business “angels” and a Silicon Valley giant who remains anonymous. The undertaking now appears to have the means to fulfil its ambitions, despite the extremely heavy initial investment and a concept that has yet to attract the attention of the (general) public. $2.5 million is required to open a space similar to TechShop San Francisco; with 600-700 regular members, the profitability threshold would be reached in three years.

To Director Mark Hatch, personal fabrication sites are the next fitness clubs: places to visit regularly to build and develop one's ideas. The lofty ambitions of the upper management team (8 openings planned before the end of 2012) are buoyed by the level of enthusiasm that has been generated at the openings of every site in the Bay area.

Hackerspaces

Hackerspaces are protean in nature, bringing together individuals from a variety of backgrounds with the goal of brainstorming, creating and sharing. They use technology and the digital domain as a springboard. Activities may depend on space, culture or space managers.

Hackerspaces usually operate through workshops, presentations and courses. They provide space for their members to work on personal projects and to collaborate with other members or on other projects. Learning, pooling and sharing talent are at the heart of the hackerspace ecosystem. The community is integral to space steering and operations.

Hackerspaces have their roots in 60's counter-culture independent movements. The first hackerspaces were established in squats, alternative cafés, cooperative farms, etc. This culture persists in the themes and projects developed.

They operate through membership fees, although their legal status varies from space to space.

They may be non-profit (charitable) organisations (registered under *Loi 1901* in France, and 501(c)(3) in the US), collectives or cooperatives. Highly influenced by hacker culture, hackerspaces often have network servers, Internet connexions, A/V equipment, small electronics components, and tools to build physical objects. Contrary to Fab labs and TechShops there is no common inventory, yet in each hackerspace (depending on members and projects) the use of digitally controlled machinery is common.

NoiseBridge

San Francisco's NoiseBridge (https://www.noisebridge.net/) was founded in 2007 by a group of hackers led by Mitch Altman, among others.

NoiseBridge is located in a disused textile workshop. With massive bay windows running along two walls, it enjoys sweeping views of the Mission District. The elongated space is full of light and an outrageous level of clutter. An open kitchen, library and film projection space complement three smaller rooms dedicated to workshops, programming (the 'Turing Room') and making (the 'Dirty Shop'). The chaotic open space area is organised around an electronics area, a sewing area, and large area for current projects and donated materials that are ready to be revisited. To this dense topography is added a small darkroom, and a tiny room entirely occupied by a laser cutter. Machines on hand include a few MakerBots (3D printers), the aforementioned laser cutter, and sewing machines; shelves groan with electronic components, the library contains rare editions…and the entire space is pervaded by the spirit of cooperation shared by its members, whose numbers can swell to over one hundred on certain nights.

The space breathes community and sharing. The profusion of creativity and the truly unique atmosphere reveal strata of activity, discussion, and project collaboration. The walls are covered with posters and messages that make references to the shared hacker culture: "Shut up and hack!"

The quick tour provided by the owner underlines the dual nature particular to hackerspaces: expertise plus community. Although it advertises itself as open to anyone, NoiseBridge is really reserved for experts who may appear intimidating to the uninitiated. In addition to the "organised chaos" that reigns in the space, all decisions are made collectively, and there is no leader. NoiseBridge is open day and night; membership fees are left to each member's discretion, as is financial participation in the purchase and repair of hardware. There is only one rule: "Be excellent."

FAB LAB BUSINESS MODEL(S) ///

Investment budget

To start a Fab lab, the initial investment is $90k (€67k). This number would pay for the complete inventory list provided by MIT (http://fab.cba.mit.edu/about/fab/inv.html), including machines, components, material, computers, videoconferencing equipment, Wi-Fi routers, etc. Fab Managers we spoke with explained that the (exhaustive) list can be pared down and still equip a lab comfortably. An average of €40-50k would be sufficient as a starting point.

The table below summarises the initial investment budgets provided by several labs. It includes:

- eventual space purchase/lease
- machine and materials purchase
- staff wages for the first year
- overhead costs for the first year (electricity, heating, machine repair)

	Barcelona (ES)	Manchester (UK)	Groningen (NL)	Cape Town (SA)
Initial investment (in €k)	175	118	200	120

Initial investment figures in Groningen and Barcelona stand out. The budget in Barcelona included the purchase of an expensive architectural "robotic arm", while Groningen intended to purchase two professional 3D printers with a combined price tag of €80k.

Several Fab labs revealed their monthly operating costs:

	Amsterdam (NL)	Man-chester (UK)	Gronin-gen (NL)	Norway	Pabal (NL)	Cape Town (SA)
Operations (€k/month)	18.5	13.6	8	7	5.3	4.25

These monthly operating costs include:

- Salaries
- Machine maintenance and repair
- Costs generated by the space (rent, heating, electricity, Internet, telephone, etc.)
- Consumables and other small purchases

Fab lab creation

In our discussions with the various Fab labs, we uncovered two ways a Fab lab can emerge (or sometimes a hybrid of the two).

Support structure financing

In the first instance, supporters/sponsors assume responsibility for financing the lab entirely. These may be universities who donate space and operational manpower in addition to purchasing or lending the machines required (e.g.: Fab lab Barcelona/IaaC), or private firms (Fab lab Lisbon is exclusively financed by Portugal Electric), or financing granted by public authorities (e.g.: Fab lab South Africa).

In this instance the user community will initially have a direct link with the supporter/sponsor. At universities, students will be the first to visit and take advantage of the space. The key is to create ties and engage with others who bring fresh skills and know-how along with them.

For example, in the Netherlands, the "Unlimited Design Contest" (http://unlimiteddesigncontest.org/en) was initiated in an effort to promote Dutch Fab labs beyond their user base; it reached designers, architects, and a public audience of advanced D.I.Yers that had never before heard of such places.

A Fab lab from the bottom up

This kind of lab relies primarily on some kind of established community (Arduino heads, model hobbyists, amateur robotics buffs, electronic artists, hackers) that has grown over time. To make prototyping tasks easier and/or to enlarge the community, the community will move toward the creation of a Fab lab by buying or building their own digitally controlled machine. Fablab Amsterdam bought a laser cutter to complete a project, extended its purchases to include the rest of the Fab lab inventory, and ultimately opened its space to a wider audience.

Fab lab Artilect

The Fab lab in Toulouse also emerged in this fashion. Electronics and robotics aficionados came together and created the Artilect (http://www.artilect.com) association (NB: a French *association* is a term meaning a non-profit organisation); Anwsering call for projects, allowed them to buy their first digitally controlled milling machine. Housed in one room at the university, they collectively purchased the rest of the machines found in a Fab lab. Today, Toulouse is an MIT-labelled Fab lab with a wider audience sharing a range of skills.

Toulouse is operated by volunteers; this means that public orientation outside a limited number of hours can be very problematic, explained Director Nicolas Lassable. As the space becomes more popular, it has become increasingly difficult for volunteers to both cope with demand and spend time on their own projects.

The MIT Fab lab "label"

In order to use the MIT "label" (i.e.: use the logo for fundraising, promoting and advertising lab activities) and become a fully-fledged member of the worldwide Fab lab community, essentially a lab must be equipped as described previously, and adhere to the Charter (see annex).

We discussed the issue further with Sherry Lassiter, Program Manager at the Center for Bits and Atoms. Although adhering to the charter remains the most important point, Lassiter lists four factors that must be observed if a lab wants to call itself a Fab lab.

To apply the conditions set out below, please also refer to the Fab Lab conformity rating (http://wiki.fablab.is/wiki/Fab_Lab_conformity_rating) which explains how a lab can partially fulfill those criteria and still is be able to call itself a Fab Lab.

Also note, that the label is "Fab Lab" (or Fablab or FabLab) and that you are not entitled to use anything like "MIT Fab Lab" etc. However, you can always say that your Fab Lab is modeled after the MIT concept or anything along these lines.

These key characteristics create an enabling environment that we call a fab lab. Provided that a lab effort is aligned with the below, they can and should use the logo for fund raising, promoting and advertising the fab lab and its activities.

- First and foremost, public access to the fab lab is essential. A fab lab is about democratizing access to the tools for personal expression and invention. So a fab lab must be open to the public for free or in-kind service/barter at least part of the time each week.
- Fab Labs support and subscribe to the fab lab charter: http://fab.cba.mit.edu/about/charter/ This charter should be published somewhere on the website and also in the fab lab.
- Fab Labs must share a common set of tools and processes. The critical machines and materials are in this list: http://fab.cba.mit.edu/about/fab/inv.html and there's a list of open source software and freeware that we use online as well (embedded in fab academy modules here: http://academy.cba.mit.edu/classes/). The idea is that all the labs can share knowledge, designs, and collaborate across international borders.
- You have to participate in the larger, global fab lab network, that is, you can't isolate yourself. This is about being part of a global, knowlege-sharing community through the videoconference, attending the annual fab lab meeting, and otherwise collaborating and partnering with other labs in the network on workshops, challenges or projects. Participating in Fab Academy is yet another way to connect with the global network community.

Discussion/Notes:

- If I make something here in Boston and send you the files and documentation, you should be able to reproduce it there, fairly painlessly. If I walk into your lab anywhere in the world, I should be able to do the same things that I can do in Ghana, South Aftrica, Amsterdam or Boston fab labs. But essentially it's the processes and the codes and the capabilities that are important.
- A prototyping facility is not the equivalent of a fab lab. A 3D printer is not a fab lab.
- The brands are unimportant but the transferability of files and processes are. Generally: laser cutter for 2D/3D design and fabrication, a high precision milling machine for making circuits and molds for casting, a vinyl cutter for making flexible circuits and crafts, a fairly sophisticated electronics workbench for prototyping circuits and programming microcontrollers, and a large wood

routing machine for furniture, housing, structures, and other applications like the FabFi. We just added a fairly cheap but robust and fair resolution Chinese 3D printer to the list. Lots of labs want and need 3D printing, but we've been extremely unhappy with 3D printers.

- The electronics can cover Arduino kits, Scratch kits, Pico Crickets, and Mindstorms -- all for people learning electronics or who want to use them as platforms for development. But equally, if not more important, the fab lab includes high speed, low cost microcontrollers (Atmel AVRs) and surface mount components that allow you to develop almost anything from the bottom up, and allow you to do your own development, far beyond what the kits provide. This includes onsite in circuit programming.

CONCLUSION ///

Rather than be bound by the constraints of project-based research, this study sought to go beyond the numbers and investigate the organic reality present at Fab labs across the globe. Fab labs have taken the solid foundation erected by MIT and articulated it through the local societies, cultures and economies of their host countries. Our travels revealed the adaptability inherent to these facilities: their differences and local colours became apparent, in addition to their complementary natures. In conclusion, we would like to highlight the following points, whose importance was underlined by many of the people we interviewed.

The importance of free, open access.
This is the first term listed in the Fab lab charter; the charter's "mission" (Fab labs are members of a worldwide network that exists to enable individual access to the tools of digital fabrication) is shared by all Fab labs. While the charter is generally respected, free and open access to the lab varies by country, team and populace. All the Fab labs we visited granted free or low-cost access to the premises at least one day per week (payment could be a small membership fee, a project documented publicly, providing hours of newcomer assistance, etc.). Open days place great demands on Fab Managers and their teams; the resources provided by new users, who contribute to community creation, expansion and enrichment, outweigh the lack of revenue they generate and the considerable effort they solicit. We concluded that the more public funding a lab received, the more free access it would be able to provide. Some offer a mixture of services targeting a variety of users, while many rely on services aimed at businesses and professionals to balance their budgets.

The community.
The second most important point underlined by the majority of people we interviewed deals with the community of users. They inject (new) life into the lab, provide (new) skills and specific expertise and devise innovative methods and practices. Varying degrees of community members' personal investment imparts a unique dynamic to each lab. Lab operators stimulate the user community with competitions, cross-disciplinary projects, targeted presentations, etc. Having the right equipment is not enough; an active community transforms a static space into a dynamic breeding ground for innovation. Careful planning that contributes to a vibrant user community right from the beginning is one way to guarantee the future success of a Fab lab.

The democratisation of digital fabrication tools and techniques.
When we asked people how they perceived the evolution of Fab labs over the next 10 years, many drew parallels with the degree of expansion enabled by the Internet. Today, Fab labs most likely represent the cornerstone of an emerging personal fabrication "democracy". This process–one person able to manage the entire chain of production–is very similar to artisanal practice. Many lab users see Fab labs as open access workshops for the 21st century. Like the Internet, the Fab lab is an accessible platform for innovation.

The financial burden placed on users is minimal, vastly lowering a major barrier to innovation. Democratisation of the means of production presents a larger question concerning what Bernard Steigler calls the “new industrial world”. What if Fab labs (similar to the Internet) actually are the cornerstone of newly “horizontal” innovative practices that transform mass production, urban amenities, distribution channels, cities, living things…What if some so-called “amateur” practices increasingly resemble professional practices, as we have seen in multimedia, software and online services content design recently? And what if this “new industrial world” obeyed an entirely new set of laws than the old, specifically in relation to “consumers” and service “providers”? These questions will have to go unanswered, for now.

SUMMARY AND RECOMMENDATIONS ///

Equipment

- Due to ease of use, the laser cutter is the most frequently used piece of machinery in the Fab lab. Jobs can be completed so quickly that many people can use it each day.
- The router has to be located in a closed room, separate from the rest of the Fab lab, to protect people and machinery from noise, sawdust, and woodchips. This machine can be dangerous, and numerous Fab labs only permit its use under strict supervision by a Fab manager or trained volunteer.

Project documentation

- Project documentation guarantees that each lab has a stake in network and shared knowledge development. Documentation ensures that the Fab lab does not turn into a bland, self-service rapid prototyping centre.
- On "Open lab" days, many Fab labs allow entry on the condition that jobs are republished and documented using a creative commons (or similar) license.

Reception with open arms

- Several Fab lab managers clearly stated the importance of valuing users' efforts without "judging" the pertinence of a given project. Even the most basic project allows a user to gain confidence and creates a virtuous cycle of learning.
- Users require a certain level of competence with CADCAM software to operate the digitally-controlled machinery available at a Fab Lab: many Fab labs offer introductory courses on 2D and 3D design software in addition to equipment training.

Learning

- Learning by doing, learning through mistakes, taking things step-by-step, and peer learning are all educational models utilised and developed at Fab labs.
- To take some of the pressure off the Fab manager, certain Fab labs grant free, unlimited access to certain users, if, once they have completed the requisite training, they are willing to take charge of training and assisting new users.

Fab Managers

- The Fab manager is the all-around handyperson at the Fab lab. He keeps the machines in working order, helps users, manages inventory, etc.
- In conjunction with lab supporters, the Fab manager adds individual colour to the space. In Amsterdam, for example, the Fab manager was trained in industrial design; as his "social network" is composed of designers, they were the first to take advantage of the lab. In Portugal, where the Fab manager is an engineer, the majority of users we met were engineers.

Network

- The Fab Academy provides comprehensive skills training for Fab managers.
- Videoconferencing enables the worldwide network of Fab labs to deepen their ties and discuss practices and techniques.

- Establishing and maintaining a French network would entail weekly meetups, regular workshops, etc.

Communities

- The community is very important; people invest time and energy in the lab, suggest projects, etc. It needs stimulation and the support provided by regular meetings, lab-sponsored events, presentations, etc.
- Several Fab labs mentioned the importance of hybridizing the "geek" and "pro-am" "neo-artisan" communities. This remains to be seen.
- Cross-disciplinary projects, involving the talents of several Fab lab community members in unison, are favourable. These foster a community environment and cement ties between members.

ANNEXES ///

During visits to Fab labs and other publicly accessible spaces dedicated to digital fabrication, the students put together summaries, conducted interviews with Fab Managers and users, and took photos and video. All this content can be found on the Fing website (www.fing.org).

Machines

Desktop Vinyl cutter

Figure 1 - Roland CAMM 1 GX-24

Figure 2 - CraftRobo Pro

A vinyl cutter is a printer whose print heads are not inkjets but sharp steel blades. It allows for high precision cutting of vinyl, certain kinds of paper, transfer decals, certain fabrics and copper film to build printed circuit boards. It is relatively easy to operate, and used primarily to customise individual pieces and create basic printed circuits.

There are two models available at Fab labs, the Roland GX-24 and the CraftRobo pro. Prices from €1,500 to €2500.

Digital milling machine (portable)

Figure 1 - Roland Modela MDX-15

Figure 2 - Roland Modela MDX-20

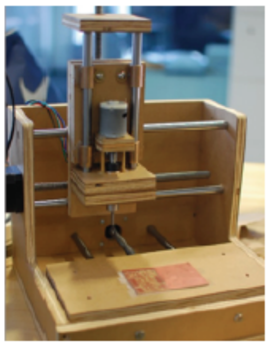


Figure 3 - Mantis V9.1

The digital milling machine is a digitally controlled device with a spindle that moves along three axes (X,Y and Z). Similar to a laser cutter, the rotating spindle cuts away material according to a particular shape; the spindle can be changed for various applications (milling, sanding, drilling, etc.).

At Fab labs these machines can have several uses, but they are typically used to build printed circuits (copper film over epoxy resin) or moulds. These are the most frequent applications, although this little mill can also shape wood, foam, etc.

Two models can generally be found at Fab labs: the Roland Modela MDX-15 and her big sister the MDX-20. They only differ in terms of machinable work surface. Apart from the milling spindles, these two machines come with a "sensor" (that replaces the milling spindle) that can scan entire objects placed on the work surface. This feature makes it possible to move directly to the (re)production phase, minus the initial CAD concepting phase. Both machines cost between €3,000 and €5,000.

Because the functionality of this machine is relatively simple (a spindle is rotated by three motors - X, Y, and Z axes) plans and step-by-step instructions to build this kind of device at home are now appearing on the Internet. The CBA, wishing to lower the financial barriers for emerging Fab labs, has begun to explore the making of machines in their MTM program (Machines That Make http://mtm.cba.mit.edu/). The "Mantis" (http://makeyourbot.org/) is a fully functional "D.I.Y." milling machine whose plans, materials list and operating software are free and open source. This powerful machine capable of building printed circuits can itself be built for about €100.

CNC Wood Router

Figure 1 - ShopBot

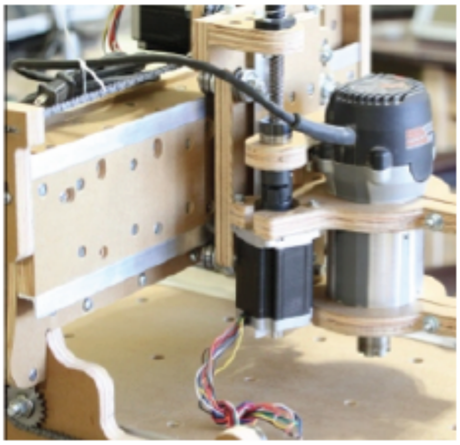


Figure 2 - BlueChick

The router is a digitally controlled milling machine with a powerful cutting spindle intended to work thicker materials (solid wood) across a wider work surface (more than 2m). A majority of Fab labs have only one type of router: the ShopBot. It is available in two versions: a more expensive model with safety bars, and a less expensive model without. Routers can work with large wooden surfaces, and are appropriate for architectural designs, carpentry, etc. For example, MIT created pre-fab kit homes for the victims of Hurricane Katrina, which were produced exclusively using ShopBots. (For a project presentation, visit: http://fab6.nl/speakers/larry-sass/).

Depending on peripherals (dust extractor, filters, work surface dimensions) a ShopBot costs between €14,000 and €20,000. Similar to its little sister the milling machine, plans have emerged online that allow D.I.Y. non-professionals to build their own digitally controlled router. Several construction kits are available online that cost ten times less than the price stated above. The BlueChick and her equally "free" peers can be built for €800-€2,200 (http://buildyourcnc.com/default.aspx).

NB: At most of the Fab labs we visited, the ShopBot was the only machine whose access was strictly regulated. At Fablab Amsterdam, the presence of a Fab Manager is required to use the router. In Portugal, Fab managers must examine any project that includes the use of the router. Routers are potentially dangerous tools that generate large amounts of sawdust and send woodchips flying. In all the Fab labs we visited, the router was in a closed room and the computer controller was protected from dust. As the parameters require delicate adjustment (speed, material, etc.), the router takes a certain amount of training before users are proficient.

3D Printer

Figure 1 - Dimension 1200 es Series

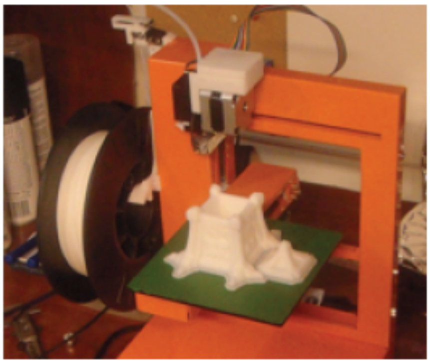


Figure 2 - Up! 3d Printer

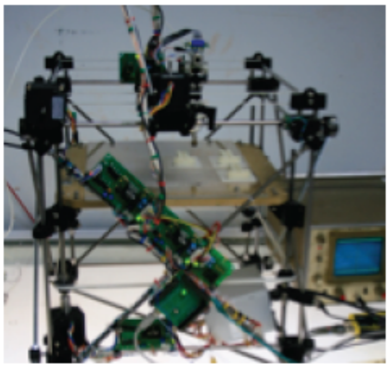


Figure 3 - RepRap

Despite their popularity at Fab labs, until 2011 the official MIT inventory list did not include 3D printers. According to Neil Gershenfeld[12], the machines currently on the market are too expensive (the Dimension 1200 starts at €25k), too slow and the materials they require are too costly for them to be suitable for "collective" use. Although a 3D printer is capable of producing remarkable results, pieces can take up to 15 hours to execute. These professional printing machines are mostly used at Fab labs to create moulds for object replication.

Today MIT recommends the Up! 3D Printer for labs that wish to invest in one. Less powerful than its commercial-grade cousins, the Up! is relatively inexpensive (€2,000) and executes with precision.

Again, there exist many online sources providing "free" and "open" plans for 3D printers. The most well known is the RepRap; numerous iterations, lovingly developed by a passionate group of followers, makes this an inexpensive option (€600) equal in performance to the Up! model.

NB: Many Fab labs use the RepRap as an educational tool: the simple effort it takes to build one during a workshop is the perfect opportunity to get one's

[12] Neil Gershenfeld Fab6 conference http://fab6.nl

hands “dirty”. As the RepRap is able to produce the parts necessary to build other RepRaps, the cost price can be quite low.

Laser cutter

Figure 1 - Trotec Speedy 100

Figure 2 - Epilog mini 24

Figure 3 - LaserPro Spirit GE

Laser power levels are generally between 25-50w, thus establishing the maximum thickness of machinable materials and the speed of execution (the more powerful the laser, the faster the execution). From what we saw and heard at the Fab labs, the laser cutter is one of the most popular machines. Its simplicity (vector drawing software is all that is required), its safety (the workspace is closed off; if opened, the machine halts operation automatically) and its speed contribute to the central role it occupies. It is easily handled by beginners and easily appropriated (our experience at Fab lab Squared demonstrated that users could work autonomously after only a few hours.)

A laser cutter allows users to

- Cut a wide variety of materials (wood, paper, card, PMMA, leather, etc.)
- Create markings (metal, aluminium, stone, etc.)
- Engrave (engraving removes more material than marking).

Wood, plywood, particleboard and PMMA (between 2-10mm) are the materials most used at the labs. A laser cutter usually costs between €15-30k, depending on the brand and peripherals selected (smoke/fume extractors, magnetic table, etc.)

NB: These three laser cutters are entry-level models. More powerful models have increased laser power and a larger work area. The Trotec Speedy has a 610 x 305mm work area, the Speedy 300 a 720 x 450mm work area. They cut material between 0-10mm. According to what we heard at the Fab labs, these machines require laborious upkeep (lens cleaning, mirror and motor swaps). Fab managers recommended keeping one or two repair kits on hand. Certain materials, including PVC, are highly discouraged, as they can generate noxious fumes when machined. Toolmaker websites often provide lists of useable materials together with recommended speed and laser settings for each sample.

During machining, particleboard produces a significant amount of dust and smoke. During the week that it was used at the Fab lab Squared event, the team had to change the filter twice (€150). Several Fab labs have inexpensively resolved this issue by installing an extractor fan…

In terms of brand selection, and despite the endorsement of Epilog by MIT, we concluded that Trotec was a better choice in France: they have offices in France, whereas Epilog and Laser Pro are only represented by resellers.

Supplementary hardware

Depending on the particular Fab lab or team, there might be other machines on hand. In Amsterdam, several sewing machines are available, while in Groningen there are PCB (printed circuit board) fabricators. These tools are not included on the MIT inventory list. Non-inventoried material typically includes:

Equipment type	Utility/Model/Application
Computers	Machine control, documentation processing
Small electronics	Oscilloscopes, soldering irons, Arduino, electrical components, FPGAs, etc.
Videoconferencing material (to link with labs worldwide)	Polycom V500, Polycomp HDX6000, etc.
Software	• Open source: Inkscape, Blender, Gimp, Wings3d, etc. • Proprietary: Google Sketchup, Rhino 3D, Adobe Corel Draw, etc.
Machinable materials	Wood, acrylic, vinyl, Mdf, PMMA, resin, etc.
Safety material	Goggles/glasses, aspirateurs, fire extinguishers first aid kit, etc.
Workbench materials	Drill press, vice, wood plane, drills, routers, etc.
Library	There is generally a small library with basic works dedicated to fabrication, DIY, computer programming, basic electronics, etc.

Fab Lab Charter

Mission: fab labs are a global network of local labs, enabling invention by providing access for individuals to tools for digital fabrication.

Access: you can use the fab lab to make almost anything (that doesn't hurt anyone); you must learn to do it yourself, and you must share use of the lab with other uses and users

Education: training in the fab lab is based on doing projects and learning from peers; you're expected to contribute to documentation and instruction

Responsibility: you're responsible for:

safety: knowing how to work without hurting people or machines
cleaning up: leaving the lab cleaner than you found it
operations: assisting with maintaining, repairing, and reporting on tools, supplies, and incidents

Secrecy: designs and processes developed in fab labs must remain available for individual use although intellectual property can be protected however you choose

Business: commercial activities can be incubated in fab labs but they must not conflict with open access, they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs, and networks that contribute to their success.

(http://fab.cba.mit.edu/about/charter/)

Bibliography

Vers une économie de la contribution, Bernad Stiegler, 2011, Owni, http://owni.fr/2011/11/30/vers-une-economie-de-la-contribution/

Le nouveau monde industriel, Denis Tersen, 2011, Laboratoire des idées, http://www.parti-socialiste.fr/articles/le-nouveau-monde-industriel

Compte-rendu de l'intervention de Von Hippel sur son étude sur les makers en Grande Bretagne, Hubert Guillaud, 2010, InternetActu, http://www.internetactu.net/2010/09/23/eric-von-hippel-il-y-a-2-a-3-fois-plus-dinnovations-de-la-part-des-consommateurs-quil-ny-en-a-dans-lindustrie/

Measuring User Innovation in the UK, Von Hippel, 2010, http://www.nesta.org.uk/publications/reports/assets/features/measuring_user_innovation_in_the_uk

Democratizing Innovation, Eric VON HIPPEL, MIT Press, 2005

Business models for open hardware, fablabs, DIY and craft, 2011, Openp2pdesign, http://www.openp2pdesign.org/projects/past-projects/report-business-models-for-open-hardware-fab-labs-diy-craft/business-models-for-open-hardware/

Fablab Benchmarking Report, Portugal Electric, 2010, http://fablabedp.edp.pt/sites/default/files/uploaded_files/Benchmarking%20report.pdf

Commons-Based Peer-Production of Physical Goods: Is There Room for a Hybrid Innovation Ecology?, Peter Troxler, 2010, http://papers.ssrn.com/sol3/Papers.cfm?abstract_id=1692617

Overall goals within the Fab ecosystem, http://www.fablab.is/w/index.php/Proposal#Overall_Goals_within_the_Fab_ecosystem

TechShop + Kickstarter = A New Paradigm for Manufacturing?, Txchnologist, 2011, http://www.txchnologist.com/volumes/advanced-manufacturing/TechShop-kickstarter- a-new-paradigm-for-manufacturing

Big DIY: The Year the Maker Movement Broke, Wired, 2011, http://www.wired.com/ epicenter/2011/08/big-diy

Will 3D printing revolutionise manufacturing?, BBC, 2011, http://www.bbc.co.uk/news/ business-14282091

Éloge du carburateur: Essai sur le sens et la valeur du travail (*Shopclass as Soulcraft*), Matthew B. CRAWFORD, La découverte, 2010

Institue for The Future (IFTF) think tank website, http://www.openfabrication.org/

Makers: Faire société, Mathilde Berchon and Véronique Routin, 2011, InternetActu, http://www.internetactu.net/2011/05/25/makers-12-faire-societe/

Makers: Refabriquer la société, Mathilde Berchon et Véronique Routin, 2011, InternetActu, http://www.internetactu.net/2011/05/26/makers-22-refabriquer-la- societe/

Creative Commons Photography Attributions
Arthur Schmitt: https://picasaweb.google.com/107924850883858611464
Fing: http://www.flickr.com/photos/photosfing
Jean-Baptiste Labrune: http://www.flickr.com/photos/jeanbaptisteparis
Ton Zijlstra: http://www.flickr.com/photos/Tonz

Acknowledgements

Our appreciation is extended to Aurialie Jublin, for her meticulous proofreading; to Daniel Kaplan, for his pertinent advice; to Marie Quilvin, for the layout; to Véronique Routin, for her crucial support and active contribution and to Peter Troxler for his proofreading and advice.

In addition, thanks go to Gabriella Polisel, Matthieu Bonneric, Arnaud Clavreul, Nicolas Parisot, Armand Michaud for their efforts prior to the execution of this report.

We also like to thanks the following persons who took time to discuss with us. Tomas Diez (Fab Lab Barcelone), Joris van Tubergen (Protospace), Alex Schaub (Fab Lab Amsterdam), Christine Van Den Horn (Fab Lab Amsterdam), Gertjan Willemsen (CabFabLab), Alexandre Korber, Nicolas Lassabe, Mathilde Berchon, Michael Shiloh, Dale Dougherty, Paulo Blikstein, Neil Gershenfeld, members of bootfablab@PiNG : Julien Bellanger, Cédric Doutriaux, Boris Papin, Arthur Schmitt, Stéphanie Bacquère, Fabrice Lourie, Thierry Mbaye, Emmanuel Gilloz, Laurent Décremps, Julien Vouilloux, Jérôme Combaz, Laurent Gouteyron, Inouk Bourgon, Loïc Fejoz, Bastien Mairet, Alexandre Aguila, Emmanuelle Roux, Laurent Ricard, John Le Jeune. We hope we didn't forget anyone…

Céline C. for the theatres / le 167 for the civ and the lulz

This study was supported in part by:

About the Fing

The Fing (*Fondation internet nouvelle génération*) is devoted to inspiring and spreading new and actionnable ideas that anticipate the transfomations brought about by the digital age. www.fing.org | www.interntactu.net

The Fing is supported by its largest members and selected sponsors:

"Translated from the French by Jianne Whelton" jianne.whelton@gmail.com